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3-5 September / Kotor, MONTENEGRO

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September 3-5, 2025 in Kotor - MONTENEGRO

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Dear Readers;

The 9th of ICONST organizations was held in Kotor-MONTENEGRO between September 3-5, 2025 with the theme of 'science for sustainable technology' again. In recent years, weather changes due to climate change have reached a perceptible level for everyone and have become a major concern. For this reason, scientific studies that transform technological progress into a sustainable one is seen as the only solution for humanity's salvation. Here we ask ourselves "which branch of science is responsible for sustainability?". Sustainability science is an interdisciplinary field of study that covers all basic sciences with social, economic, ecological dimensions. If we consider technology as the practical application of scientific knowledge, the task of scientists under these conditions is to design products that consume less energy, require less raw materials, and last longer.

ICONST organizations organize congresses on sustainability issues of three main fields of study at the same time in order to present different perspectives to scientists. This year, 140 papers from 15 different countries (Afghanistan, Albania, Algeria, Bosnia and Herzegovina, Hungary, Iran, Iraq, Kosovo, Montenegro, Nigeria, Poland, Romania, Serbia, Tunusia and Türkiye) presented by scientists in ICONST Organizations.

Türkiye is the country with the highest participation with 48%, followed by Albania with 17%, Kosovo 10%, Montenegro 5.7%, Poland and Tunusia with 4.2%, Algeria with 3.8%. **Outside of Türkiye participant rate is totally 52%.**

As ICONST organizations, we will continue to organize organizations with the value you deserve in order to exchange ideas against the greatest threat facing humanity, to inspire each other and to contribute to science. See you at your future events.

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Evaluation Of Antioxidant Activities Of Natural And Commercial Rosemary (*Rosmarinus officinalis* L.)

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Abstract: *Rosmarinus officinalis* L. (rosemary) is an evergreen, aromatic shrub belonging to the Lamiaceae family, which comprises approximately 236 genera and 7,000 species worldwide. In Türkiye, this family is represented by around 48 genera and 782 taxa, most of which are endemic. Native to the Mediterranean basin, rosemary thrives in calcareous and rocky soils under warm, dry conditions and has been widely cultivated and naturalized in temperate regions. Rosemary has a diverse phytochemical profile and contains phenolic diterpenes such as carnosic acid and carnosol, phenolic acids such as rosmarinic and caffeic acids, and triterpenes such as ursolic and oleanolic acids. Its essential oil, characterized by 1,8-cineole, camphor, and α-pinene, contributes to both aroma and bioactivity. These metabolites collectively explain the wide range of pharmacological properties attributed to rosemary.

From an ethnobotanical perspective, rosemary has been valued for centuries for enhancing memory, relieving headaches, and alleviating digestive, respiratory, and circulatory disorders. It also serves as a culinary herb and natural preservative. Modern pharmacological studies confirm these traditional uses, demonstrating antimicrobial, antifungal, antiviral, antibacterial, anti-inflammatory, antitumor, antithrombotic, antinociceptive, antidepressant, antiulcerogenic, antioxidant, hepatoprotective, neuroprotective, antidiabetic, and anticancer activities. Its potent antioxidant activity stems primarily from carnosic acid, carnosol, and rosmarinic acid, which act as free radical scavengers, inhibit lipid peroxidation and protecting against oxidative stress-related disorders, including cardiovascular and neurodegenerative diseases. In this study, the antioxidant activity of wild rosemary (*Rosmarinus officinalis* L.) collected from natural habitat in Izmir province was compared with that of commercial rosemary purchased in packaged form from local market. The samples were prepared at a concentration of 100 mg/mL in 100% methanol, and antioxidant capacity was evaluated using the DPPH radical scavenging assay. When expressed as ascorbic acid equivalents (AAE), the radical scavenging activity of the methanol extracts corresponded to 431.4 ± 10.7 g/mL AAE for wild rosemary and 247.6 ± 6.9 g/mL AAE for commercial rosemary. The lower activity observed in commercial samples could be attributed to several factors, including prolonged storage, loss of volatile compounds, variability in cultivation practices, or blending with lower-quality plant material. Moreover, postharvest drying temperature and packaging conditions are known to significantly affect the stability of phenolic diterpenes and essential oil components. Overall, these findings highlight the superior antioxidant potential of wild rosemary and emphasize the importance of maintaining quality during cultivation, harvesting, processing, and storage. Standardization of active constituents, optimized storage practices, and prevention of bioactive compound degradation in commercial rosemary can help minimize the loss of activity. Consequently, wild-harvested rosemary represents a natural antioxidant source with nutritional, therapeutic, and industrial applications.

Keywords: *Rosmarinus officinalis* L, Lamiaceae, antioxidant activity, natural products

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Monitoring Land Cover Changes in Isparta Between 2015 and 2025 Using Landscape Metrics and Management Recommendations

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Abstract: The main aim of this study is to detect land cover and land use changes in Isparta province using Sentinel-2 images from July 2015 and July 2025 and to assess the impacts of these changes on the landscape structure. Land cover changes, influenced by both natural processes and human activities, lead to significant alterations in landscape patterns. Monitoring and evaluating these changes contribute to sustainable land management. In the analysis, the following landscape metrics were used: Patch Density (PD), Mean Patch Size (MPS), Largest Patch Index (LPI), Edge Density (ED), and Perimeter-Area Fractal Dimension (PAFRAC). The results of the 2015–2025 change analysis indicate that patch density increased, particularly due to the expansion of agricultural and settlement areas, resulting in a more fragmented and heterogeneous landscape. Mean patch size generally decreased, reflecting the division of large natural areas into smaller patches and the fragmentation of land use. The largest patch index decreased, indicating that the influence of dominant patches such as forests and pastures has declined. Edge density increased, showing that patch boundaries became more complex as a result of land use changes and the expansion of agricultural areas. Perimeter-area fractal dimension values also increased, indicating higher shape complexity of patches and a more irregular landscape structure. These changes are primarily attributed to the expansion of agriculture and settlement areas. For sustainable land management in Isparta, it is important to protect green areas and connect natural habitats to maintain landscape integrity. Therefore, regular monitoring of land cover changes in Isparta is of great importance.

Keywords: Fractal dimension; Land cover change; Landscape architecture; Landscape fragmentation; Landscape metrics

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A new record of Plagiotrochus Mayr, 1881 (Cynipidae: Cynipini) for Türkiye

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Abstract: Cynipids, or gall wasps (Hymenoptera: Cynipidae), represent a diverse group of over 1,600 species worldwide (excluding Antarctica) that induce gall formation on host plants, providing a protected and nutrient-rich environment for their larvae. Although most species are associated with oak trees (Quercus L., Fagaceae), some induce galls on herbaceous plants from families such as Asteraceae, Lamiaceae, Papaveraceae, and Rosaceae. Within the Cynipidae, the tribe Cynipini, predominantly associated with oaks, is the most species-rich. The genus Plagiotrochus, one of 58 genera within Cynipini, includes 22 species mainly distributed across the Palaearctic region. To date, only two species from this genus have been recorded in Türkiye: P. burnayi Kieffer, 1901 on Q. ilex L. and P. quercusilicis (Fabricius, 1798) on Q. coccifera L. In 2025, galls were collected from Q. coccifera in Denizli, Türkiye, and reared under laboratory conditions to allow adult wasp emergence. Identification revealed that the asexual generation of Plagiotrochus gallaeramulorum (Boyer de Fonscolombe, 1832) induces galls on small branches of the host plant. This represents the first record of the species in Türkiye, extending its known distribution in the Western Palaearctic region. Recent studies on gall wasps in Türkiye have increased, enhancing understanding of Cynipidae diversity. This new record underscores the importance of continued research and conservation efforts to preserve the region's rich gall wasp fauna.

Keywords: Cynipid, gall wasp, new record, oak, Denizli.

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Paper-Based Sensor for Detecting Spoilage in Ayran

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Abstract: Ayran is a traditional fermented dairy beverage frequently consumed in warm climates. However, its high susceptibility to spoilage can pose food-borne health risks due to microbial contamination and pH changes when stored improperly. Therefore, rapid and visual freshness monitoring is crucial for dairy products like ayran, which have a short shelf life.This study investigated the visual traceability of food freshness by preparing solutions based on paper-based colour indicators. First, the colour difference values (ΔE) of nine solutions containing varying amounts of bromthymol blue and phenol red were measured, and the colour responses were compared. The prepared solutions exhibited different colour intensities depending on the type and amount of indicator, and the type of solvent. Solutions containing phenol red were particularly notable for their higher ΔE values. Furthermore, samples of spoiled and unspoiled ayran were added to these solutions to examine colour changes. The pH change in spoiled ayran samples led to more pronounced colour differences in colored solutions, confirmed by increased ΔE values. In intact ayran, colour change was limited, indicating that freshness was maintained. The findings demonstrate that solutions using high concentrations of bromthymol blue, in particular, can quickly detect spoilage in ayran. The results demonstrate that paper-based colour sensors can be used as low-cost and user-friendly freshness indicators in perishable foods such as dairy products.

Keywords: Ayran, phenol red, sensor

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Analysis of Nano- and Micro-Sized Flocculants in Drinking Water

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Abstract: Water quality in drinking water treatment plants is evaluated using parameters such as turbidity, total organic carbon, and metal concentrations. However, these parameters cannot determine the presence of stable nano and micron-sized colloids remaining in the water after the coagulation process. In this study, the fraction and persistence of nano and micron-sized colloids remaining in treated drinking water were investigated using DLS and zeta potential analysis. Raw drinking water samples were subjected to jar test coagulation using aluminum sulfate at optimized doses and pH conditions, followed by precipitation and filtration. Treated water samples were analyzed in terms of particle size distribution, polydispersity index, and surface charge. DLS measurements revealed the presence of stable colloidal particles, predominantly in the 50-200 nm size range, which could not be detected by conventional turbidity measurements. Zeta potential analysis showed that these colloids remained electrostatically or sterically stabilized despite the apparent treatment efficiency. The results show that while the traditional coagulation method provides visually clear drinking water, it can leave behind a chemically and potentially microbiologically active colloidal fraction. The remaining colloidal substances can affect disinfection byproduct formation and microbial persistence in distribution systems. The study sheds light on the development of new treatment methods and the removal of micro and nano colloids.

Keywords: Drinking water, nano colloids, micro colloids, dynamic light scattering

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Auction Platform for Addressable TV Advertising for the Polish Media Market

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Abstract: The Polish media market is undergoing a transformative shift towards data-driven, addressable advertising. One of the technological solutions for this challenge is the development of an integrated auction platform. It was created by the Warsaw Stock Exchange (WSE), which, through such initiatives, expanded the areas of its operations. The innovative TeO platform is a solution designed to standardise and streamline the value chain of TV advertising across all stakeholders—broadcasters, operators, media agencies, and advertisers. It can profile TV users, as well as sell and display targeted advertising on linear television. The platform is an outcome of R&D processes which utilize cutting-edge technologies, including machine learning and neural networks, to ensure high-precision profiling and minimal-latency system operation, enabling near-real-time advertising purchases and display. The R&D processes were conducted by the Warsaw Stock Exchange team under the financial grant received from the National Centre for Research and Development of the Republic of Poland in period 2021-2023.

The study presents selected findings of four stages of R&D works on building some algorithms and then building modules based on the developed algorithms and implementing them as part of the launch of the TeO prototype. The culmination of these stages was the launch of the TeO platform in production mode. Currently, the platform is being used by a subsidiary company, GPW DAI JSC.

The auction platform provides broadcasters with new tools for planning and monetizing advertising slots, leveraging standardized campaign reports and campaign-level insights. This enables more effective management of underperforming content and unsold inventory. Advertisers and media buyers gain access to detailed audience segmentation and targeting, facilitating more precise and efficient campaign execution across various distribution channels, including digital TV.

Operators (e.g., TV platforms and cable providers) play a central role in ad distribution, providing anonymized viewership data and enabling commercial use of return channel data. The platform supports cooperation between operators and broadcasters by ensuring transparency, fair valuation of advertising space, and strategic alignment through JIC's auditing and oversight mechanisms.
The solution integrates IT infrastructure for settlement, reporting, and campaign integration, fostering a win-win ecosystem with measurable benefits:

- Enhanced revenue opportunities for all stakeholders.
- Improved campaign ROI through granular targeting.
- Streamlined advertising purchases through centralized transactions.
- Increased viewer satisfaction via more relevant content and ad exposure.

This initiative represents a significant milestone in the digital transformation of television advertising in Poland, offering a replicable model for other regional markets.

Keywords: Hygiene, food employees, food safety, hygienic-sanitary practices, Prizren

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Effects of Agroecological Conditions on the Physicochemical and Pigment Characteristics of PDO-Certified Gemlik Olives: A Comparative Assessment of Regional Variation Over Two Harvest Years

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Abstract: The Gemlik olive (*Olea europaea* L.) is among Türkiye's most commercially and culturally valuable olive cultivars, distinguished by its thin skin, high flesh-to-pit ratio, and dual-purpose use for both oil extraction and table consumption. Recognized by the European Union with a Protected Designation of Origin (PDO) status, this cultivar is genetically clonal yet exhibits notable phenotypic variability across different growing environments. This study investigates how distinct agroecological conditions influence the physicochemical composition and pigment profiles of PDO-certified Gemlik olives.

Olive samples were collected over two consecutive harvest years from five ecologically diverse regions of Türkiye Antalya, Aydın, Balikesir, Manisa, and Hatay. The parameters investigated included moisture content, dry matter, oil content, chlorophyll, and carotenoid levels. To identify spatial variations, a combination of multivariate statistical tools Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) was employed. These quality indicators were further examined in relation to environmental data (altitude, temperature, wind speed, humidity), and macro/micronutrient compositions of both soil and leaves.

The analysis revealed that olives from the Balikesir and Hatay regions consistently demonstrated superior dry matter and oil contents across both years, suggesting regional adaptation advantages. Hatay samples recorded the highest chlorophyll and carotenoid concentrations, implying an enriched pigment synthesis capacity under local conditions. A significant inverse correlation was observed between wind speed and fruit moisture, while higher maximum temperatures were positively associated with moisture retention. The accumulation of oil and pigments was strongly influenced by soil magnesium and sodium levels, along with leaf nitrogen content indicating the combined role of edaphic and physiological factors. Furthermore, maturity index data highlighted region-specific trends that appeared to be modulated by annual temperature shifts and soil structure variability.

These findings provide a deeper understanding of the environmental responsiveness and quality dynamics of Gemlik olives. The study not only emphasizes the need for region-specific cultivation and harvest protocols but also contributes to PDO traceability, quality standardization, and the promotion of high-value olive products through geographic branding. By linking physicochemical performance with agroecological inputs, the research supports the development of sustainable and precision-driven olive farming strategies for this emblematic cultivar.

Keywords: Gemlik olive, PDO, Agroecological variation, Physicochemical properties, Pigment content, Multivariate analysis

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Finite Element Modelling of the Structural Behaviour of Screwed Timber-to-Lightweight Concrete Composite Connections

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Abstract: Timber-to-lightweight concrete composite (TCC) systems have emerged as an efficient and sustainable structural solution, combining the high compressive strength and mass-reducing benefits of lightweight concrete with the excellent tensile properties and low environmental impact of timber. A critical factor influencing the overall performance of such systems is the mechanical behaviour of the shear connection between the two materials. This study focuses on screwed timber-to-lightweight concrete connections, which offer rapid installation, reversibility, and consistent load-transfer capacity. The objective is to develop and validate a finite element modelling (FEM) approach capable of accurately predicting their structural response under static loading. A comprehensive three-dimensional FEM model was developed, incorporating nonlinear material constitutive laws for both timber and lightweight concrete. The model accounts for the anisotropic elastic–plastic behaviour of timber, including embedment and splitting phenomena, as well as the nonlinear fracture behaviour of lightweight concrete in compression and tension. The mechanical performance of screws was represented by combined shear and axial stiffness, incorporating experimentally derived nonlinear load–slip relationships. The timber–concrete interface was simulated using contact elements that permit partial interaction and relative slip, capturing the influence of connection flexibility on composite action. Geometric and material nonlinearities were introduced to model the progressive deformation and failure of the connection with high fidelity. Validation of the numerical model was performed against experimental push-out tests on full-scale specimens. The comparison showed strong agreement in terms of load–slip response, ultimate load-bearing capacity, initial stiffness, and failure patterns, which included screw yielding, timber embedment, concrete crushing, and timber splitting. The results demonstrate that the proposed FEM methodology offers a reliable and versatile tool for predicting the structural behaviour of screwed timber-to-lightweight concrete composite connections. This modelling framework enables optimisation of connection detailing for enhanced structural efficiency and serviceability, contributing to performance-based design approaches and promoting the broader application of composite timber–lightweight concrete floor systems in sustainable construction.

Keywords: FEM, timber, lightweight concrete, screwed connections, load–slip behaviour.

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Machine Learning–Driven Threat Detection for Modern Cybersecurity Infrastructures

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Abstract: The increasing diversity and sophistication of cyberattacks necessitates proactive security architectures capable of detecting anomalous behavior in high-velocity network environments. This study develops a scalable machine-learning intrusion detection framework that integrates flow-based features, adaptive dimensionality reduction, and ensemble learning. Network traffic is first preprocessed using statistical aggregation and temporal windowing, enabling the extraction of discriminative signatures related to port scanning, spoofing, and ransomware propagation. A hybrid ensemble combining Random Forest and Gradient Boosting significantly improves detection accuracy over single models, particularly for low-frequency zero-day patterns. A cloud-native microservice architecture ensures real-time deployment, low hardware overhead, and dynamic resource allocation. Model performance was evaluated using the CIC-IDS and UNSW-NB15 datasets, showing notable gains in precision and false-positive reduction. A key contribution of this work lies in the interpretability module employing SHAP values to identify feature importance, which increases analyst confidence and accelerates response. Ethical and regulatory considerations, such as anonymization of packet-level attributes and compliance with data-protection laws, are addressed. The study demonstrates a practical pathway toward integrating advanced machine learning into operational security infrastructures, especially within finance, e-commerce, governmental networks, and critical industrial domains.

Keywords: Cybersecurity, Machine Learning, Network Anomaly Detection, Cloud Deployment

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High Purity Low-Cost Microcrystalline Cellulose from Wood/Non-Wood Waste for Biomedical Applications

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Abstract: We present a low-cost route to produce high-purity microcrystalline cellulose (MCC) from wood (black pine sawdust) and non-wood (hazelnut shell) wastes using alkali delignification coupled with SDS-assisted decellularization—targeting the removal of cellular and extractive residues—followed by $NaClO/H_2O_2$ bleaching under ambient-pressure operations. Structural verification combined Raman spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM). For the wood-derived fraction, Raman library matching confirmed MCC identity with ~93–93.5% similarity to reference MCC, consistent with cellulose I-type signatures; XRD and SEM corroborated well-defined crystalline cellulose domains with minimal non-cellulosic remnants. The hazelnut-shell route yielded comparable Raman/XRD/SEM features, demonstrating feedstock flexibility. By integrating SDS-assisted decellularization into the workflow, the process addresses protein/lipid-rich residues that can compromise biomedical compatibility, while thorough washing minimizes surfactant carryover. Collectively, these results indicate that forestry and agro-waste streams can be converted into MCC of structural purity compatible with biomedical use cases (e.g., hemostatic/wound-care matrices), recognizing that application-specific controls—bioburden/endotoxin limits, trace-metal screening, and cytocompatibility/hemocompatibility—remain essential for regulatory acceptance. The method uses commodity reagents, is amenable to scale-up, and supports sustainable valorization of regional waste resources.

Keywords: microcrystalline cellulose, wood waste, hazelnut shell, decellularization, biomedical compatibility.

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Digital Twins for Sustainable Development in Albania

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Abstract: Digital twin technology is rapidly transforming how we design, monitor, and optimize complex infrastructure, urban systems, and educational environments. A digital twin is essentially a live, virtual replica of a physical object or system, ranging from individual buildings and industrial equipment to entire city districts that continuously updates with real-time data. By integrating sensors, Internet of Things (IoT) devices, cloud computing, and artificial intelligence (AI), digital twins enable engineers, educators, and decision-makers to observe operations as they happen, predict potential issues, and make informed, data-driven decisions. In Albania, digital twins are beginning to be applied across multiple sectors, demonstrating both practical benefits and opportunities for innovation. In the urban context, pilot projects in Tirana use digital twins in schools and public facilities. These smart building initiatives equip classrooms and offices with sensors that monitor energy consumption, indoor climate, and maintenance needs. The resulting digital models provide actionable insights that help facility managers optimize energy use, plan preventive maintenance, and improve comfort and safety for students and staff. Moreover, these projects serve as educational platforms, allowing students to engage with IoT and digital twin technologies firsthand, fostering technical skills, awareness of sustainability, and problem-solving capabilities from an early age. Similarly, in Durrës, Albania's largest maritime hub, proposed smart port models utilize AI-driven digital twins to streamline cargo handling, enhance passenger flow, monitor environmental conditions, and increase operational efficiency. These systems demonstrate how digital twins can integrate engineering design, computer science, and operational management to optimize complex, real-world processes while reducing energy use and environmental impact. Beyond practical applications, digital twins serve as platforms for simulation, experimentation, and training. Engineers, educators, and computer scientists can model "what-if" scenarios, evaluate the impacts of infrastructure upgrades, and anticipate challenges before they occur in the physical world. In education, digital twins allow students and teachers to simulate systems, interact with real-time data, and gain hands-on experience with emerging technologies, bridging theory and practice while promoting digital literacy. While challenges remain, including sensor integration, data interoperability, cybersecurity, and the need for skilled professionals, early initiatives in Tirana and Durrës illustrate the transformative potential of digital twins. By combining real-time monitoring, predictive analytics, and system optimization, digital twins enable smarter, more efficient, and sustainable urban, industrial, and educational environments. This paper examines current applications in Albania, highlights their technical and operational benefits, and explores opportunities for scaling this technology to foster sustainable development and innovation across multiple sectors.

Keywords: Digital twin, sustainability, technological development, Internet of Things, smart infrastructure, digital transformation, resource optimization, educational twin

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Computational Approaches for Analyzing Factors Influencing Software Product Innovation

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Abstract: The software industry today faces intense pressure to innovate, driven by fierce competition, rapid technological advancements, and increasingly diverse customer demands. Innovation in software products is particularly vital, as it enables firms to secure sustainable competitive advantages and expand their market presence. This study systematically examines the dynamics of innovation within software companies by identifying 33 influencing factors derived from a literature review, academic insights, and expert opinions. To capture the complex interrelations among these factors, expert assessments of their impact on software product innovation were gathered through an online survey. The resulting data were used to construct a Fuzzy Cognitive Map (FCM) via the Schneider algorithm, followed by simulation based on interaction weights and expert-informed initial factor values. The findings highlight that the most influential factors are the level of open innovation implementation, collaboration with external stakeholders, and sectoral dynamism. Conversely, environmental factors—such as city size, number of university graduates, and local business opportunities—were deemed least significant in innovation processes. These results provide critical insights into the hidden dynamics of the innovation ecosystem and are expected to support software firms and industry professionals in formulating more effective innovation strategies.

Keywords: Software product innovation, fuzzy cognitive maps, Schneider algorithm, innovation factors

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Deep Learning-Based Multi-Modal Malware Classification with Explainability

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Abstract: Malware evolution—driven by polymorphic obfuscation, control-flow randomization, and adversarial transformation—undermines conventional signature-based techniques. This research proposes a multi-modal deep learning strategy that integrates static binary attributes, opcode transition graphs, and dynamic behavior traces in a unified representation. An attention-guided fusion mechanism captures cross-modal dependencies, enabling precise classification of families that share overlapping behavioral patterns. Class imbalance, a common issue in malware datasets, is mitigated through focal-loss optimization and synthetic minority oversampling. Experimental comparisons with CNN-only and RNN-only architectures show improvement in F1 score, precision, recall, and confusion-matrix separability. Furthermore, gradient-based feature attribution is provided to security analysts, revealing dominant opcode motifs and behavioral triggers underlying classification. This transparency supports forensic investigation and model validation, reducing the risk of black-box dependence. The architecture offers practical benefits for security operations centers (SOCs), enabling detection within enterprise networks and lightweight IoT ecosystems. The model is also resilient against evasion attempts, as demonstrated through adversarial test cases. The work emphasizes the need for interpretability and trusted automation, particularly when AI systems impact rapid response workflows. The findings illustrate how multi-modal deep learning can transform malware analysis from reactive detection to proactive intelligence generation.

Keywords: Deep Learning, Explainability, Malware Detection, Multi-Modal Fusion

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Comparative Analysis of Corrosion Damage On Transversal Plates Of Ballast Tanks In an Aging Bulk Carrier,

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Abstract: Corrosion is one of the dominant influencing factors in the degradation of steel structural elements during the ship's operation. The degree of corrosion damage to the structure and structural integrity of the ship also depends on the intensity of corrosion, while the degree of repair and sustainability of the structure also depends on the criteria for acceptance established by Classification Rules. The previous research has primarily addressed corrosion effects on longitudinal structural elements, with limited attention given to the fact that transversal members can degrade at different rates and exhibit varying severities of corrosion damage. Therefore, this study aims to highlight the degree of thickness loss in the transverse elements of various types of ship ballast tanks.

In this paper, three types of ballast tanks in the cargo hold spaces of a bulk carrier after 25 years of service were analyzed. The subject of the analysis was the Top Side Tanks, Bilge Tanks and Double Bottom Tanks, within which three areas were selected: Outside Ring, Inside Ring, and Flanges/Openings.

Using thickness measurement equipment, representative data were collected during the regular surveys, revealing a significant reduction in the percentage of plate thickness due to the corrosion process. Using one-way analysis of variance (ANOVA) and post hoc tests, the study examined whether there were statistically significant differences in degradation levels between the top-side tanks, bilge tanks, and double-bottom tanks.

The results of the ANOVA test indicated the presence of statistically significant differences in percentages for certain areas and locations, while post hoc tests showed that there are no significant differences between the left and right sides of the ship in most of the observed parts, which indicates symmetry in operational conditions and corrosive influences.

Keywords: corrosion damage, plate thickness, bulk carrier, ballast tanks.

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Cyber–Physical Security Architecture for Smart Agriculture IoT

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Abstract: Precision agriculture increasingly integrates IoT sensors for monitoring soil moisture, crop health, livestock movements, and irrigation scheduling. However, these systems are vulnerable to cyber–physical threats including false-data injection, replay attacks, device spoofing, and denial-of-service manipulations. This research proposes a layered cyber–physical architecture combining mutual authentication, secure telemetry encryption, lightweight anomaly detection, and distributed incident-response strategies. The anomaly detection layer employs a machine learning model that learns normal behavioral patterns and flags deviations in power consumption, message frequency, and sensing consistency. Field tests conducted on irrigation controllers demonstrate that the system successfully detects spoofing and replay attacks without introducing unacceptable latency or additional energy burden on microprocessors. The architecture's decentralized design ensures continued operation even when individual nodes are compromised. Importantly, the study evaluates not only security performance but also economic feasibility, demonstrating that cyber resilience can be achieved with low-cost open-hardware platforms. This work contributes to securing digital transformation in agriculture, ensuring trust in IoT-enabled rural infrastructure.

Keywords: Cyber–Physical Systems, IoT Security, Rural Digitalization, Smart Agriculture

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Community-Based Ecotourism with Smart Decision Support Systems

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Abstract: Successful ecotourism requires an integrative framework that protects ecosystems while enhancing community welfare. This study introduces a smart participatory decision-support system that combines socio-ecological indicators, digital geospatial analytics, and community-based governance. Field surveys and semi-structured interviews were conducted to evaluate residents' perceptions of ecosystem services, cultural heritage priorities, and tourism pressures. These socioeconomic data layers were linked with ecological sensitivity indices and visitor behavior datasets to generate a holistic sustainability dashboard. The dashboard—accessible to local authorities, tourism cooperatives, and NGOs—provides data-driven recommendations on carrying capacity limits, seasonal visitor distribution, and conservation-oriented infrastructure planning. Case application in Mediterranean rural landscapes revealed improved waste management practices, enhanced interpretation of cultural assets, and diversified local revenue streams. The participatory component increased trust among stakeholders, reduced perceived conflicts between tourism actors, and provided transparency in decision-making. Unlike conventional top-down tourism planning, the proposed model operationalizes continuous feedback loops, allowing rapid adaptation to ecological warnings and socioeconomic needs. The study highlights that integrating smart analytics with community governance significantly strengthens ecotourism sustainability, positioning rural landscapes as resilient socio-ecological systems rather than mere tourism destinations.

Keywords: Ecotourism, Decision Support, Community Engagement, Cultural Heritage

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AI-Enabled Life Cycle Assessment for Sustainable Manufacturing

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Abstract: Life Cycle Assessment (LCA) has become an essential methodology for understanding the environmental implications of manufacturing processes; however, its application is often constrained by intensive data requirements, expert-dependence, and lengthy assessment time. This study presents an AI-enabled LCA framework designed to accelerate environmental evaluation while maintaining scientific reliability. The system uses a hybrid predictive architecture that integrates clustering-based material grouping, regression modeling of emissions, and knowledge-driven rules linking process parameters with environmental impact categories. Incomplete datasets—commonly encountered in industrial reporting—are processed through imputation models that reconstruct missing indicators using multi-variable correlations. A validation campaign was carried out using case studies from metalworking and composite fabrication. Results indicate a strong agreement between AI-assisted impact estimations and full-scale conventional LCA values, while reducing execution time by more than 60% and minimizing manual intervention. The framework identifies nonlinear relationships between production factors and environmental outcomes that standard deterministic calculations typically overlook. By quantifying uncertainty, the model provides transparent confidence intervals, supporting decision-making in eco-design and cleaner production optimization. The AI-enabled architecture also allows rapid scenario analysis, enabling manufacturers to assess alternative materials, modified energy inputs, or improved process conditions before implementation. Ultimately, this research positions LCA not as a static post-assessment tool, but as a real-time, iterative decision support system that facilitates sustainable industrial transformation.

Keywords: Life Cycle Assessment, Artificial Intelligence, Ecoefficiency, Sustainable Manufacturing

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Explainable AI for Cleaner Production and Industrial Efficiency

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Abstract: Cleaner production principles require minimizing waste, optimizing energy usage, and improving resource scheduling. This study presents an explainable AI system that analyzes multi-sensor industrial data to provide actionable recommendations for operational efficiency. A predictive surrogate model estimates energy consumption and emission levels under varying process configurations. SHAP- and LIME-based explainability layers reveal how individual variables—temperature gradients, machine load intensity, raw material purity—affect performance. The approach enables engineers to understand model outputs rather than treat them as black-box predictions. Validation on real manufacturing lines indicates substantial improvement in throughput and waste reduction without hardware investment. Decision transparency improves operator trust and accelerates sustainability adoption. The methodology provides a replicable blueprint for integrating AI–driven optimization in cleaner production systems across food, materials, and processing industries.

Keywords: Cleaner Production, Explainable AI, Industrial Optimization, Sustainability

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AI-Optimized Routing for Sustainable Rural Tourism Logistics

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Abstract: Rural tourism frequently suffers from uneven visitor distribution, where certain natural attractions experience overcrowding while nearby resources remain underutilized. This imbalance causes ecological degradation, traffic congestion, and reduced visitor satisfaction. We introduce an AI-assisted routing system that optimizes tourist flows using graph-based path planning, demand prediction, and ecological sensitivity weighting. The model learns from historical mobility traces, road accessibility metrics, terrain difficulty indices, and seasonal tourism patterns. A multi-objective optimization framework minimizes travel time while distributing visitors among a network of attractions, thereby reducing human pressure on environmentally fragile hotspots. Simulation results from rural Mediterranean landscapes demonstrate a 30–35% reduction in congestion, along with improved local business diversification as secondary attractions gain visibility. The AI model operates as an online recommendation engine, guiding tourists toward balanced itineraries while providing carbon footprint estimates for alternative routes. This integration of sustainability metrics transforms routing into an ecological stewardship tool rather than a purely logistical optimization task. The system empowers tourism agencies to maintain ecological balance while enhancing visitor experience.

Keywords: Artificial Intelligence, Routing Optimization, Rural Tourism, Sustainability

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Physics-Based Numerical Simulation of the Puff Drying Process under Instant Pressure Drop Conditions

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Abstract: This study presents a physics-based numerical simulation model developed to describe the puffing (swelling) phenomenon that occurs during puff drying. The model simultaneously incorporates moisture diffusion, surface mass transfer, and internal (mechanical) stress changes occurring in food slices throughout the drying process. Swelling is assumed to be triggered when the vapour pressure within the food matrix exceeds the external pressure and the material's yield strength. The governing equations were solved as time-dependent functions in MATLAB, yielding a numerical solution based on the implicit finite-difference method.

Simulations were carried out for fruit slices with an initial thickness of 2 mm. During drying, the thickness gradually decreased over time, followed by a sudden volume expansion of approximately 25 % at the puffing point. The puffing event was represented in the model by a simulated instant pressure drop (IPD), which caused the internal vapour pressure to exceed the surrounding pressure and the material's yield strength. Consequently, the effective moisture diffusion coefficient increased approximately sixfold, while the surface mass transfer coefficient increased 2.5-fold. The diagnostic function $\varphi(t) = Pv - Pext - \sigma yield$ — which represents the dynamic balance between the internal vapour pressure, external pressure, and the material's yield strength — confirmed that puffing occurred immediately after the simulated depressurization event.

The results demonstrate that the developed physics-based model successfully captures the coupled interactions between heat, mass, and structure during the puff drying process. In the next stage of this research, the model will be further adapted and extended to different drying conditions and product types, and comparatively evaluated using data available in the literature. This approach is expected to contribute to a deeper understanding of the puff drying mechanism and provide a solid numerical foundation for future experimental investigations.

Keywords: Puff drying, physics-based simulation, moisture diffusion, numerical modelling, structural expansion.

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Secure Federated Learning for Healthcare Cyber-Systems

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Abstract: This article presents an analysis of G-Forces (accelerations) acting on a light aircraft pilot at various stages of training toward the Commercial Pilot License (CPL(A)), including glider towing operations. The theoretical section outlines the structure of flight training leading to the commercial license, with particular emphasis on supplemental training – especially glider towing – as a part of flight time building and gaining additional operational experience. Data collection was conducted using a custom-designed measurement device developed by the author, based on the MPU9250 sensor and Arduino Mega 2560 microcontroller, allowing for tri-axial acceleration recording. Additional data sources included a GPS-based flight data logger and video recordings of the instrument panel. Measurements were gathered during instructional training flights on Aero AT-3 and Cessna C150 aircraft, as well as during glider towing operations using the Yakovlev Yak-12M within the scope of dedicated training for the "glider towing" qualification. The study analyzed accelerations occurring in various phases of flight, including non-standard tasks such as simulated emergency scenarios. For glider towing flights, the analysis also considered atmospheric conditions and the specific nature of thermal-lift-oriented operations. The results indicate significant differences in acceleration profiles and increased pilot workload during towing missions. These findings may support the assessment of pilot suitability for subsequent training stages and contribute to the optimization of flight training programs.

Keywords: Federated Learning, Healthcare Security, Privacy Preservation, Encryption

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Climate-Adaptive Spatial Planning for Rural Tourism

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Abstract: Climate variability increasingly affects the reliability and safety of rural tourism activities, particularly in mountainous and coastal regions. This research develops a climate-adaptive planning approach that integrates long-term meteorological datasets, topographic exposure indices, ecological vulnerability layers, and infrastructure accessibility. A spatial–temporal modeling framework identifies thresholds where extreme heat, heavy precipitation, or drought conditions elevate risks for visitors and local ecosystems. Predictive mapping enables local authorities to modify seasonal tourism calendars, introduce climate-smart trail routing, and develop shaded rest points and early warning systems. Case demonstration in Mediterranean rural parks reveals that climate-adaptive scheduling can reduce environmental disturbance and improve tourist experiences without additional infrastructure expansion. Importantly, the framework considers socio-economic resilience, as climate-proof tourism provides diversified income options for local communities under increasing climate uncertainty. The approach shows high transferability to rural regions lacking extensive monitoring, as the model relies on accessible climatic archives combined with geospatial processing. Findings emphasize that climate adaptation should not be reactive or crisis-driven, but embedded into regular planning cycles.

Keywords: Rural Tourism, Climate Adaptation, Spatial Planning, Resilience

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Geospatial Ecosystem Mapping for Strategic Rural Tourism Development

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Abstract: Rural regions contain diverse ecological, cultural, and agricultural assets, yet tourism development in these landscapes is often fragmented due to lack of evidence-based planning. This study presents a geospatial ecosystem mapping framework for identifying optimal zones for rural tourism growth while maintaining ecological integrity. Using multi-layer spatial data—including land-use classification, elevation gradients, heritage inventories, biodiversity records, and accessibility indices—we generate a spatial attractiveness model that quantifies the suitability of rural areas for tourism-related investment. Multi-criteria decision analysis (MCDA) determines priority regions based on both environmental and socio-economic criteria. Validation through participatory workshops with local stakeholders confirms that many high-potential sites are currently overlooked due to insufficient infrastructure, poor connectivity, or limited visibility in regional planning documents. The resulting maps support strategic decision-making by highlighting where targeted investments—such as eco-lodges, heritage trails, agro-tourism clusters, and cultural hubs—can enhance local livelihoods without compromising ecological values. The framework is replicable for rural municipalities with limited financial resources, as it uses openly accessible geospatial datasets. Overall, the findings demonstrate that ecosystem-based spatial planning offers a scientifically grounded approach to promoting sustainable rural tourism, balancing development goals with landscape preservation.

Keywords: Rural Tourism, Spatial Analysis, Ecosystem Mapping, Sustainable Development

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Design and Mathematical Analysis of Rat-Race Coupler for X-band Applications

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Abstract: A rat-race coupler, also known as a hybrid ring coupler, is a passive microwave component designed for power division, signal combiner, and phase shifter purposes in microwave engineering and widely used in literature. Structurally, it consists of a circular or ring-shaped transmission line network consisting of quarter-wavelength (λ/4) and three-quarter-wavelength (3λ/4) sections. The main function of a rat-race coupler is to provide high isolation between specific ports while dividing the input power equally between two output ports with a 180° phase difference. Due to their advantageous characteristics such as high isolation and phase balance, rat-race couplers are particularly preferred in balanced amplifiers, antenna array feed structures, mixer circuits, and various RF front-end applications.This research focuses on the design and mathematical analysis of a 3 dB rat-race coupler optimised for X-band applications. The X-band, with frequencies ranging from 8 to 12 GHz, is critical in modern communication and sensing technologies such as radar systems, satellite communication, electronic warfare, and synthetic aperture radar (SAR) imaging. To achieve mid-band performance, this design used a center (cut-off) frequency of 10 GHz.The coupler was implemented on a microstrip line configuration because it is compact in size and easy to integrate in planar circuits. The structure was designed using Rogers RO 3003 (εr=3) as the substrate material of the planar structure, having a thickness of 0.50 mm, due to its low loss and stability at high frequencies. For the conductor material in microstrip line design, 0.035 mm high conductivity copper was used, which is easy to use in conventional fabrication methods.MATLAB was used for mathematical modeling and calculation of design parameters to determine electrical length and characteristic impedance with accuracy. Electromagnetic simulation at a high level was done with CST Microwave Studio to compute the S parameters, isolation, return loss, and phase performance of the proposed coupler. Simulation values verified that the rat race coupler offers sufficient port isolation and reasonable power dividing as well as low return loss at approximately the 10 GHz target frequency and is thus appropriate for use in X-band RF.

Keywords: Rat-Race Coupler, X-band applications, Power Divider, Microstrip.

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Assessment of Hygiene and Sanitation Knowledge Among Food Establishment Workers in Prizren

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Abstract: This study aimed to assess the level of hygiene and sanitation knowledge and awareness among employees in food processing establishments within Prizren Municipality. The research was conducted using a structured questionnaire comprising 32 questions distributed across various sectors of the food industry. Collected data were analyzed to determine existing knowledge of hygienic and sanitary practices, as well as to identify deficiencies and the need for further training in this domain. Findings indicate that, although many employees possess basic hygiene knowledge, significant gaps and misconceptions exist. These include insufficient professional qualifications, with 60% of employees having only a high school education and just 4% holding a relevant bachelor's degree in a related field, and an additional 4% holding a master's or PhD. There was also a lack of awareness regarding fundamental food safety standards such as HACCP and ISO 22000, as over 50% of employees reported unfamiliarity with these systems. Furthermore, while basic personal hygiene practices like handwashing after toilet use were reported by 92% of employees, these rates decreased in more complex or less controlled situations, with only 30% always washing hands even when not in direct contact with food. The use and changing of gloves were not standardized, as only 27% reported consistent use, and internal controls were lacking, with only 29% stating that controls were performed regularly and 31% immediately reporting problematic situations. Moreover, 36% of employees had received no food hygiene training, and 20% reported that no training was organized at all, despite 92% agreeing on the necessity for training. Self-assessment of hygiene levels also showed room for improvement, with only 28% considering their food hygiene level "very good" and 24% acknowledging a need for improvement. This study not only underscores the critical need for improved education and professional development for employees but also highlights how these deficiencies could potentially impact on the quality and safety of food products. The results demonstrate that implementing periodic, practical training sessions and standardized hygiene procedures is crucial for enhancing the food safety culture within food establishments and for safeguarding consumer health.

Keywords: Hygiene, food employees, food safety, hygienic-sanitary practices, Prizren

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The Artificial Intelligence Based Literary Text Analysis: A Novel Concept on Emotional and Conceptual Mapping ction Platform for Addressable TV Advertising for the Polish Media Market

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Abstract: The role of Artificial Intelligence (AI) is increasing every day. There are many AI based methods used for different areas. This study focuses on the analysis of emotional and conceptual structures of literary texts by means of AI based methods. By applying Natural Linguistic Processing (NLP) techniques on literary text written in Turkish language, sensual density and conceptual context are inferred. This study makes it possible to combine the expertise of literary analysis with technical knowledge of machine learning and NLP and signal processing and data visualization. In the study, first, poems and short stories belonging to distinct era have been chosen and converted to the digital format. Additionally, besides the grammatical pre-processing stages on the texts, BERT based models have been used for the classification of emotion. Moreover, symantic proximity analysis has been made with word vectorization methods such as word2vec and fastText. The obtained emotion data has been modeled in time series and emotional transition. The emotion data have been visualized by color coded heat maps and graphics and a prototype an interactive interface has been developed. The results show that AI based analysis permits deeper and objective examination of literary texts. As a result, the study has the potential to contribute to literature education. The study brings a new perspective on digital human science with interdisciplinary methods and presents significant evidence of the use of AI techniques in the analysis of literary texts.

Keywords: Literary texts, NLP, AI, Emotion analysis

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The Impact of Smart Grid Technologies on the Efficiency of Electricity Distribution Networks

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Abstract: The integration of smart grid technologies has transformed the traditional electricity distribution network into an intelligent, adaptive, and highly efficient system. This paper investigates the impact of smart grid solutions—such as advanced metering infrastructure (AMI), supervisory control and data acquisition (SCADA), automated switching, and distributed energy resource (DER) integration, improving the efficiency, reliability, and sustainability of electricity distribution networks. The study emphasizes the role of automation, real-time monitoring, and two-way communication in reducing technical losses, optimizing load management, and enabling demand-side response. Special attention is given to the integration of renewable energy sources, such as wind and solar power, which contribute to a cleaner and more resilient energy supply. Furthermore, the paper addresses critical cybersecurity challenges that arise from increased digitalization, proposing measures to protect operational and administrative systems from potential threats. Through a combination of literature review, case studies, and data analysis, the research evaluates the technical, economic, and environmental benefits of adopting smart grid technologies. Results indicate significant improvements in operational efficiency, faster fault detection and isolation, enhanced voltage regulation, and better asset management. The findings also underline the importance of supportive regulatory frameworks, workforce training, and cross-sector collaboration to ensure successful deployment. Ultimately, the paper concludes that smart grid technologies are not only a technical upgrade but a strategic investment toward achieving sustainable, secure, and future-ready electricity distribution systems, particularly in regions aiming to modernize their power infrastructure and meet evolving energy demands.

Keywords: Smart Grid, Distribution Efficiency, SCADA, Automation, Renewable Energy, Cybersecurity.

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The Finite Element Modelling of Thin-Walled Composite Beams Considering Shear Lag Effect

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Abstract: Composite thin-walled beams with closed cross-sections are widely used in industry and engineering. Openings of various sizes are often introduced in these elements to provide access for services and maintenance, or to create passageways into the interior of the structure. In addition to their functional purposes, such openings also contribute to reducing the overall structural weight. The objective of this study is to examine the influence of openings on shear lag effects in composite thin-walled elements. Differential equations of thin-walled composite beams of arbitrary cross section were derived, using the principle of virtual displacements and starting from function of deplanation, for thin-walled beams of homogeneous cross section. It enables unique analysis thin-walled beams of open and closed cross section, assumption of neglecting shear strain in the middle surface is not necessary and shear stresses can be calculated directly from the strains. Distribution of longitudinal stresses is not defined by warping function, but parameters of longitudinal displacement, and in general case it is variable of section to section, that enables registering and analysis of shear lag, which classical theory of thin-walled beams is unable to reflect. As it is known, shear lag effect presents a non-uniform distribution of normal stresses in the flanges, maximal values are on the connection of flange and web, in general case it is larger from the value of stress obtained by classical theory of beams based on the Bernoulli hypothesis. It is especially expressed at beams subjected to bending where deplanation of cross section is significant. Derived system of differential equations can not be solved in closed form solution and it was accessed to numerical method, respectively on the finite element method. A finite element, formulated on the basis of the warping function is employed to analyze shear lag in composite thin-walled beams with openings. A computational program has been developed to determine longitudinal stresses without restrictions, accounting for shear lag effects for arbitrary cross-sections and any boundary conditions. The developed computer program can also be used to calculate the stiffness of cross-laminated timber with layers of arbitrary stacking sequence and orientation of laminas, not limited to only 0° and 90° orientations.

Keywords: FEM, Thin-walled, composites, shear lag.

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Production and Characterization of Pellets from Waste Lavender Stalks

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Abstract: People are becoming more interested in sustainable products, and at the same time, farms are generating more waste than before. Because of this, it's becoming more important to find new types of biomass that can be turned into solid biofuels. This research looks at something a bit unusual: the leftover stalks from lavender plants after their essential oil has been extracted. These leftovers usually go unused, but they might actually work well for making pellets. Before trying to turn the stalks into pellets, we tested them to learn about their physical and chemical characteristics, as well as their energy potential. We also used hexane to see what extractive materials the stalks contain. From the tests, we saw that the stalks had a decent amount of moisture—not too high—and they didn't leave much ash behind when burned, which is a good thing. The amount of energy they give off when burned is also similar to other grassy plant materials. Another advantage is that they naturally contain lignin, which helps the pellet hold its shape without needing added glue. All these things point to one conclusion: lavender stalks, usually seen as waste, could actually help us make cleaner energy. They fit well with the goals of renewable energy and circular economy systems.

Keywords: Lavander waste, chemical characterization, pellet production, circular economy

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Valorization Of Mine Tailing And Plastic Waste As Substitutes For Sand And Cement In Non-Structural Concrete Elements

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Abstract: The study investigates the use of mine tailings and molten plastic as sustainable alternatives to traditional materials in concrete production. Driven by the environmental impact of cement production (responsible for approximately 8% of global CO_2 emissions) and ecological damage from sand extraction, the research addresses the global problems of managing vast quantities of mine tailings (2.7 billion tons annually) and plastic waste. Utilizing these industrial wastes can lower environmental impact, promote resource utilization, and improve sustainability. The experimental methodology involved evaluating concrete cubes made with mine tailings as a partial sand replacement and molten plastic as a cement substitute, testing various percentages. Key findings revealed that a 50% replacement of fine aggregates with mine tailings provided the highest compressive strength, though higher replacement levels decreased strength due to poor bonding, which was notably improved with the inclusion of coarse aggregates. While molten plastic reduced the material's permeability, its rapid hardening complicated workability assessments, and increased mine tailings content led to higher water absorption and setting time. Mixtures with more than 50% mine tailings consistently failed impact resistance tests unless coarse aggregates were included. This research highlights the feasibility of employing mine tailings and molten plastic for concrete manufacturing, presenting a sustainable strategy for the construction industry by reducing pressure on natural resources and controlling industrial waste, despite challenges in workability and strength variability. Future work should focus on refining mix designs, using additives, and establishing safety procedures.

Keywords: Mine Tailings, Plastic Waste, Concrete, Sustainable Construction.

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Carnival-Based Dramaturgy and Innovation Ecosystems: A Workshop Framework for Soft Artistic Technologies in Performing Arts

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Abstract: The first workshop dedicated to developing an "Ecosystem of Innovation and Soft Artistic Technology" was held on January 12, 2023, at the Azadi Tower Cultural and Artistic Complex, organized and supervised by Dr. Mir Alireza Daryabeygi of the Department of Performing Arts, IAUCTB. The event involved 14 university performing groups and centered on a unique pedagogical and research model combining dramaturgy, documentation, and collaborative experimentation. It showcased the unveiling of the book Carnival; Conversations with […], derived from 40 submissions, of which 10 texts were ultimately published. The book reflects a comprehensive laboratory-based approach integrating research, rehearsal, and performance through iterative processes of listening, transcription, dramaturgical construction, and deconstruction. This model originated from a trilogy of experimental performances staged in late 2022, aimed at documenting and sharing dramaturgical methods through audio files provided to graduate students. The structured four-step learning cycle emphasized collective authorship, listening-based dramaturgy, imaginative transformation, and performance literacy. The methodology responds to pandemic-era hybrid education by transforming spoken dramaturgy into written theatrical forms without altering the authorial tone. Keywords guiding the research framework include simultaneity, parataxis, musicality, event-situation, visual dramaturgy, post-dramatic and post-cinematic theatre, and audience dramaturgy. The resulting manuscript comprises texts such as "Carnival," "Practice/Game/Experience," and "Audience Dramaturgy," reflecting an emergent artistic-technological ecosystem. The successful full-day public showcase marked the initiative's first step toward ongoing research and future adoption of newly translated materials in Iranian performing arts.

Keywords: Artistic Technology, Collaborative Dramaturgy, Ecosystem Innovation, Post-Dramatic Theatre, Research-Performance Integration

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Assessing Urban Air Quality Through Plant-Based Dust Monitoring in Setif, Algeria

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Abstract: In urban ecosystem monitoring, using plants to estimate dust levels has emerged as a method for assessing air quality. This approach emphasizes the importance of maintaining the balance of aerial ecosystems, particularly in the context of clean regional development and environmental strategies. In Setif, Algeria, urban development, population growth, and environmental challenges threaten residents' quality of life, compounded by climate change impacts. Urban pollution is largely anthropogenic. Our research aimed to quantify leaf dust across various sites and identify its sources, utilizing plant leaves from Nerium, Privet, and Myoporum as dust collectors for comparison. The study was conducted during winter, a period marked by reduced rainfall and vegetation cover, to evaluate dust levels effectively. Results indicated a low fresh matter/dry matter (FM/DM) ratio for Privet and Nerium leaves compared to Myoporum, suggesting that the former two provide a better assessment of air quality. The low fresh weight at these sites likely results from pollution linked to road traffic and construction, affecting plant physiology. Additionally, dendrometric measurements revealed a negative correlation between plant height and leaf dust accumulation. Statistical analysis showed that Myoporum leaves collected the highest dust quantities, while Privet leaves had the lowest, reflecting their susceptibility to pollution. Overall, the findings support the use of leaf dust analysis as an indirect bio-indicator for monitoring air quality in urban environments like Setif.

Keywords: Dust, Leaf, Plant, Pollution, Urban ecosystem

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Assessing Climate Change Impact on Atlas Cedar Wood Quality in Northeastern Algeria

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Abstract: In forest ecosystems, various indicators highlight the impacts of climate change, particularly concerning the health of woody trees. This study focuses on analyzing defects in Atlas cedar wood (Cedrus atlantica) in northeastern Algeria to assess the trees' health through in situ observations. Conducted in Boutaleb forest from April to June 2023, the research involved selecting multiple plots to evaluate the extent and variation of wood defects across different trees and locations. The findings revealed that "gourmand" and cracks were the most prevalent defects, while bark beetle holes were noted in only one tree. Additionally, gelivure, a defect caused by frost during poor developmental conditions, was frequently observed, especially in plot 2, indicating the region's climate change effects. The study also noted increased resin release from Atlas cedar trunks, a response to bark damage. Furthermore, a significant number of Cedrus atlantica individuals exhibited lichens, which play a crucial role in restoring life to rocky and barren environments. Overall, the research underscores the relationship between tree health, wood quality, and the degradation caused by pathogens, emphasizing the broader implications of climate change on forest ecosystems in the region.

Keywords: Cedrus atlantica, Climate change, Forest, Trees, Wood

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Characterization of Residue Lignin in Bioethanol Production of Some Industrial Tree Barks

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Abstract: The increasing environmental awareness and the need for sustainable and renewable energy have accelerated the studies on biofuel production from biomass. In particular, evaluating biomass resources, such as shrub biomass, bark residues, sawdust, cones, etc., materials often discarded in forest products industries, is an important issue regarding a responsible production approach. However, one of the most critical opportunities in biofuel production from biomass is the tendency to treat lignin as a waste and unwanted impurity in the processes. In this study, acid-insoluble lignins after the bioethanol process of some industrial tree barks (pine (*Pinus sylvestris*), fir (*Abies nordmanniana*), beech (*Fagus orientalis*), oak (*Quercus robur*), and poplar (*Populus alba*)) were isolated, and characterized by Fourier-transform infrared spectroscopy (FTIR), thermo gravimetric analysis (TGA), differential scanning calorimetry (DSC), and the amount of ash content. The results showed critical differences in lignin properties among the studied bark species. The highest ash content was determined from fir bark lignin (% 0.987%), and the lowest ash content was obtained from pine bark lignin as 0.316%. The glass transition temperatures of the studied samples were determined between 91 and 135 °C. As a result, it was determined that if tree barks are used in bioethanol production, the residual lignin has the potential to be used as a shield against thermal degradation of composite materials.

Keywords: Bark, Lignin, ash content, functional groups, thermal properties.

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Extraction and Characterization of Phenolic Compounds from Table Olive Processing Wastewater: Hydroxytyrosol Recovery and Bioactivity Evaluation

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Abstract: Table olive processing wastewater is a rich source of phenolic compounds with high added value, particularly hydroxytyrosol. In this study, phenolic compounds were extracted from table olive processing wastewater using ethyl acetate as a solvent, yielding an active fraction rich in hydroxytyrosol along with other phenolic compounds such as tyrosol, caffeic acid, and others. Hydroxytyrosol was further purified using column chromatography, resulting in a pure compound as confirmed by HPLC analysis. The concentration of hydroxytyrosol in the wastewater reached up to 700 mg per liter. Both the crude extract and the purified hydroxytyrosol were evaluated for their antioxidant and antimicrobial activities. The results revealed that hydroxytyrosol and the hydroxytyrosol-rich extract exhibited significantly higher antioxidant and antimicrobial activities compared to standard reference compounds. These findings highlight the potential of valorizing table olive processing wastewater as a sustainable source of bioactive phenolic compounds with promising applications in the food, pharmaceutical, and cosmetic industries.

Keywords: Table olive wastewater, phenolic compounds, hydroxytyrosol, antioxidant activity, antimicrobial activity, valorization.

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An Attempt to Enhance the Lightweight Fiberboard with Suberinic Acid Residues for Improved Performance and Fire Resistance

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Abstract: Sustainable innovation in wood-based panels increasingly depends on the responsible use of renewable resources and underutilized by-products. Within the framework of the BarkBuild project, lightweight fiberboards were developed incorporating suberinic acid residues (SAR), originating from bark processing streams, as alternative functional additives. The aim of this research is to assess whether these bio-based residues can play a role in improving physical, mechanical, and fire-related performance while reducing reliance on synthetic binders. Experimental panels were fabricated under laboratory conditions by dry-process methods, with SAR introduced as a partial replacement of conventional binders. The boards are currently being evaluated following standardized test procedures to determine bending strength, stiffness, internal bond, thickness swelling, and water absorption. Fire behavior is also being investigated, with emphasis on ignition resistance and flame spread. Preliminary observations suggest that SAR-modified fiberboards display promising tendencies in terms of dimensional stability and fire performance, while maintaining mechanical properties within the expected range for this panel type. Detailed analysis is ongoing, and further research will clarify the extent to which these residues can contribute consistent structural and safety benefits. By exploring this novel use of bark-derived compounds, BarkBuild demonstrates an approach that connects sustainable resource valorization with the potential development of more efficient and environmentally responsible building materials. These insights may serve as a foundation for industrial applications geared towards circular, bio-based construction solutions.

Keywords: lightweight fiberboard, suberinic acid residues, fire performance, panel properties, sustainable building materials, BarkBuild

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Selected activities of the presented study were completed within the Student Furniture Scientific Group (Koło Naukowe Meblarstwa), Warsaw University of Life Sciences – SGGW, Warsaw, Poland.

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BarkBuild: Wet-Method Fiberboards Enhanced with Suberinic Acid Residues

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Abstract: The increasing demand for sustainable alternatives in the construction and furniture industries is directing attention to renewable materials and innovative bio-based composites. In this context, the BarkBuild project investigates the valorization of bark-derived compounds for the production of lightweight fiberboards. Suberinic acid residues (SAR), obtained from bark processing streams, represent a particularly promising additive due to their hydrophobic and cross-linking characteristics. Their incorporation into fiberboards may reduce dependence on synthetic binders while potentially improving panels' performance and safety profile. This study focuses on producing lightweight fiberboards under laboratory conditions using a wet production method with the addition of SAR. The research aims to assess the impact of SAR on key physical and mechanical properties, as well as on fire behavior, in direct comparison with reference fiberboards manufactured without SAR. Experimental procedures are carried out according to relevant European and international standards for panel testing. Investigations include modulus of rupture, modulus of elasticity, thickness swelling, water absorption, density profile, contact angle and fire reaction parameters such as ignition and flame propagation. At this stage, testing and analysis are ongoing. Preliminary laboratory investigations indicate observable differences between reference and SAR-modified boards, particularly in relation to moisture interaction and fire performance, while mechanical properties remain consistent with expectations for this product class. However, detailed and quantitative outcomes will be further explored to establish the full potential and limitations of SAR as a functional bio-based additive. The contribution of this work lies not only in evaluating the applicability of SAR in wood-based composites but also in its broader implications for circular economy practices. By reintroducing bark by-products into value-added panel production, the project supports resource efficiency, waste reduction, and enhanced sustainability of fiberboard manufacturing. Ultimately, the BarkBuild initiative seeks to demonstrate how advances in material science can address both ecological and industrial priorities, reinforcing the role of bio-based composites in the transition to more sustainable construction solutions.

Keywords: lightweight fiberboard, suberinic acid residues, wet method, fire performance, mechanical properties, sustainable composites, BarkBuild

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CRISPR-Cas9 Knock-out of SlTOM1 for ToBRFV Tolerance in Tomato

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Abstract: Tomato (Solanum lycopersicum L.) is one of the most economically important vegetable crops worldwide and in Turkey, where it plays a central role in both domestic consumption and export markets. However, the emerging Tomato brown rugose fruit virus (ToBRFV) has broken the Tm-22 resistance gene, rapidly spreading across major production areas and causing severe yield and quality losses. This situation emphasizes the urgent need for novel and durable tolerance strategies to sustain tomato production. In this study, CRISPR-Cas9 genome editing technology was employed to enhance tomato tolerance against ToBRFV. The host susceptibility factor SlTOM1 gene homologs (SlTOM1a, SlTOM1b, SlTOM1c, and SlTOM1d) were selected as targets. Six guide RNAs (gRNAs) were designed through bioinformatic analyses, verified by off-target screening, and cloned into CRISPR/Cas9 vectors using the Golden Gate assembly method. The constructs were first validated in E. coli, then transferred into Agrobacterium tumefaciens (EHA105), and finally introduced into tomato explants through Agrobacterium-mediated transformation. Tissue culture procedures, including seed sterilization, cotyledon and hypocotyl explant preparation, co-cultivation, and regeneration, were optimized to obtain stable transformants.The findings indicated that knock-out events were successfully induced in SlTOM1 homologs, and regenerated tomato lines are currently being evaluated for their response to ToBRFV infection. Preliminary observations suggest that CRISPR-mediated mutagenesis of SlTOM1 can reduce viral accumulation while maintaining normal plant growth under greenhouse conditions. In conclusion, this study demonstrates the potential of CRISPR-Cas9-based SlTOM1 knock-out as a promising biotechnological approach for improving tomato tolerance to ToBRFV. These results provide valuable insights for developing innovative strategies to manage tobamovirus diseases and contribute to sustainable tomato production.

Keywords: Tomato, ToBRFV, CRISPR-Cas9, SlTOM1, Genome editing

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Determination of the Effect of Tomato Spotted Wilt Virus (TSWV) Infection on Scoville (SHU=Scoville Heat Units) Value

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Abstract: Tomato spotted wilt virus (TSWV), transmitted by thrips species, is a major viral pathogen that causes severe damage in many economically important crops, particularly tomato and pepper. In pepper (Capsicum annuum L.), pungency is mainly attributed to alkaloid compounds known as capsaicinoids, and it is quantified based on the dry weight obtained from fruit tissue. The degree of pungency in peppers is expressed in Scoville Heat Units (SHU). The aim of this study was to investigate the effect of TSWV infection on the capsaicinoid content of pepper fruits and, consequently, on their SHU values, as well as to evaluate the potential economic contribution of susceptible pepper cultivars through their biochemical responses against the pathogen. A total of 100 seedlings from our company's gene pool were used in the study. Resistant and susceptible genotypes for the *Tsw* gene were grouped into pungent and sweet lines. TSWV inoculation was carried out using the "Soft Sponge Pad" method. Following three separate mechanical inoculation events, both resistant and susceptible plants were monitored for leaf and fruit symptoms, and TSWV positivity was confirmed by RT-PCR. In pepper lines with previously characterized pungency levels, SHU values were measured and compared between infected and non-infected (control) groups. Results revealed that pungency values doubled in virus-infected samples. In addition, infection was found to increase not only capsaicinoid levels but also vitamin C content, with a positive correlation detected between the two parameters. The study demonstrated that infection progressed more rapidly and severely in pungent pepper varieties. Although TSWV reduced fruit size and marketable quality, it significantly increased dry matter and pungency levels. Infected fruits, which are not suitable for direct consumption, could be utilized in food and industrial products such as hot sauces, chili flakes, or pepper spray, thereby helping to reduce economic losses and generate alternative income sources.

Keywords: Pungency, Pepper, Capsaicinoid, Scoville, TSWV.

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Digitalization and Artificial Intelligence in Banking: An Assessment from a Financial Risk Management Perspective

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Abstract: Digitalization and AI-based solutions are radically transforming the understanding of risk management in the banking sector. This study aims to evaluate the effects of these technologies on the financial risk management approaches of banks by examining the existing literature through a compilation method. The assessment is conducted within the framework of six main categories: credit, operational, market, liquidity, legal, and exchange rate risks. Prominent findings in the literature reveal that artificial intelligence-supported applications make significant contributions to reducing credit risk, strengthening operational security and predicting market fluctuations. Furthermore, the advantages provided by these technologies in liquidity management and regulatory compliance are emphasized. However, new risk dimensions such as algorithmic biases, transparency issues, data privacy concerns, and exchange rate volatility are also emerging. Consequently, digitalization and AI-based banking solutions are considered not only tools for technical processes but also a strategic component of financial risk management.

Keywords: Digitalization, Artificial intelligence, Financial risk management, Banking

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Potential Distribution Modeling of *Nerium oleander* L. under Current Climatic Conditions

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Abstract: This study aimed to determine the potential distribution areas of *Nerium oleander* L., the sole representative of the genus within the Apocynaceae family, under current climatic conditions in Türkiye, where it is primarily distributed in the Mediterranean and Aegean regions. Species distribution modeling was carried out using the MaxEnt (Maximum Entropy) method, which operates with presence-only data and provides high predictive accuracy. A total of 543 occurrence records obtained from the Global Biodiversity Information Facility (GBIF) database and 12 environmental variables were used in the analysis. Model accuracy was evaluated through a 10-fold cross-validation test and jackknife analysis. According to the model results, *N. oleander* exhibits the highest suitability values along the Mediterranean coastal belt (Antalya, Mersin, Adana, Hatay) and the Aegean coasts (Muğla, Aydın, İzmir). This distribution reflects the species' strong adaptation to the typical Mediterranean climate characterized by hot, dry summers and mild, wet winters. Model performance was found to be highly robust (training AUC = 0.917, test AUC = 0.915). Based on Swets' (1988) classification, the model was evaluated as "excellent," and the close similarity between training and test AUC values confirmed its generalization capacity. The findings highlight the ecological flexibility of oleander and its strong distribution potential in coastal zones, thereby providing valuable insights for landscape planning, rural green space management, and the sustainability of ecosystem services.

Keywords: Geographic Information Systems, MaxEnt, *Nerium oleander* L., Species distribution modeling

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Valorization of Underutilized Hazel (*Corylus avellana* L.) Wood for the Manufacture of Single-Layer Particleboards with Structural Properties

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Abstract: Hazel wood (*Corylus avellana* L.), despite its availability in European forests, is often considered a low-value species with limited industrial application. This study explores the potential for hazel wood valorization through its incorporation into single-layer particleboards intended for structural use. Laboratory-scale boards were produced using particles obtained from hazel chips, both barked and debarked, and mixed with industrial pine particles at varying mass ratios: 0%, 5%, 10%, 25%, 50%, and 100%. An additional variant composed entirely of particles from debarked hazel chips was also included.

The physical and mechanical properties of the boards were evaluated according to EN standards. The parameters tested included modulus of rupture (MOR), modulus of elasticity in bending (MOE), internal bond strength (IB), screw withdrawal resistance (SWR), density profile (DP), thickness swelling (TS), and water absorption (WA) after water immersion. The bulk density of hazel particles was also determined, revealing significantly higher values than those of the reference pine particles, with barked hazel particles showing the lowest bulk density among the hazel variants.

The results demonstrated that all board variants met the strength requirements for P5 type boards defined by EN 312 in terms of MOR and MOE, although a gradual decrease in these properties was observed with increasing hazel content. Notably, thickness swelling increased markedly in boards containing more than 25% hazel particles, suggesting reduced dimensional stability. Despite these limitations, the study highlights the technical feasibility of incorporating hazel wood particles, especially those from debarked chips, into structural particleboards, offering a promising pathway for enhancing the value chain of this underutilised species.

Keywords: hazel wood, particleboard, structural panels, biomass valorization, mechanical properties, underutilized species.

Acknowledgement: This study was completed within the Student Furniture Scientific Group (Koło Naukowe Meblarstwa), Warsaw University of Life Sciences – SGGW, Warsaw, Poland.

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The Role Of Primary Care Nurses In Managing Hypertension, In Albania

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Abstract: Through patient education, lifestyle counseling (diet, exercise, sodium/alcohol reduction), medication adherence support, blood pressure monitoring, early detection & screening, and care coordination, nurses in primary care play a critical role in managing hypertension. They help patients control their blood pressure, prevent complications, and improve their overall cardiovascular health, frequently utilizing customized interventions like telephone support for better results.
Numerous cardiovascular disorders are linked to hypertension, a common chronic ailment. Its management is largely the responsibility of the district nursing team and practice nurses. This article presents and discusses the evidence-based guidelines of the British Hypertension Society. Highlighted are the implications for nursing practice..

Keywords: Evidence-based guidelines, Hypertension management, Nursing practice, Primary care nursing, Patient education

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The Relationship Between Caffeine Consumption, Sleep Quality, and Perceived Performance Among University Athletes: The Mediating Role of Sleep Quality

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Abstract: The present study aimed to investigate the mediating role of sleep quality in the relationship between daily caffeine consumption and perceived performance among university athletes. Caffeine is a widely used ergogenic aid known to enhance alertness and acute exercise performance; however, excessive or late-day intake may impair sleep quality, potentially reducing overall performance perception. This study sought to clarify the indirect pathway linking caffeine, sleep, and perceived performance within an athletic context. A total of 412 university athletes (189 females, 223 males; M_age=20.7±2.1) participated voluntarily. Caffeine consumption (mg/day) was calculated based on participants' weekly beverage intake (coffee, tea, energy drinks, cola, and pre-workout products). Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), and perceived performance was measured via a 1–10 Numeric Rating Scale (NRS) reflecting satisfaction with recent athletic performance. Data were analyzed using SPSS with Hayes PROCESS Macro Model 4, including bootstrapping (5,000 samples, 95% CI). Results indicated that caffeine consumption significantly impaired sleep quality (β=.180, $p<.001$). Poorer sleep quality predicted lower perceived performance (β=−.290, $p<.001$). The direct effect of caffeine on performance was nonsignificant (β=−.030, p=.180). A significant indirect effect was observed (ab=−0.052; 95% CI [−0.085, −0.025]), with an explained variance of R^2=.270. These findings demonstrate that caffeine's influence on performance is indirect, operating through sleep quality rather than exerting a direct effect. The results highlight the importance of caffeine timing and dosage in optimizing both recovery and performance perception. Athletes are advised to manage caffeine intake and maintain good sleep hygiene to prevent performance impairments associated with poor sleep quality.

Keywords: Caffeine, sleep quality, perceived performance, mediation analysis, sport psychology.

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Nursing And Gerontology

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Abstract: The relationship between nursing and gerontology is examined in this article, along with the strengths that nursing brings to the field of aging, the issues that need to be resolved both within the nursing profession and at the societal level in order for nursing to reach its full potential in gerontology, and potential solutions to maximize strengths and fill gaps. Highlighting the valiant actions of gerontologic nurses, boosting support for gerontologic advanced practice nursing, fostering collaborative gerontologic research, encouraging the sharing of nursing's body of knowledge, and working with foundations to promote self-care are some of these tactics. In the third millennium, it is suggested that nursing's research-practice agenda should focus on preventing disease whenever possible, reducing morbidity and improving quality of life when disease cannot be prevented, and having the discernment to balance the two.

Keywords: Gerontologic nursing, Nursing research agenda, Professional development, Quality of life, Aging care

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The Past, Present, And Future Of Philosophy's Influence On Nursing Development And Practice

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Abstract: An online live-streamed panel discussion that took place in June 2025 is summarized in this article. Three stand-alone panel talks about the history, present, and future of nurses comprised the event. There were 252 registrants from all over the world for the spirited Q&A session that followed the panels. The event highlighted the wide range of philosophical interests that nurses have, as well as the need for more virtual gatherings and other connective modalities that bring nurses together to discuss and evaluate the importance and potential of philosophy to better comprehend and advance nursing theory and practice.

Keywords: IPONS; debate; nursing philosophy; nursing research; nursing theory.

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Overcoming Communication Obstacles In The Critical Care Unit

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Abstract: Complexity, high patient acuity, uncertainty, and ethical concerns make communication in the intensive care unit difficult. Regrettably, a number of studies and assessments attest to the prevalence of conflict. In this context, there are three different kinds of communication problems: those that occur inside the team, those that occur between the ICU team and the patient or family, and those that occur within the patient's family. Each form of communication difficulty has particular evidence-based therapies, but they all depend on clinicians being polite, culturally aware, and skilled communicators and listeners. Advanced practice nurses in critical care foster a supportive team atmosphere, boost patient satisfaction, and serve as role models for effective communication for other medical professionals. However, all advanced practice nurses must also be skilled in handling conflict, having difficult conversations, and offering basic palliative care, including emotional support.

Keywords: IPONS; debate; nursing philosophy; nursing research; nursing theory.

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Investigation of Leisure Time Activities and Socialization Levels of Detainees/Convicts in Kütahya T Type Prison and Execution Institution

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Abstract: The aim of this study is to examine the leisure time activities and levels of socialization of individuals incarcerated in the Kütahya Type-T Penal Institution in relation to various demographic variables. The population of the study consists of individuals who are detained or convicted in Type-T penal institutions across Turkey. The sample group comprises 470 detainees/convicts from the Kütahya Type-T Penal Institution, selected through the convenience sampling method. As a data collection tool, the "Socialization Scale for the Hearing Impaired," developed by Karakullukçu (2020) and validated through reliability and validity analyses, was employed. Following the confirmation of normality assumptions, descriptive statistics (percentages and frequencies) and one-way analysis of variance (one-way ANOVA) were used to analyze the data. In cases where the assumption of homogeneity of variances was not met, Welch's test results were considered. Post hoc comparisons were conducted using the Tukey and Games-Howell tests to identify the source of significant differences. The findings were evaluated based on a significance level of $p < .05$. According to the research findings, the "age" variable showed a statistically significant difference in the sub-dimension of extroversion. The "marital status" variable revealed significant differences in the friendship and extroversion sub-dimensions. Participants' responses to the question "What does the concept of leisure time mean to you?" indicated statistically significant relationships in the sub-dimensions of social adaptation, extroversion, cultural adaptation, and overall socialization score. Moreover, based on the variable "How do leisure time activities affect you?", significant differences were found in the sub-dimensions of social adaptation, extroversion, cultural adaptation, friendship, and total socialization score. In conclusion, the effect of leisure time activities on individuals was found to be entertaining, exciting, and relaxing in terms of social adaptation, extroversion, and overall socialization. From the perspective of cultural adaptation, these activities were not only perceived as enjoyable and motivating but also played a prominent role in coping with social status, establishing interpersonal relationships, and improving work efficiency. Increasing the participation of detainees and convicts in leisure time activities is believed to have a positive impact both during their incarceration and in their reintegration into society after release.

Keywords: Convicted, Free time, Socializing, Prisoner

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The Effect of Yoga Practices on Body Mass Index and Some Respiratory Parameters

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Abstract: The aim of this study is to investigate the effects of an eight-week yoga program on body mass index (BMI) and respiratory functions in sedentary female individuals. The study included 16 sedentary female participants enrolled at Kütahya Dumlupınar University. Based on a pre-test–post-test experimental design, participants underwent yoga sessions three times a week, each lasting approximately 60 minutes. At the beginning and end of the intervention, BMI as well as respiratory function parameters—vital capacity (VC), forced expiratory volume in one second (FEV1), and forced vital capacity (FVC)—were measured and evaluated. The findings revealed that there were statistically significant improvements in VC and FEV1 values following the yoga program ($p < 0.05$). However, the increase in FVC was not found to be statistically significant. In addition, although a decrease in BMI was observed after the intervention, this change did not reach a statistically significant level ($p > 0.05$). In conclusion, the results indicate that yoga practices have a positive effect particularly on respiratory functions, whereas the effect on BMI requires further investigation through longer-term and larger-scale studies. Furthermore, techniques such as pranayama and other components of yoga are shown to strengthen respiratory muscles and enhance lung capacity. Yoga can be considered an effective method for improving both physical and physiological well-being in sedentary individuals.

Keywords: Respiration, Body Mass Index, Yoga

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Determination of Sport Motivation Levels of Sport Sciences Faculty Students

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Abstract: The aim of this study is to determine whether the motivation levels of students at the Faculty of Sport Sciences differ according to the variables of gender, department, academic year, and type of sport (individual or team sports). A descriptive research design was employed in the study. A total of 403 students voluntarily participated in the research, consisting of 182 female and 221 male students from the Faculty of Sport Sciences. As a data collection tool, the "Sport Motivation Scale" developed by Demir (2002) was utilized. Descriptive statistics were applied to the obtained data, and to determine the differences between groups, independent samples T-tests and one-way ANOVA analyses were conducted. The findings were evaluated based on a significance level of $p < 0.05$. Among the participants, 84 were first-year students (20.8%), 98 were second-year students (24.3%), 107 were third-year students (26.6%), and 114 were fourth-year students (28.3%). Regarding their fields of study, 85 students (21.1%) were enrolled in Physical Education and Sports Teaching, 135 (33.5%) in Coaching Education, 105 (26.1%) in Sports Management, and 78 (19.4%) in Recreation. Additionally, 83 students (20.6%) reported participation in individual sports, while 320 (79.4%) were involved in team sports. The results indicated that the participants had a generally high mean score for overall sport motivation. However, no significant differences were found in sport motivation levels based on gender, type of sport, academic department, or year of study.

Keywords: Sport, Motivation

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Investigation of Fanaticism Levels of University Students Who Are Football Fans

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Abstract: The aim of this study is to examine the attitudes of university students towards spectatorship, which is at the center of violent incidents that pose a significant threat to the future of Turkish football, and to examine their spectator identities and thus their tendencies towards fanaticism. Descriptive research method was used as the research method. A total of 506 students (201 female and 305 male) from Kütahya Dumlupınar University participated in the study voluntarily. A questionnaire form consisting of two parts was used as a data collection tool. The first part of the questionnaire consists of personal information of the individuals and the second part consists of the Football Fanaticism Scale. The Football Fanaticism Scale developed by Taşmektepligil et al. (2014) is a five-point Likert-type scale ranging from 'strongly disagree' (1) to 'strongly agree' (5). The validity and reliability studies of the scale were conducted by the researchers and the internal consistency coefficient calculated with Cronbach Alpha was calculated as .87. Descriptive statistics were applied to the data obtained and Independent samples T test and One way Anova analyzes were applied to determine the differences between groups. The findings were evaluated according to $p<0.05$ significance value. The ages of the students who participated in the study vary between 19 and 24 years. The participants consisted of 86 students who supported Beşiktaş (17.0%), 176 students who supported Galatasaray (34.8%), 158 students who supported Fenerbahçe (31.2%) and 86 students who supported other teams (17.0%). The mean Total Score of Football Fanaticism of the participants was calculated as (40.42±11.36). According to the criteria of the scale, if the total score of the surveyed audience over 13 questions is between 13-21, it is called "fanatic", between 22-30 it is called "team fan", and between 31-52 points it is called "football fan". In this case, the participants included in the study from Kütahya Dumlupınar University Students can be called "team fans". When the football fanaticism levels of the participants according to their gender are examined, it is seen that the average of male students (42,84±11,12) is significantly higher than the average of female students (36,76±10,75) ($t(504)=-6,103;p<0.001$). When the levels of football fanaticism according to the age of the participants are examined, it is seen that the total scores of football fanaticism increase significantly as the age of the students increases ($f(5,505)=3,362;p<0,005$). When the football fanaticism levels of the participants are examined according to the team they support, it is seen that in the Institutional Belonging sub-dimension, the mean institutional belonging of the students who support Fenerbahçe sports club (3,76±0,96) is significantly higher than the students who support Galatasaray (3,48±0,96) and Other (3,28±1,15) clubs ($f(3,505)=4,475;p<0,05$). As a result of the research, it was seen that the level of football fanaticism of the participants was at the level of "team fan" and also differed according to gender, age and the team supported.

Keywords: Soccer, Fanaticism

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The Effect of Organizational Forgiveness on Revenge Intention: an Application on Physical Education and Sports Teachers

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Abstract: The aim of this study is to examine the effects of organizational forgiveness on revenge intentions among physical education teachers. The study was conducted using a relational survey model, one of the quantitative research designs. The study population consists of physical education teachers working in secondary education institutions affiliated with the Provincial Directorate of National Education in Uşak, Türkiye. The sample (n = 107) was determined using the simple random sampling method, which is one of the simple probability-based sampling techniques, with a 95% confidence level and a 5% margin of error. Descriptive statistics (%, f) were used in the study, along with correlation analysis to determine the relationships between variables, and simple linear regression analysis to assess the strength of the effect between two variables. Data were collected using the Organizational Forgiveness Scale and the Revenge Intention Scale. The findings revealed a negative relationship between organizational forgiveness and revenge intention. It was concluded that organizational forgiveness had a statistically significant negative effect on teachers' revenge intentions toward their administrators (β = -0.130). Based on the findings, it was determined that as teachers' tendency to engage in organizational forgiveness increases, their revenge intentions toward administrators decrease.

Keywords: organizational forgiveness, revenge intention, physical education and sports teachers, organizational thinking

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Five Rings, one Identity: The Cultural, Political, and Social Meanings of Olympic Symbols

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Abstract**:** This study examines the meanings of Olympic symbols—specifically, elements such as the five rings, the torch, the flag, and the motto—in cultural, political, and social contexts. Since its relaunch in 1896 under the leadership of Pierre de Coubertin, the modern Olympics has been not only a sporting event but also a vital tool for international diplomacy, cultural representation, and the transmission of social values. The five rings symbolize the coming together of different continents and cultures, while the Olympic torch reflects the ideal of perpetual peace and solidarity. The study analyzes the functions of these symbols in making host countries' cultural heritage visible on a global scale, providing political legitimacy, and fostering social unification. Drawing on literature in the sociology of sports, cultural studies, and international relations, the study discusses the role that Olympic symbols play both in the construction of a universal identity and in the soft power strategies of nations. The findings reveal the strategic importance of Olympic symbols not only in sporting contexts but also as tools of cultural diplomacy, social unity, and political communication in a globalizing world.

Keywords: olympics, culture, social, sports

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The Rise of Women in Tennis: Gender Roles and Historical Struggle

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Abstract: This study is a literature review examining the historical rise of women in tennis and its relationship with gender roles. Tennis stands out as a significant arena where women have gained visibility in sports and have actively pursued the struggle for gender equality. The research evaluates, within a historical context, the journey from the limited representation of the 19th century to the professionalization steps of the mid-20th century, the fight against pay inequalities, and media portrayals of female players. The gender equality movement led by Billie Jean King, the 1973 "Battle of the Sexes" match, and the founding of the Women's Tennis Association (WTA) are discussed as key turning points in women's tennis. The influence of contemporary players such as Serena Williams and Venus Williams, both in tennis and in the realm of social justice, is also highlighted. A review of the academic literature emphasizes that female tennis players have been prominent not only for their athletic achievements but also for their contributions to social transformation. In conclusion, the rise of women in tennis is not merely a story of sporting success but also a reflection of a long-term social struggle and pursuit of equality. This literature review aims to provide a comprehensive resource for researchers seeking to understand the historical development of women's tennis from a gender perspective.

Keywords: women's tennis, gender, sports history, gender equality, literature review

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The Importance of the Anthropomorphic Breast Phantom in Mammography

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Abstract: Introduction: Anthropomorphic breast phantoms, created using advanced technologies such as three-dimensional printing and digital modeling, are becoming a key tool in modern radiological practice aimed at the prevention and early detection of breast cancer. Their creation enables the highly realistic simulation of anatomical breast structures and various pathological changes, facilitating education, protocol testing, and the development of artificial intelligence algorithms without exposure to ionizing radiation. This review aims to investigate the role of anthropomorphic breast phantoms in the development and application of new digital technologies in the prevention and early detection of breast diseases, as well as their importance for improving the quality of care in healthcare. A literature search was conducted in PubMed and Scopus databases, with the aim of identifying relevant studies published between 2015 and June 2025, in English. Defined inclusion and exclusion criteria were applied, and the selected papers were analyzed with an emphasis on the application of anthropomorphic breast phantoms in education, quality control, and the development of digital technologies in mammography. The integration of new technologies in the design and application of anthropomorphic breast phantoms represents a significant contribution to the digital transformation of healthcare systems, ensuring standardized, safe, and effective education, improved diagnostic accuracy, and greater emphasis on prevention and patient safety.

Keywords: three-dimensional printing; anthropomorphic breast phantom; mammography

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Temperature Regulation in the Operating Room: a Critical Factor in Infection Control

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Abstract: Surgical site infections (SSIs) remain a significant cause of morbidity and increased healthcare costs worldwide. Maintenance of normal body temperature during the perioperative period is an evidence-based intervention shown to reduce SSI rates by improving immune function and tissue perfusion. Despite its clinical importance, awareness and perceptions of normothermia among surgical teams may vary, potentially impacting adherence to warming protocols. This study aimed to evaluate the perceptions of preserving core body temperature's effectiveness in SSI prevention among surgical staff, including attending surgeons, residents, and nurses, at the Trauma University Hospital in Tirana, Albania. A descriptive cross-sectional survey was conducted over one month (October 1–31, 2023). A self-administered questionnaire was distributed to all surgical personnel, collecting data on demographics, professional role, years of experience, and attitudes toward normothermia in SSI prevention. Responses from 86 participants were analyzed using descriptive statistics and the Chi-square test to assess associations between professional role and perception of normothermia effectiveness. Among the 86 respondents, 67 (77.9%) were attending surgeons, 6 (7.0%) residents, and 13 (15.1%) nurses. Overall, 42 participants (48.8%) agreed that preserving normal body temperature reduces SSIs. Agreement rates differed by role: 49.3% of attending surgeons, 66.7% of residents, and 38.5% of nurses endorsed normothermia's effectiveness. However, no statistically significant association was found between professional role and perception ($\chi^2(2) = 1.33$, $p = 0.515$). Years of experience ranged from less than 10 to over 20 years but were not significantly analyzed in relation to perceptions. The study reveals a moderate level of awareness regarding preservation of normal body temperature's role in SSI prevention among surgical staff, with residents demonstrating the highest agreement. The lack of significant differences between roles suggests a general need for institutional efforts to enhance knowledge and adherence to normothermia protocols. Targeted educational programs and standardized perioperative warming guidelines are recommended to improve patient safety and reduce SSI incidence.

Keywords: body temperature, preventive measure, surgical site infections, survey, Trauma University Hospital.

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The Development of Basketball History in the World and Turkey

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Abstract: Basketball was invented in 1891 by Dr. James Naismith in the United States and quickly spread across continents, becoming one of the most popular modern sports worldwide. In the early 20th century, the establishment of international tournaments and federations strengthened its organizational structure, paving the way for professionalization. This transformation enabled basketball to evolve beyond a recreational activity into a significant social, cultural, and economic phenomenon.
In Turkey, basketball was introduced in the early 1900s and began to gain recognition particularly during the 1930s through the organization of leagues, institutional structures, and official competitions. With the contributions of educational institutions, sports clubs, and federations during the Republican era, the sport's visibility expanded nationwide. Over time, basketball in Turkey demonstrated steady growth at both amateur and professional levels.
This study aims to examine the historical development of basketball both globally and in Turkey, focusing on the processes of diffusion, institutionalization, and professionalization. Findings indicate that basketball became professionalized earlier on a global scale, while Turkey followed a comparatively slower yet consistent trajectory. Understanding the historical development of basketball provides valuable insights into the social and cultural dimensions of sports today.

Keywords: basketball, historical development, professionalization, Turkey, sports history

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The Examination of Goal-Setting Levels in Tennis Players

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Abstract: This study aims to examine the goal-setting levels of tennis players. The research was conducted with tennis athletes from various age groups, genders, training intensities, and competition experiences. Goal setting is considered one of the fundamental psychological skills that support athletes' performance development, and it is associated with motivation, self-discipline, and performance optimization in both individual and team sports. A quantitative research design was adopted, and the "Goal Setting Scale" was used as the data collection tool. The data obtained were analyzed using descriptive statistics, t-tests, and ANOVA. The findings revealed that tennis players' goal-setting levels differed significantly according to age, gender, and sports experience. In particular, athletes with higher training frequency and longer sports experience had higher goal-setting scores compared to other groups. In conclusion, enhancing tennis players' goal-setting skills plays a critical role in training planning and performance improvement strategies.

Keywords: tennis, goal setting, sport psychology, performance, motivation

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The Impact of Light on Visual Performance and Eye Fatigue in Prolonged Readind Students

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Abstract: To evaluate the impact of different lighting sources on visual performance during prolonged reading.
Methods: The participants were selected to read a near texts under three lights: compact fluorescent light (CFL), light emitting diode (LED) and tungsten (TUNG), with constant illuminations (400- lux). Then, we measured the visual acuity, the eye refraction, dry eye, and we evaluated the visual comfort indicators expressed by the participants under the three lights.
Results: There was no difference between the near and the distance visual acuity of males and females under CFL, but they were been worst under the LED and TUNG. The eye refraction was around the zero under CFL, then it increased during the reading under LED and TUNG. In addition, the visual comfort symptoms were present under CFL and decreased under LED and TUNG.
Conclusion: This study demonstrates the influence of the different lights on visual comfort and performance during the extended reading, however, both males and females preferred CFL for a comfortable reading and visual comfort. It is important to note that the visual performance was acceptable under LED, but it was uncomfortable for a long time of reading and causes advanced symptoms of fatigue. The reading under the TUNG was bad from the beginning to the end and presents a high visual discomfort.

Keywords: visual acuity, eye refraction, lighting sources.

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The Relationship between Prefrontal Cortex and Striatum: The Role of the Reward Mechanism in Sports Psychology

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Abstract: This study aims to review the current literature on the role of the interaction between the prefrontal cortex (PFC) and the striatum in the reward mechanism within the context of sport psychology. Research published between 2020 and 2025 was examined, and three main themes emerged: motivational processes, performance and decision-making, and self-regulation and psychological adaptation.

Findings indicate that the striatum processes reward expectations through dopamine, which enhances athletes' intrinsic motivation, while the prefrontal cortex directs this motivation through strategic decision-making, attention, and self-regulation. Moreover, studies employing neuroimaging methods such as fMRI and EEG reveal that PFC–striatum interaction plays a critical role in athletes' decision-making under pressure, stress management, and psychological resilience.

In conclusion, the functional connectivity between the prefrontal cortex and striatum is considered a key mechanism in sustaining motivation, optimizing performance, and ensuring psychological adaptation in athletes. Future research should further investigate this interaction and integrate findings into sport psychology interventions.

Keywords: Prefrontal cortex, Striatum, Reward Mechanism, Sport Psychology, Motivation

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Visualization Of The Functioning Of The Nervous System's Neural Network

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Abstract: AI systems are widely and intensively used by humans, but can only be built by a small group of developers. But even they cannot see the connections between the nodes in the network, or the signals running through them. But in a living central nervous system, that is what we want to see, the active areas of the system in real time (fMRI, PET, MEG). 4D visualisation is just as informative in a living neural network model motivated by the living nervous system, for which there is no adequate published solution. In our work, we create a neural network similar to those currently intensively researched connectomes (C. elegans, Drosophila sp.). We provide appropriate input data from sensors representing the sensory organs. Its operation will be visualized in real time in 4D using proprietary visualization software. A neural network can be built language independently underneath the software, as it communicates through input and output files, making the system platform-independent. We have succeeded in creating an efficient visualization, which will be an important basis for our multiprocessor neural network, which is currently being developed and implemented in hardware.

Keywords: Connectome Modeling, Neural Network Visualization, Platform-Independent AI Systems, Real-Time 4D Imaging

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Fanaticism, Loyalty, Digital Commitment and Ethical Attitudes in the Context of Fandom: A Theoretical Review

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Abstract: This study theoretically reviews fanaticism, loyalty, digital commitment, and ethical attitudes in the context of sports fandom. Drawing on the Social Identity Theory, fandom is discussed as a source of identity and belonging for individuals. Fanaticism is addressed as an excessive and potentially pathological form of loyalty, while digitalization is highlighted as a driving force transforming fan–club relations through social media platforms. Ethical attitudes and fair play are examined as essential elements for the sustainable and healthy development of fandom. Measurement tools used in the literature are introduced, and their psychometric features and applications are compared. This review aims to provide a comprehensive contribution to the literature on sports fandom.

Keywords: Fandom, Fanaticism, Loyalty, Digital Commitment, Ethical Attitudes

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Efficacy of Kangoo Jump Exercises for Primary Dysmenorrhea in Young Women: Results from a Pre-Post Study

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Abstract: Primary dysmenorrhea is a common menstrual disorder among young women, often resulting in significant pain and reduced quality of life. While non-steroidal anti-inflammatory drugs (NSAIDs) and oral contraceptives are the mainstay treatments, their potential side effects have increased interest in non-pharmacological alternatives such as exercise. To evaluate the effect of Kangoo Jump exercises on pain levels in women aged 18–22 with primary dysmenorrhea, using the McGill Pain Questionnaire. Fifty-one women aged 18–22 years with regular menstrual cycles participated in a single-arm, pre-post interventional study. Participants engaged in Kangoo Jump exercises sessions twice weekly for ten weeks. Menstrual pain was assessed using the McGill Pain Questionnaire before and after the intervention. The paired sample t-test was used to evaluate data. There was a statistically significant reduction in pain scores across all McGill Pain Questionnaire subscales following the Kangoo Jump exercises program (all $p<0.001$). Effect sizes ranged from moderate to large. Kangoo Jump exercises are associated with significant improvements in dysmenorrhea symptoms among young women and may serve as an effective non-pharmacological intervention.

Keywords: pilot training, in-flight accelerations, glider towing, light aircraft, flight dynamics

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Fan Tokens and Web3-Based Fan Engagement: Value Creation, Regulation and Risks – A Comprehensive Review

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Abstract: The rapid digitalization of the sports industry has facilitated the emergence of fan tokens and Web3-based engagement platforms, creating new paradigms for fan involvement and club financing. Fan tokens, initially promoted as innovative tools for enhancing democratic fan participation, have become tradeable crypto assets in global markets, raising concerns about speculation and financial risks. This review synthesizes academic and sectoral studies published between 2018–2025, as well as regulatory reports (ESMA, SEC, MASAK) and industry analyses (UEFA, Deloitte, Binance Research). Four main themes are identified: (i) value creation and revenue models, where clubs utilize token offerings for significant financial gains and global brand expansion; (ii) limitations of participation, as token holders mostly influence symbolic decisions such as kit design or match-day music rather than strategic governance; (iii) regulatory gaps, given that current frameworks in Europe and Turkey provide only partial coverage for crypto-assets, leaving consumer protection issues unresolved; and (iv) financial risks, as high volatility exposes fans often with limited financial literacy to speculative dangers. A bibliometric mapping analysis further reveals three dominant clusters in the literature: “fan engagement and sport marketing,” “blockchain and regulation,” and “financial risk and speculation.” The findings highlight that while fan tokens present short-term opportunities for clubs, their long-term sustainability depends on transparent governance, regulatory clarity and ethical fan education practices. The study concludes that sport managers must approach fan tokens not only as financial instruments but as governance challenges requiring robust policy frameworks.

Keywords: Fan Tokens, Web3, sports management, regulation, fan engagement

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Nurses' mental health and wellbeing following the COVID-19 pandemic`

INDRIT BIMI *[1]

Abstract: There is a growing need for interventions to improve well-being in healthcare workers, particularly since the onset of COVID-19. Evidence of articles related well-being of nurses after COVID-19.
Design: Systematic literature review. PubMED, Medline, Embase, Emcare, CINAHL, PsycInfo and Google Scholar were searched in October 2020-October 2025. English-language full-text articles underwent independent screening and quality evaluation. Both quantitative and narrative styles were used to display the synthesized results. Because study designs and results varied, meta-analysis was not feasible. A total of 150 articles were reviewed and it is distributed in different years based on the Table 1. Negative factors including burnout and turnover intentions have been the main focus of the majority of studies on nurses' mental health during the COVID-19 epidemic.

Keywords: Covid-19, nursing, mental health

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Planetary Health, Climate Change, And The Metaparadigm Of Nursing

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Abstract: This paper provides a theoretical analysis of the reasons behind the nursing profession's tardiness in addressing the climate change issue. We propose that the early stages of nursing's professionalization may have contributed to this delay. In particular, we look at the major theorists' conceptions of the environment and the nurse-environment link, the widely recognized metaparadigm, and nursing's professional mandate. We draw the conclusion that nurses have not been encouraged to comprehend these ideas from a wider viewpoint because these works may have led nurses to conceptualize the environment and their relationship with it only in terms of the particular patient.
It is not unexpected that nurses have responded slowly to climate change and may not have seen it as a professional concern because they lack the philosophical and theoretical underpinnings to comprehend the environment in relation to society. It is recommended that nursing education, research, and practice be grounded in a planetary health perspective. By adopting a planetary health perspective, nurses may advance their field and help healthcare systems transition to a future that is climate resilient.

Keywords: Metaparadigm, Nurse–environment relationship, Nursing philosophy, Planetary health, Professionalization

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Diabetes Management In Assisted Living Facilities

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Abstract: People with diabetes who reside in nursing homes and care facilities do not receive enough assessment, monitoring, or specialized care, according to a number of Albanian Scientist articles published earlier this year. Many homes do not routinely check their residents' blood glucose levels or screen for diabetes. Patients are at risk for hypoglycemia and complications from diabetic foot, and staff education and training are inconsistent. The audit was carried out by the nursing scientist, which has advocated for stricter regulations to enhance care.
Under the direction of a home-wide policy, managing diabetes in care facilities entails individualized plans, staff training, routine monitoring (blood sugar, foot checks), balanced nutrition, appropriate exercise, and clear protocols for hypo/hyperglycemia. It also focuses on resident safety, individual needs (frailty, cognition), and collaboration with community diabetes teams for complex cases.

Keywords: Diabetes management, Long-term care facilities, Nursing audit, Patient safety, Staff training

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Management Of Type 1 Diabetes And Nursing Care In Albania

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Abstract: In order to maintain stable blood sugar levels and avoid problems, managing Type 1 Diabetes (T1D) mostly involves lifelong insulin supply (injections or pump) in conjunction with careful blood sugar monitoring (meters, CGM), carb counting, a nutritious diet, frequent exercise, and stress management. In addition to essential psychosocial support and routine health examinations, advanced technology such as automated insulin delivery (artificial pancreas) and novel non-insulin medications provide additional control.
Comprehensive therapy of type 1 diabetes necessitates knowledge of the disease's pathogenesis and the capacity to compare it to type 2 diabetes. Since they frequently interact with patients for the first time, nurses need to be knowledgeable on the latest developments in diagnosis, treatment, and symptoms of complications. Type 1 diabetics are particularly vulnerable to hyperglycemia problems from possibly avoidable drug administration mistakes, which might be lessened with the right knowledge.

Keywords: Autoimmune; Glucose management; Insulin therapy; Nursing; Type 1 diabetes.

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Assessment And Nursing Management Of Hypertension In The Perioperative Period In Albanian Healthcare Facilities

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Abstract: Perioperative hypertension assessment includes determining the risk of end-organ damage, continuing medication, and preoperative blood pressure measurements (which frequently require repeat or ambulatory monitoring for accuracy). In order to prevent complications like ischemia, bleeding, and stroke by keeping blood pressure within 20% of baseline, particularly during surgery, nursing management focuses on patient-specific BP targets, frequent monitoring (pre/intra/post-op), structured bedside assessments for BP shifts, managing stress/pain, giving prescribed medications (like Esmolol), and educating patients.
One of the most prevalent anomalies in perioperative patients is hypertension, which affects many people in Albania. Hemodynamic control during anesthesia, postoperative complications, and the risk of comorbidities that might not be apparent until the patient is under stress are just a few of the perioperative concerns raised by hypertension, which is frequently found during the preoperative evaluation of the patient scheduled for surgery. The detection of hypertension prior to surgery, potential issues related to hypertension during the entire perioperative period, and pharmacologic and nursing care are the main topics of this article.

Keywords: Blood pressure monitoring, Nursing management, Perioperative care, Preoperative assessment, Surgical risk

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Pediatric Hypertension: A Guideline Update For Albanian Nurses

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Abstract: The 2017 AAP guidelines (and later revisions) for pediatric hypertension emphasize the use of percentile-based definitions for younger children (<13) (Normal, Elevated, Stage 1/2 Hypertension) and adult guidelines for adolescents (≥13) (Elevated, Stage 1/2). They also replace "prehypertension" with "elevated BP," simplify screening, align with AHA/ACC standards, and concentrate management on lifestyle modifications with little evidence for primary cases. New normal-weight-based blood pressure tables and the ability to identify possible harm at lower blood pressure levels are important modifications that indicate growing knowledge.
Pediatric hypertension is becoming more common. Childhood hypertension continues to be a significant risk factor for unfavorable cardiovascular outcomes in later life. To provide better care for this patient group, NPs should be knowledgeable on the most recent recommendations for the screening, diagnosis, and management of hypertension in children.

Keywords: Blood pressure percentiles, Clinical guidelines, Pediatric hypertension, Risk stratification, Screening and diagnosis

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The Contribution of Tennis Tournaments to the Regional Economy in Turkey: A Literature Review

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Abstract: Participation in recreational activities is considered an important factor that supports individuals' psychological and social well-being. However, women are often more restricted than men in engaging in such activities due to various barriers such as social roles, safety concerns, time constraints, and individual factors. Previous studies have shown that women's participation in recreational activities reduces stress levels and enhances coping strategies. The aim of this study is to examine the relationship between women's recreational participation barriers and coping strategies, as well as to evaluate the role of demographic variables (age, income, marital status) in this relationship. The study was designed in a correlational survey model. The sample consisted of 334 women participants, selected on a voluntary basis. Data were collected online using the Recreational Participation Barriers Scale and the Coping with Stress Scale. Descriptive statistics, Cronbach's alpha reliability coefficients, Pearson correlation, independent samples t-test, one-way ANOVA, post-hoc Tukey tests, and multiple regression analyses were conducted; assumptions were also tested. The findings revealed a positive and significant relationship between recreational participation barriers and coping with stress ($r=.36$, $p<.001$). No significant difference was found according to marital status ($p>.05$), while small but significant differences were observed across age groups ($F=3.06$, $p=.028$). Regression analysis indicated that the strongest predictor of coping with stress was the perception of recreational participation barriers ($\beta=.355$, $p<.001$). This study demonstrates that recreational barriers significantly affect the use of coping strategies among women. The findings highlight that facilitating women's access to recreation is critical for strengthening psychological resilience and stress management.

Keywords: Recreation, participation barriers, coping with stress, women, psychological resilience.

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Nursing Care For Obese Children: A Theoretical Approach

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Abstract: The purpose of this article is to outline a theoretical model of nursing care for obese children in PMC. Virginia Henderson's theoretical and philosophical framework as well as grounded theory were applied. In Tirana, Albania, the study was carried out in Specialized Services and Family Basic Health Units. Four sample groups consisted of a total of twenty-four participants. Semi-structured interviews were used to gather data between April and October 2025, and the constant comparison approach was used for analysis. Initial coding, diagram and memo construction, axial coding, selective coding, and reflection on the paradigm and evolving theory were all used in the analysis. The results revealed six groups. The theoretical premise was that nurses were concerned about the treatment of obese children as a neglected area in primary health care.

Keywords: Childhood obesity, Grounded theory, Nursing care model, Primary health care, Theoretical framework

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Protocol For Nursing Care For Critically Ill Patients On Mechanical Ventilation Who Have Tracheostomies

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Abstract: The goal is to create and evaluate a nursing care regimen for patients with tracheostomies who are severely ill and on mechanical ventilation.
Methods: a methodological study that was created in two stages, I) target audience characterization and II) technology development, under the direction of the 5W2H management tool.
Outcomes: Participating in this study were thirty-four nursing professionals who discussed their educational needs for the care of critical users with tracheostomies, with a focus on continuous education and standardizing treatment through a protocol.
The development and validity of new technologies for this purpose increased nursing professionals' empowerment and participation in the health institution's macrosectoral and microsectoral actions, underscoring the need for public policies that ensure a line of care for tracheostomy users.

Keywords: Critical care nursing, Educational technology, Mechanical ventilation, Tracheostomy care, Nursing protocol

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Teacher and Student Perceptions Regarding the Participation Process of Refugee Students in Physical Education and Sports Classes in Schools Implementing Inclusive Education

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Abstract: The purpose of this research is to examine the inclusive education practices implemented for refugee students in physical education and sports classes, based on the opinions of physical education teachers, Turkish students, and refugee students. For this purpose, this research employed a case study, a qualitative research method. The study group consisted of five physical education teachers working at three secondary schools in Yozgat city center where refugee students attend high school, as well as 15 refugee students and 15 Turkish students studying in a mixed-gender environment with Turkish students in the same schools. A classroom observation form and an interview form were used as data collection tools. Classroom observations were conducted first, with each teacher observing for 80 minutes per week for five weeks, for a total of 400 minutes, and these observations were recorded on the observation form. In the second part of the data collection process, focus group interviews were conducted with Turkish students in groups of five and refugee students in groups of five, seeking answers to the questions identified in the interview form. All collected data were included in the analyses. The collected data was analyzed and categorized into themes and codes. Analyses revealed that Turkish students showed understanding towards refugee students, formed friendships and helped each other, increased communication during sporting activities, and had positive social relationships. However, due to language-related communication deficiencies, disagreements could arise and disrupted fluency in lessons. It was also observed that although refugee students experienced temporary adjustment difficulties, they gradually embraced the classroom, were able to participate in games and activities, and generally had positive communication. Teachers made personal efforts to include refugee students in the classroom and strived to establish communication. Interviews with physical education teachers also revealed that teachers generally preferred traditional teaching methods in classes, encountered problems such as lack of communication and disinterest, primarily due to insufficient Turkish language skills. Turkish language courses were not sufficiently valued, and in-service training on inclusive education was inadequate. Classroom observations revealed that Turkish and refugee students have good social relationships, cooperate, participate in activities together, and foster an atmosphere of mutual love and respect. However, lessons sometimes falter, and teachers generally prefer traditional teaching methods.

Keywords: Physical Education Teacher, Inclusive Education, Refugee, Student.

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A Scoping Review of Nursing Care in Healthcare-Associated Infections

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Abstract: In addition to systemic challenges such as understaffing, burnout, and unfavorable working conditions—which contribute to missed care and healthcare-associated infections (HAIs), particularly non–device-related infections—this scoping review maps the current state of knowledge on nursing care for HAIs and identifies core nursing practices, including hand hygiene, aseptic technique, effective communication, and staff education. The findings highlight the need for strengthened protocols, a more robust evidence base, and targeted interventions addressing systemic factors such as workload. Emphasis is placed on the critical role of fundamental nursing care (e.g., oral care and hydration) alongside broader organizational and system-level considerations in the prevention of HAIs.

Keywords: Healthcare-associated infections, Infection prevention, Nursing care, Scoping review, Systemic factors

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A Systematic Review and Meta-Analysis of the Impact of Comprehensive Nursing Care on Heart Failure Patient Management

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Abstract: By increasing patient self-care, decreasing hospital readmissions, improving quality of life, and managing psychological distress through education, monitoring, and holistic support, comprehensive nursing care dramatically improves heart failure (HF) management, resulting in better clinical outcomes and lower costs. In order to promote independence and improved long-term health, nurses empower patients through lifestyle modifications (diet, exercise), medication adherence, symptom monitoring, and emotional support.
Better Self-Care & Adherence: By teaching HF patients about low-sodium diets, fluid restrictions, exercise, and symptom recognition, nurses greatly improve their capacity to control their illness.
Decreased Hospitalizations: Exacerbations and expensive readmissions are avoided through organized follow-ups, early symptom recognition, and patient education.
Improved Quality of Life (QoL): Nurses enhance patients' general well-being, satisfaction, and capacity to manage their chronic illness by attending to their physical and emotional needs.

Keywords: Heart failure management, Nursing care, Patient education, Quality of life, Self-care

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Breathing-Based Mindfulness to Reduce Competitive Anxiety in University Athletes: A Review and Practical Implications

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Abstract: Competitive anxiety undermines performance in university athletes. Breathing-based mindfulness (slow/“resonance” breathing, pranayama, brief mindfulness cues) is a low-cost, scalable option. To synthesize interventional evidence on breathing-based mindfulness for reducing competitive anxiety in athletes and to propose a pragmatic protocol. Rapid review of PubMed and Google Scholar (2010–31 August 2025). Eligible studies: athlete samples; breathing-focused or mindfulness-with-breath interventions; anxiety outcomes (e.g., CSAI-2, state anxiety); English or Turkish full text. Heterogeneity precluded meta-analysis; a narrative synthesis was conducted. Two randomized trials and several small pre–post or quasi-experimental studies met criteria. A therapist-supported, app-delivered mindfulness program in university athletes yielded mixed or non-significant anxiety changes, likely limited by adherence and timing. By contrast, a seven-week, face-to-face mindfulness program in sprinters produced significant reductions in CSAI-2 cognitive and somatic anxiety and improved self-confidence. Convergent evidence from broader populations indicates small-to-moderate anxiety reductions with breathwork, especially when sessions are guided, repeated, and extend ≥4 weeks. Mechanistically, slow/resonance breathing may enhance vagal tone and autonomic balance, supporting anxiolysis. Breathing-based mindfulness appears feasible and potentially effective for mitigating competitive anxiety in student-athletes, with greater benefits when programs are structured, supervised, and sufficiently long. We propose a four-week protocol (5–10 minutes/day, 5 days/week) combining diaphragmatic 4-4-6 breathing, 5–6 breaths-per-minute paced breathing, and a 30–60-second mindful focus. Controlled, sport-specific trials comparing delivery modes (face-to-face vs mobile) and linking anxiety change to performance outcomes are warranted.

Keywords: sport psychology; breathwork; mindfulness; competitive anxiety; athletes.

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Challenges Related To Homeland Security In Nursing Practice

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Abstract: The concept, legislation, rules, programs, and procedures that create the operational framework for health care readiness must be thoroughly understood by nurses. The evolution of homeland security, rules and regulations impacting health care, and compliance and regulatory challenges for health care businesses are important components of this knowledge base. After evaluating the state of nursing's involvement (in homeland security) as depicted in the professional literature, this essay discusses key elements in both of these fields.
Protecting healthcare facilities, managing mass casualty events (such as bioterrorism or pandemics), addressing workforce security (such as staff shortages, violence, and immigration policies that affect caregivers), ensuring supply chain resilience for essential medications and personal protective equipment, and integrating new technology while protecting patient data from cyber threats are all challenges related to homeland security that require strong emergency preparedness and interagency coordination for consistent, high-quality care during crises.

Keywords: Emergency preparedness, Health care security, Homeland security, Nursing involvement, Regulatory compliance

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Current Challenges And Issues Facing Nursing In Albania

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Abstract: This column discusses nursing in Albania. Recruitment and retention, an aging workforce, violence and bullying, diversity, undergraduate and graduate education, professional development, information technology, clinical pathways, models of care delivery, and funding models are among the contemporary challenges and topics that the writers discuss. Additionally, they discuss developments in Albania concerning the scope of nursing practice, the growth of the nurse practitioner role, nursing leadership, and nursing research.

Keywords: Health workforce challenges, Nursing education, Nursing leadership, Nursing practice development, Nursing research

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Family Coping: Problems And Difficulties For Cancer Nurses

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Abstract: Managing severe family distress (anxiety, grief, isolation, resentment) that either mirrors or surpasses the patient's, navigating complex family dynamics (pre-existing issues, hostility), striking a balance between structured patient care and holistic family needs (especially children), and feeling overburdened by increased responsibilities and scarce resources—all of which can lead to burnout and make it difficult to advocate for family-centered care—are just a few of the difficulties cancer nurses encounter.

There is currently a substantial amount of data indicating that a cancer diagnosis has a profound impact on families and that they require a variety of support services. Specifically, research indicates that coping with the emotional stresses of having a family member with cancer is particularly challenging, and that these strains significantly affect family members' daily lives. Despite this data, the nature of the families' experiences with cancer and the consequences for nursing practice of the particular characteristics of family connections and interactions in the context of illness have not received much attention.

A critical assessment of the limitations on family care initiatives and the creation of care strategies that recognize the interdependence of family reactions and the significant needs of family members for practical and emotional support are two specific suggestions for attaining such improvements.

Keywords: Cancer nursing, Family-centered care, Family distress, Nursing burnout, Psychosocial support

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The Relationship Between Digital Leisure Exposure and Psychological Well-Being: The Mediating Role of Perceived Stress and the Moderating Role of Physical Activity

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Abstract: With the rapid digitalization, increasing screen exposure among university students has been associated with adverse effects on psychological well-being. These effects are thought to occur particularly through stress, while physical activity may play a protective role in this process. The aim of this study was to examine the mediating role of perceived stress in the relationship between digital leisure exposure and psychological well-being, as well as the moderating role of physical activity. The study sample consisted of 385 university students (58% female, 42% male; M age = 21.4 ± 2.2) from various faculties in Istanbul. Data were collected through an online survey. The measurement tools included the Smartphone Addiction Scale – Short Version (SAS-SV), the Perceived Stress Scale – 10 Items (PSS-10), the Warwick–Edinburgh Mental Well-being Scale (WEMWBS), and the International Physical Activity Questionnaire – Short Form (IPAQ-SF). Data were analyzed using SPSS 26.0 and Hayes' PROCESS Macro Model 14. The significance of indirect effects was tested via the bootstrap method with 5000 resamples and 95% confidence intervals. Results indicated that digital leisure exposure significantly increased perceived stress ($\beta = .342$, $p < .001$), and stress strongly reduced psychological well-being ($\beta = -.511$, $p < .001$). Physical activity had a significant moderating role in the stress–well-being relationship ($\beta = .163$, $p = .008$); conditional indirect effects were stronger at low physical activity ($\beta = -.234$) and weaker at high activity levels ($\beta = -.118$). This study demonstrates that the impact of digital leisure exposure on psychological well-being occurs through perceived stress, and that physical activity weakens this adverse pathway. The findings highlight the importance of digital awareness and physical activity–based interventions in promoting students' mental health.

Keywords: Digital leisure exposure, psychological well-being, perceived stress, physical activity, mediation, moderation.

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Exercising Under Cameras: A Pilot Scale Study to Measure Perceptions of Privacy and Anxiety Regarding Video Footage in Gyms

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Abstract: The purpose of this study was to examine the effects of increasingly widespread video footage in gyms on individuals' perceptions of privacy and anxiety levels, and to obtain pilot data to develop a measurement tool for this purpose. The research was conducted with a cross-sectional, quantitative design. Data were collected via a survey from individuals exercising in gyms on the European side of Istanbul. The draft scale consists of 23 items measuring discomfort, perceived privacy, and anxiety regarding video footage in gyms. Descriptive statistics, reliability analysis (Cronbach's α), item-total correlations, and comparisons based on demographic variables were used in data analysis. The study population consisted of gym users on the European side of Istanbul. A total of 204 participants (81 male, 123 female) were selected using a convenience sampling method and were included in the study. 44.6% of the participants were between the ages of 18 and 29, and 84.3% had higher education (associate or bachelor's degree). Regarding duration of gym membership, 53% of the participants had been members for less than a year. Descriptive analyses showed that participants generally felt moderate to high levels of discomfort with video recordings in gyms. The highest-rated items were “it would be disturbing if others were recording videos” (Mean = 3.90) and “there should be sections in the gym where cameras are prohibited” (Mean = 3.72). In gender comparisons, female participants reported significantly higher means than males for all items (e.g., “I feel more anxious about my body in video recording environments”: female = 3.99, male = 2.96). When examined according to gym usage duration, new members (0–6 months) were found to have higher perceptions of privacy and anxiety, while long-term members had lower levels. Furthermore, participants who shared their workouts on social media reported feeling no discomfort with video recording, while participants who did not share had significantly higher levels of discomfort and privacy concerns. The internal consistency reliability of the scale was found to be quite high (Cronbach's α = .959). Item-total correlations ranged from .65 to .76, and removing any item did not increase reliability. The findings indicate that video recording in gyms creates a perception of privacy violation and anxiety in individuals, with these perceptions being particularly strong among women and gym newcomers. Furthermore, users who do not produce content on social media were found to have higher privacy sensitivity. The study emphasizes the need to consider digital privacy in sports environments in terms of sports psychology and exercise motivation and serves as a strong pretest for the future development of the scale.

Keywords: anxiety, perception, sports, video analysis

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Measuring And Connecting Nurse Actions To Patient Outcomes In Acute Care Settings Presents Challenges

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Abstract: It is challenging to measure and connect nursing interventions to patient outcomes in acute care because of complicated, multifactorial patient conditions, the dilution of nursing's unique impact by team-based care, problems with nurse autonomy, missed care, inconsistent documentation, and the challenge of separating nursing's contribution from other factors (such as physician orders, patient compliance, and system issues). The dynamic care environment, patient comorbidities, the absence of standardized e-measures, and the sheer complexity of practice are major obstacles that make it difficult to establish causal causation for outcomes like satisfaction or falls. It is a crucial task with professional, economical, and political implications to measure and link patient outcomes to nursing intervention. There are several emergent aspects that affect the process of effectively evaluating patient outcomes, thus the significance and difficulty of doing so should not be disregarded. These include nursing's lack of autonomy within the system, the challenges encountered when attempting to connect patient outcomes to nursing interventions, the turbulent practice context, variations in care due to the large number of health professionals, individual patient characteristics impacting outcomes, and choosing appropriate nursing outcome measures.

Keywords: Acute care nursing, Measurement challenges, Nursing interventions, Patient outcomes, Quality evaluation

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Recreational Participation Barriers and Coping with Stress: A Study on Women

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Abstract: Participation in recreational activities is considered an important factor that supports individuals' psychological and social well-being. However, women are often more restricted than men in engaging in such activities due to various barriers such as social roles, safety concerns, time constraints, and individual factors. Previous studies have shown that women's participation in recreational activities reduces stress levels and enhances coping strategies. The aim of this study is to examine the relationship between women's recreational participation barriers and coping strategies, as well as to evaluate the role of demographic variables (age, income, marital status) in this relationship. The study was designed in a correlational survey model. The sample consisted of 334 women participants, selected on a voluntary basis. Data were collected online using the Recreational Participation Barriers Scale and the Coping with Stress Scale. Descriptive statistics, Cronbach's alpha reliability coefficients, Pearson correlation, independent samples t-test, one-way ANOVA, post-hoc Tukey tests, and multiple regression analyses were conducted; assumptions were also tested. The findings revealed a positive and significant relationship between recreational participation barriers and coping with stress ($r=.36$, $p<.001$). No significant difference was found according to marital status ($p>.05$), while small but significant differences were observed across age groups ($F=3.06$, $p=.028$). Regression analysis indicated that the strongest predictor of coping with stress was the perception of recreational participation barriers ($\beta=.355$, $p<.001$). This study demonstrates that recreational barriers significantly affect the use of coping strategies among women. The findings highlight that facilitating women's access to recreation is critical for strengthening psychological resilience and stress management.

Keywords: Recreation, participation barriers, coping with stress, women, psychological resilience.

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Rapid Measurement of Parent Satisfaction and an Improvement Cycle in Youth Sports Schools: A 10-Item Toolkit and Implementation Guide

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Abstract: Sustaining youth sports programs hinges on service quality, perceived safety, coach–parent communication, age/level fit, and alignment of schedules with family routines. We present an action-oriented, threshold-based framework that integrates a 3–5-minute, 10-item Parent Satisfaction Short Scale (VMKÖ-10) with a single-item Net Promoter Score (NPS) within a continuous collect–analyze–share–improve–review cycle. The framework includes QR-based data capture, a one-page executive summary (domain bar chart, branch×domain heatmap, NPS panel), and action management (Action Card, RACI matrix, timeline) guided by interpretation thresholds (3.50 = critical watch; 4.00 = strong). A cross-sectional rollout—with no separate pilot—involved n=128 parents from gymnastics (n=42), basketball (n=56), and football (n=30). Findings indicate coach approach & communication as the strongest domain, whereas program design & schedule fit is the primary area for improvement; open-ended comments frequently cited greater schedule flexibility, transparent timing of fees/add-ons, and improvements to waiting/facility areas. Analyses were performed in Microsoft Excel (O365) and Python 3 (matplotlib); Cronbach's alpha was computed using the classical item-variance formula, and NPS was reported as the percentage difference between promoters and detractors. Overall, the model is low-cost, replicable, and scalable, strengthening transparent decision-making and parent trust, and it provides a robust foundation for subsequent psychometric validation of VMKÖ-10 (content validity, EFA/CFA, test–retest).

Keywords: youth sport, parent satisfaction, service quality, NPS, quality improvement.

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Investigation of Coaches Voice Hygiene, Voice Use Habits, and Level of Knowledge

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Abstract: Coaching is a profession that inherently requires frequent and intensive voice use. This condition increases the importance of voice hygiene practices, healthy vocal behaviors, and knowledge related to vocal health. The present study aimed to evaluate coaches' levels of voice hygiene, voice use habits, and knowledge concerning vocal health. A set of assessment tools developed and scored by three certified speech and language therapists was administered to 30 coaches via Google Forms in an online format. Data were analyzed using the Shapiro-Wilk test to assess normality, while relationships between variables were examined with Spearman's correlation analysis, and gender differences were evaluated using the Mann-Whitney U test. The participants had a mean age of 30.57 ± 11.36 years; 60% were male (n = 18) and 40% were female (n = 12). Regarding professional experience, 20% (n = 6) had 1 year or less, 23.3% (n = 7) had 2–5 years, 20% (n = 6) had 6–10 years, and 36.7% (n = 11) had more than 11 years of experience. The findings revealed a significant and strong positive correlation between voice hygiene levels and knowledge of vocal health ($r = 0.518$, $p < 0.05$), as well as a significant positive correlation between years of coaching experience and voice hygiene levels ($r = 0.545$, $p < 0.05$). No significant differences were found between genders in terms of voice hygiene or knowledge levels ($p > 0.05$). Voice-related health issues were reported by 20% of the participants, including pharyngitis (3.3%), vocal nodules (10%), and hoarseness (6.7%). The results indicate that coaches' voice hygiene practices are significantly associated with their knowledge about vocal health. Furthermore, increased professional experience appears to enhance awareness of vocal hygiene. In this context, it is recommended that topics such as voice hygiene and healthy voice use be systematically integrated into in-service training programs to support coaches' professional competency and vocal well-being. Incorporating preventive and protective voice care strategies into professional education may be effective in reducing the prevalence of voice-related problems within this occupational group.

Keywords: Voice hygiene, coaches, voice knowledge, vocal health, speech therapy.

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Investigation of the Relationship Between Maximal Strength and Sprint Performance in Amateur Soccer Players With Chronic Ankle Instability

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Abstract: The aim of this study is to examine the relationship between lower extremity maximal strength and sprint performance in amateur soccer players with chronic ankle instability (CAI). The findings aim to reveal the impact of ankle stability on motor performance and contribute to a holistic evaluation of performance tests. This study was conducted with a comparative cross-sectional design. A total of 20 amateur soccer players were evaluated, including 10 with chronic ankle instability (CAIT ≤ 23) and 10 without instability (CAIT > 23). In a single measurement session, all participants underwent the CAIT, navicular–medial malleolar (NMM) distance (cm), maximal strength test using Smith machine squats (kg), and 30-meter sprint test (seconds). Independent samples t-test was used for normally distributed variables, Mann–Whitney U test for non-parametric data, and Pearson or Spearman correlation analysis for relationships between variables. The mean age, BMI, and CAIT score of the CAI group were 20.50 ± 0.850 years, 24.80 ± 1.254 kg/m², and 16.10 ± 2.025, respectively. In the non-CAI group, these values were 20.10 ± 0.738 years, 26.00 ± 2.554 kg/m², and 27.90 ± 1.197, respectively. Independent t-test and Mann–Whitney U test revealed statistically significant differences between groups in CAIT score, maximal strength, 30-meter sprint performance, and NMM distance ($p < 0.05$). Furthermore, a significant positive correlation was found between CAIT scores and both maximal strength and sprint performance, whereas a significant negative correlation was observed between CAIT score and NMM distance ($p < 0.05$). Amateur soccer players with CAI demonstrated significantly lower maximal strength and sprint performance. The CAIT score showed a significant association with motor performance parameters, highlighting the impact of ankle stability on athletic performance.

Keywords: Chronic ankle instability, football player, maximal strength, sprint, performance.

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Movement and Mental Development: A Study on Psychomotor Skills in Early Education

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Abstract: The study of movement and the relationship between motor and psychic development has been a subject of enduring interest for theorists across various fields, including philosophy, medicine, and psychology. Human development is viewed holistically, as an amalgamation of biological, psychological, and physical traits that enable a child, and later an adult, to interact and integrate effectively within a dynamic and evolving social system. This concept has been approached from both theoretical and practical perspectives, understood as a technique aimed at forming and developing motor capacity and movement itself. Through movement, a child constructs a range of mental representations, from simple activities such as running to more complex physical tasks. Beyond promoting harmonious physical development, psychomotricity plays a major role in shaping temperament, personality, and facilitating appropriate social integration. In order to significantly contribute to the psychometric development of the children in primary school, a study was conducted during the 2020–2021 school year (January–June 2021). Initial testing took place in January 2021, and final assessments were carried out in June 2021 on extracurricular days (Saturdays). The traditional seven-phase structure of physical education lessons was modified into a five-phase model, introducing a novel "psychomotricity phase" aimed at enhancing motor and cognitive skills in lower primary grades (preparatory class to second grade). This phase, lasting 20 minutes per lesson, included structured psychomotricity activities aligned with specific learning objectives.The experiment involved 114 second-grade students divided equally into control and experimental groups. The control group followed standard lesson structures, while the experimental group participated in the modified lessons incorporating the psychomotricity phase. Initial and final assessments were conducted using the Bruininks–Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), with parental and school consent obtained prior to testing. The intervention spanned the entire school year, allowing evaluation of the effectiveness of the proposed model in improving psychomotor development.
The results demonstrate that the psychomotricity-based intervention contributes to enhanced motor skill acquisition, cognitive representation through movement, and improved social and emotional development. Implementing a structured psychomotricity phase in primary school physical education lessons is a viable approach for promoting holistic child development and fostering long-term engagement in physical activity.

Keywords: psychomotricity, physical education, motor development, cognitive development,primary school, educational intervention.

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Multi-Functional Valuation Approaches in Forest Economics for Sustainable Management

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Abstract: Forest ecosystems provide a wide range of goods and services extending far beyond timber production, including carbon sequestration, biodiversity conservation, recreation, and cultural values. Traditional forest economics has largely focused on market-based outputs, often underestimating the broader economic significance of forests. In recent decades, increasing environmental pressures and climate-related risks have highlighted the necessity of integrating multifunctional valuation approaches into forest management and policy frameworks. This paper examines the role of comprehensive economic valuation methods in supporting sustainable forest management.

The study synthesizes key valuation approaches, including ecosystem services assessment, contingent valuation, travel cost methods, and multi-criteria decision analysis, emphasizing their applicability in forest planning and policy formulation. By incorporating non-market values, these approaches enable decision-makers to better capture the full economic contribution of forests to society, while balancing ecological integrity and social welfare. The analysis highlights how multifunctional valuation enhances transparency in trade-off assessment, improves long-term investment decisions, and strengthens the economic justification for conservation-oriented management strategies.

In the context of increasing land-use conflicts and climate uncertainty, recognizing the total economic value of forests is critical for ensuring their resilience and continued provision of ecosystem services. The paper concludes that mainstreaming multifunctional valuation in forest economics can significantly improve sustainable management outcomes and contribute to more adaptive and economically sound forest governance.

Keywords: Ecosystem services, Forest economics, Multi-criteria analysis, Non-market valuation, Sustainable forest management

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Economic Impacts of Ecotourism on Forest Ecosystems and Rural Development

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Abstract: Ecotourism has emerged as a key strategy for linking forest conservation with local economic development, particularly in rural and forest-dependent regions. By promoting nature-based experiences while emphasizing environmental responsibility, ecotourism offers an alternative income source that can reduce pressure on forest resources. This paper explores the economic role of ecotourism in forest ecosystems and its contribution to rural development from a forest economics perspective.

The analysis focuses on the capacity of ecotourism to generate employment, diversify household incomes, and stimulate local entrepreneurship, while simultaneously supporting conservation objectives. Well-designed ecotourism initiatives can enhance the economic value of standing forests, incentivizing protection over extractive land uses. However, the paper also addresses potential risks, including environmental degradation, uneven benefit distribution, and overuse of sensitive ecosystems, which may undermine both ecological and economic sustainability if governance is weak.

Effective ecotourism development requires science-based planning, stakeholder participation, and the integration of carrying capacity concepts into management strategies. Reinforcing local benefit-sharing mechanisms and reinvesting tourism revenues into forest conservation are identified as critical elements for long-term success. The findings suggest that ecotourism, when embedded within broader sustainable forest management frameworks, can strengthen rural resilience while contributing to the conservation of forest ecosystems.

Keywords: Ecotourism, Forest conservation, Local economy, Rural development, Sustainable tourism

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Valorization of Lignocellulosic Biomass for Activated Carbon Production and Adsorption Applications

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Abstract: Lignocellulosic biomass derived from agricultural and forestry residues represents a promising and sustainable raw material for the production of activated carbon. The conversion of biomass waste into high-performance adsorbents offers an effective strategy for waste valorization while addressing environmental challenges associated with water and wastewater treatment. This study evaluates the production of activated carbon from plant-based biomass under varying processing conditions and examines its adsorption performance toward organic contaminants.

Activated carbons were synthesized through controlled thermal treatment and chemical activation processes. Comprehensive characterization was conducted to assess textural properties, surface chemistry, and porosity development. Adsorption behavior was analyzed using equilibrium, kinetic, and thermodynamic models to identify governing mechanisms and performance-limiting factors. The results demonstrate that processing conditions strongly influence adsorption efficiency, with optimized materials exhibiting high surface area, well-developed pore structures, and favorable adsorption kinetics.

The findings underscore the potential of biomass-derived activated carbons as cost-effective and environmentally benign alternatives to conventional adsorbents. By integrating waste utilization with advanced adsorption science, this approach supports circular economy principles and promotes sustainable material development. The study highlights the relevance of biomass valorization strategies for environmental remediation applications and provides a general framework applicable to a wide range of lignocellulosic resources..

Keywords: Activated carbon, Adsorption processes, Biomass valorization, Environmental remediation, Sustainable materials

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Green Extraction and Phytochemical Characterization of Plant-Based Bioactive Compounds

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Abstract: Plant-derived bioactive compounds play a crucial role in food quality, human health, and pharmaceutical applications. Recent advances emphasize the need for environmentally friendly extraction techniques that enhance efficiency while reducing solvent toxicity and energy consumption. This study examines green extraction strategies for recovering phytochemicals from selected medicinal and edible plant matrices, with particular emphasis on deep eutectic solvents (DES) and optimized process conditions.

Extraction parameters were systematically optimized to maximize yields of polyphenols, flavonoids, and antioxidant compounds. The chemical profiles of extracts were characterized using spectrophotometric and chromatographic techniques, enabling comparative evaluation across solvent systems and plant tissues. Results indicate that green solvents significantly outperform conventional solvents in both extraction efficiency and selectivity, while maintaining high antioxidant activity.

Beyond extraction performance, the study highlights the broader applicability of green extraction approaches in food technology, nutraceutical development, and natural product chemistry. The integration of sustainable solvents with process optimization provides a scalable framework for producing high-quality plant extracts with reduced environmental impact. These findings contribute to the growing body of evidence supporting green chemistry principles in phytochemical research and industrial applications.

Keywords: Bioactive compounds, Deep eutectic solvents, Green extraction, Phytochemical analysis, Sustainable processing

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Nursing-Led Strategies for Preventing Hospital-Acquired Infections in Acute Care Settings

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Abstract: Hospital-acquired infections (HAIs) remain a major challenge for healthcare systems worldwide, contributing to increased morbidity, mortality, length of hospital stay, and healthcare costs. Nurses play a central role in the prevention of HAIs through direct patient care, adherence to infection control protocols, and early identification of risk factors. This paper examines nursing-led strategies for preventing HAIs in acute care settings, with particular attention to organizational, clinical, and educational dimensions.

The review highlights core nursing interventions, including hand hygiene compliance, aseptic technique, surveillance of infection indicators, patient hygiene, and effective communication within multidisciplinary teams. It also explores systemic barriers such as understaffing, workload pressure, missed nursing care, and inconsistent documentation, which may compromise infection prevention efforts. Evidence suggests that targeted education, continuous professional development, and the implementation of standardized care protocols significantly enhance nurses' ability to reduce infection risks.

Furthermore, the paper emphasizes the importance of nursing autonomy and leadership in fostering a safety-oriented culture. Empowering nurses to actively participate in infection control decision-making and quality improvement initiatives is essential for sustainable outcomes. The findings underscore that effective HAI prevention requires not only individual competence but also supportive organizational structures and policies. Strengthening nursing practice in this area is critical for improving patient safety and healthcare quality.

Keywords: Hospital-acquired infections, Infection prevention, Nursing practice, Patient safety, Quality of care

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The Role of Nurses in Supporting Self-Management of Chronic Diseases in Primary Care

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Abstract: Chronic diseases such as diabetes, hypertension, and heart failure represent a growing burden on healthcare systems and significantly affect patients' quality of life. In primary care settings, nurses play a pivotal role in supporting patients' self-management and promoting long-term health outcomes. This paper explores the contribution of nursing interventions to chronic disease management, focusing on education, monitoring, and psychosocial support.
Nursing-led self-management support includes patient education on lifestyle modification, medication adherence, symptom recognition, and risk factor control. Regular follow-up, individualized care planning, and effective communication enable nurses to identify early signs of deterioration and prevent avoidable hospitalizations. Evidence indicates that nurse-led interventions improve clinical outcomes, enhance patient empowerment, and increase adherence to treatment plans.
The paper also addresses challenges faced by nurses in primary care, including time constraints, limited resources, and variations in patients' health literacy and social support. Despite these challenges, structured care models and evidence-based guidelines provide a strong framework for effective nursing practice. Integrating holistic and patient-centered approaches allows nurses to address both physical and psychological aspects of chronic illness.
Overall, strengthening the role of nurses in chronic disease self-management is essential for improving population health and ensuring sustainable healthcare delivery.

Keywords: Chronic disease management, Nursing role, Patient education, Primary care, Self-management

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Adaptive Anomaly Detection for Periodic Data Streams in Distributed Information Systems

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Abstract: The rapid growth of distributed information systems has led to an increasing volume of periodic data streams generated by sensors, networked devices, and monitoring platforms. Detecting anomalies within such streams is critical for ensuring system reliability, security, and operational efficiency. This study proposes an adaptive anomaly detection framework tailored for periodic data streams in distributed environments.

The proposed approach combines statistical pattern recognition with adaptive thresholding to capture both short-term deviations and long-term behavioral changes. By leveraging periodicity-aware modeling, the framework distinguishes between expected cyclic variations and genuine anomalies that may indicate faults, cyber intrusions, or system degradation. The model is designed to operate efficiently in real-time settings, minimizing computational overhead while maintaining high detection accuracy.

Experimental evaluations using simulated and real-world datasets demonstrate that the adaptive framework outperforms static detection methods, particularly in environments characterized by noise, concept drift, and heterogeneous data sources. The results show improved sensitivity to subtle anomalies without a corresponding increase in false positives. Furthermore, the modular structure of the system allows seamless integration into existing information infrastructures.

The findings highlight the importance of adaptive and scalable anomaly detection mechanisms for modern distributed systems. The proposed framework offers practical value for applications in network security, environmental monitoring, and industrial automation, where continuous data integrity and early fault detection are essential..

Keywords: Anomaly detection, Data streams, Distributed systems, Periodic patterns, System monitoring

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Design and Implementation of Secure Information Systems for Data Management and Communication

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Abstract: Secure information systems are fundamental to modern digital infrastructures, supporting data storage, processing, and communication across diverse organizational contexts. As cyber threats continue to evolve, there is a growing need for integrated security mechanisms that address confidentiality, integrity, and availability without compromising system performance. This paper presents the design and implementation of a secure information system framework focused on data management and electronic communication. The proposed system incorporates encryption-based communication protocols, access control mechanisms, and database security strategies to protect sensitive information from unauthorized access. Emphasis is placed on practical implementation, including secure data transmission, role-based user management, and resilient system architecture. The framework is designed to be scalable and adaptable, making it suitable for academic, governmental, and enterprise-level applications. Performance analysis indicates that the security enhancements introduce minimal overhead while significantly improving protection against common attack vectors such as unauthorized access, data interception, and system misuse. The study also discusses challenges related to user behavior, system configuration, and the balance between usability and security. Overall, the findings demonstrate that well-designed secure information systems can effectively safeguard data while maintaining operational efficiency. The proposed framework contributes to best practices in information security and supports the development of robust digital infrastructures in increasingly interconnected environments.

Keywords: Data security, Information systems, Secure communication, System architecture, Access control

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Techno-Economic Analysis of Negative Emission Energy Production with Biomass Gasification and Carbon Capture Integration

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Abstract: In the context of combating global climate change, energy production systems must evolve to include not only low-carbon technologies but also those capable of achieving negative emissions. In this regard, the integration of biomass-based energy production with carbon capture and storage technologies (Bioenergy with Carbon Capture and Storage – BECCS) stands out as a strategic solution in the net-zero and 1.5 °C scenarios published by the IPCC. This study examines the integration of a biomass gasification-based energy production system with a carbon capture unit and performs a techno-economic analysis of the system.

Within the scope of the study, the gasification process for a lignocellulosic biomass type was modeled using process simulation methods. The synthesis gas composition, net electricity production, and system efficiencies were determined; the amount of CO_2 captured was calculated by integrating the carbon capture process into the system. The net emission balance was evaluated considering the life cycle carbon footprint of the biomass, and the system's negative emission potential was revealed.

Within the scope of the economic analysis, the levelized cost of energy (LCOE) was calculated by taking into account investment costs, operating and maintenance expenses, and the energy penalty of the carbon capture process. The results show that, despite the increased costs associated with carbon capture integration, the negative emissions advantage provided and the potential for carbon pricing mechanisms could make the system competitive in the long term. The findings reveal that biomass gasification-based BECCS systems are a viable option for sustainable energy transition.

Keywords: Biomass Gasification, Carbon Capture and Storage (CCS), Negative Emissions, Techno-Economic Analysis

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Olive by Products: Low-Cost, Renewable Source of High Added Value Phenolic Compounds and Their Biological Activities and Functional Food

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Abstract: Phenolic compounds, present in plants, are an essential part of the human diet due to their antioxidant properties. These compounds posses an aromatic ring bearing one or more hydroxyl groups and their structures. Olive oil and olive by-products are the major sources of phenolic compounds in the Mediterranean countries. Indeed, *Olea europaea L*. organs and by-products such as: leaves, olive mill wastewater, wood, stems and roots represent a major disposal problem for the industry concerned, but they are also promising sources of phenolic compounds which have been associated with numerous *in vivo* and *in vitro* biological activities and used for traditional medicinal purposes. In fact, olive oil and some of its by-products has been the subject of investigations and have proven to be effective sources of phenolic antioxidants. Principally, biological activities and characteristic flavour and aroma are due to the presence of unique bioactive compounds both in olives and extra virgin olive oil phenolic compounds such as oleuropein, hydroxytyrosol, verbascoside and derivatives etc., and tocopherols and carotenoids. Several factors, such as agronomical conditions, climate, and level of ripening, olive cultivar and type of production process have the main effects on the profile and activities of bioactive compounds. Accumulating evidence suggests that EVOO may have health benefits; it can be considered as an example of a functional food containing a variety of biologically active phenolic components that may contribute to its overall therapeutic characteristics.

Keywords: Olive by Products, phenolic compounds, hydroxytyrosol, antioxidant activity, antimicrobial activity, functional Food, valorization.

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Authentication of olive oil using volatile composition, sensorial analysis, and stable carbon isotopes

RANIA BEN HMIDA[1], BOUTHEINA GARGOURI[1,3], ONUR SEVINDIK [2], SERKAN SELLI [4], MOHAMED BOUAZIZ[1,5]

Abstract

This study provides a comprehensive characterization of the chemical and sensory profiles of monovarietal virgin olive oils (VOOs) obtained from both autochthonous and introduced cultivars cultivated in Tunisia. The investigation encompassed the analysis of volatile compounds, fatty acid composition, triglyceride profile, total phenolic content, and sensory attributes of oils produced from Chemlali, Chétoui, Ousleti, Arbequina, Arbosana, and Koroneiki varieties across different growing regions. In addition, the stable carbon isotope composition ($\delta^{13}C$) of selected olive oil samples was determined by cavity ring-down spectroscopy (CRDS) to assess the influence of cultivar type and geographical origin on isotopic signatures. The findings revealed distinct cultivar-specific chemical fingerprints. Volatile profiles exhibited marked variability among samples, particularly in lipoxygenase (LOX)-derived C6 aldehydes and alcohols, which are key contributors to the characteristic green and fresh sensory notes of virgin olive oil. Fatty acid and phenolic compositions also differed significantly, reflecting clear compositional variability among cultivars. Sensory analysis confirmed the absence of defects in all samples, while the intensity of positive attributes varied notably between varieties. Stable isotope analysis confirmed the C_3 plant origin of the oils and revealed significant differences in $\delta^{13}C$ values associated with both cultivar and growing conditions. Overall, these results demonstrate that cultivar genetics, regional agro-climatic conditions, and their associated $\delta^{13}C$ isotopic signatures collectively influence the chemical and sensory characteristics of Tunisian VOOs, highlighting their potential application in authenticity verification and quality differentiation.

Keywords: Olive oil, Volatile compounds, sensory analysis, chemometrics, stable isotopes

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Synthesis, Electrochemical Evaluation and Antibacterial Activity of Novel Schiff Base and Reduced Amine Derivatives for Carbon Steel Protection

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Abstract: Four novel Schiff base ligands derived from benzene-1,4-diamine (L1a, L2a) and their corresponding reduced amine derivatives (L1b, L2b) were synthesized via condensation reactions followed by chemical reduction. The molecular structures were characterized using FT-IR, ^{1}H and ^{13}C NMR spectroscopy, mass spectrometry, and CHN elemental analysis. The corrosion inhibition performance of the synthesized compounds was investigated for C45 carbon steel in 0.1 M hydrochloric acid using potentiodynamic polarization measurements at 293 and 303 K. All ligands exhibited significant corrosion inhibition efficiency and acted as mixed-type inhibitors by reducing both anodic and cathodic reactions. The reduced amine derivatives L1b and L2b demonstrated superior inhibition efficiencies, reaching up to 92%, and showed excellent thermal stability. This improved performance is attributed to higher electron density on nitrogen atoms and increased molecular flexibility, which favor strong adsorption on the steel surface and the formation of a stable protective film. In addition, the antibacterial activity of the ligands was evaluated against *Staphylococcus aureus* and *Escherichia coli*. All compounds displayed notable activity against *S. aureus*, while L1a and L2a also showed moderate activity against *E. coli*. These findings highlight the potential of the synthesized compounds as multifunctional agents combining efficient corrosion protection with antibacterial properties, making them promising candidates for industrial and biomedical applications requiring simultaneous metal protection and microbial control.

Keywords: Schiff bases; corrosion inhibition; carbon steel; acidic medium; antibacterial activity; electrochemistry.

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Modeling and visualization of harmonic distortion in electrical power systems

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Abstract: Power quality is a critical factor in electrical power systems, and it directly impacts stability, performance and lifespan of electrical machines. Harmonics which cause distortions on signals are one of the considerable power quality problems. Harmonics lead to overheating and malfunctions. Ensuring the power quality is essential for operational reliability, decreasing maintenance time and improving system performance. In order to determine these challenges, this study proposes a software application that is designed to calculate THD (Total Harmonic Distortion) and PF_{THD} (Distortion Power Factor). This study is developed with the aim of providing both educational and practical values for engineers, researchers and students who are working in the field of power systems. The application allows users to input signal data either manually or by importing from a CSV file. CSV files can be obtained from energy analyzers or certain oscilloscopes. When entering data manually, users can specify the phase angle for each harmonic component. In both cases, the application can plot harmonic components, distorted signal and harmonic spectrum in bar chart form, and also calculate THD and PF_{THD}. With these features, application supports the understanding of how different harmonic orders and phase relations affect the signal quality. The mathematical modelling, signal plotting and graphical user interface developments are carried out by using python programming language

Keywords: Power Quality, Harmonics, Software

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1. INTRODUCTION

The demand for energy in our world is increasing rapidly day by day, primarily due to the electrical energy needed in production lines. To meet this demand, people utilize both fossil and renewable energy sources. However, the energy generated is deteriorating in our factories due to devices producing reactive power. This is where the notion of "power quality" becomes significant. Power quality is one of the most crucial issues in our modern era. With the increase in human needs and demands, more production facilities, more production machines, and consequently, more reactive power requirements emerge (Carretero-Hernandez et al., 2025; IEEE Recommended Practice for Monitoring Electric Power Quality, 2019).

This reactive power, in turn, disrupts the purity of the sinusoidal electrical signal coming to our post-production factories, leading to undesired distortions. Along with this issue there are more problems that affect power quality. In this study, harmonics that is one of the most encountered problems in power quality, is selected. Harmonics are the signals that their frequencies are multiple of the fundamental frequency. Harmonics in power systems cause waveform distortion in voltage and current. Main causes of harmonics are nonlinear load characteristics, power electronic applications such as switch mode power supply, rectifiers, variable frequency drives, and distributed energy sources (Li et al., 2025; Shelar et al., 2024).

In this study, a comprehensive software application is proposed for the calculation and visualization of harmonic distortion effects on the fundamental signal. The tool enables users to analyze harmonic distortion for each harmonic order individually, allowing them to examine and experience how distortions of different orders influence the waveform. This interactive capability provides an opportunity not only to calculate numerical values but also to observe how changes in harmonic orders directly alter the characteristics of electrical signals in real time.

The application features a user-friendly and intuitive graphical interface (GUI) designed to bridge theoretical concepts with practical experimentation. Users can enter system parameters manually or load a CSV file. Once parameters are set, the software computes harmonic components with precision and provides simultaneous visualization in both the time domain and the frequency spectrum. This dual-domain representation helps users better understand the correlation between waveform distortion and its spectral content. By combining accurate computation, theoretical grounding, and dynamic visualization, the proposed tool serves as a valuable resource for engineers, researchers, and students. The mathematical modelling, data analysis, signal plotting and GUI are developed by using python programming language.

2. MATERIAL AND METHOD

2.1. Harmonics

The advancement of semiconductor technology and the increasing utilization of nonlinear elements in recent years have led to an escalation in harmonic distortions within power signals, adversely affecting the components in energy systems. Therefore, it is imperative to identify and analyze these harmonics, taking necessary measures to mitigate their impact. Since these adversities may lead to interruptions or even cessation of production, they pose not only economic challenges but also the risk of unmet societal demand (Arrillaga et al., 2003; Xu et al., 2025).

Another significant concern is the impact of harmonics on essential power components such as motors, generators, and transformers. Furthermore, the presence of components with different frequencies in the current and voltage can lead to resonance, causing motors to stall. In the absence of emergency circuits, this can pose crucial risks in production lines. This situation not only results in economic losses but also poses a threat to the lives of workers on the production line (IEEE Recommended Practice for Monitoring Electric Power Quality, 2019).

To perform harmonic analysis, it is essential to have a command of Fourier series, one of the most important topics in mathematics. Fourier series theory was initially published by the French physicist and mathematician Joseph Fourier in 1822 in his paper titled "Analytic Theory of Heat." This theory examines the trigonometric expansion of functions in specific types. These series establish a relationship between functions in the time and frequency domains. If Fourier analysis is defined, it can describe a square wave by summing sine waves. The most significant reason for using Fourier series here is to express distorted energy signal as the sum of sine and cosine signals, allowing us to detect distortions at different frequencies (Ding et al., 2018; Šćekić and Mujović, 2022).

Firstly, before performing Fourier series, it is essential to ensure that certain conditions are satisfied by the function. The function must be continuous within a specific period and square-integrable over one period. The function must have a finite number of endpoints and a discrete number of maxima/minima over the period. Also, there are two situations for Dirichlet Conditions. The function must have a bounded variance over the period. Under these conditions, the Fourier series can, in certain situations, represent a function that is bounded in the limit. The function must be square-integrable over the period. Another important aspect is the parity of functions. Even functions are symmetrical to axis “y”. Odd functions are symmetrical to “origin” (Arrillaga et al., 2003; Hart, 2011).

Fourier analyze methods can be split into three: analytical method, graphical method and measurement method. The fundamental expression of Fourier series is in Eq. (1).

$$f(t) = A_0 + \sum_{n=1}^{\infty} \left(A_n cos(nt) + B_n sin(nt)\right) \quad (1)$$

This expression is the explicit representation of Fourier series that is in Eq. (2-5).

$$y = f(t) = A_0 + A_1 cos(t) + A_2 cos(2t) + \cdots + A_n cos(nt) + B_1 sin(t) + B_2 sin(2t) + \cdots + B_n sin(nt) \quad (2)$$

$$A_0 = \frac{1}{2\pi}\int_0^{2\pi} f(t)\, dt \quad (3)$$

$$A_n = \frac{1}{\pi}\int_0^{2\pi} f(t) cos(nt)\, dt \quad (4)$$

$$B_n = \frac{1}{\pi}\int_0^{2\pi} f(t) sin(nt)\, dt \quad (5)$$

t: independent variable (in electrical power systems, denoted as t = ωt)
A_0: constant term which represent with “0”, DC value.
Note that A_0 can be represent as $\frac{A_0}{2}$ in the literature because of considering half cycle of one period signal but it’s equal to first present. The derivation of the coefficients of Fourier series with proof is in Eq. (6-19).

$$f(x) \to L \quad (6)$$

$$f(x) = A_0 + \sum_{n=1}^{\infty} \left(A_n cos\left(\frac{2\pi nx}{L}\right) + B_n sin\left(\frac{2\pi nx}{L}\right)\right) \quad (7)$$

$$\int_0^L sin\left(\frac{2\pi nx}{L}\right) cos\left(\frac{2\pi nx}{L}\right) dx = 0 \quad (8)$$

$$\int_0^L cos\left(\frac{2\pi nx}{L}\right) cos\left(\frac{2\pi nx}{L}\right) dx = \frac{L}{2}\delta mn \quad (9)$$

$$\int_0^L sin\left(\frac{2\pi nx}{L}\right) sin\left(\frac{2\pi nx}{L}\right) dx = \frac{L}{2}\delta mn \quad (10)$$

$$\int_0^L f(x)cos\left(\frac{2\pi nx}{L}\right) dx = A_0 \int_0^L cos\left(\frac{2\pi nx}{L}\right) dx + \sum_{n=1}^{\infty} A_n \int_0^L cos\left(\frac{2\pi nx}{L}\right) cos\left(\frac{2\pi nx}{L}\right) dx +$$

$$B_n \int_0^L sin\left(\frac{2\pi nx}{L}\right) cos\left(\frac{2\pi nx}{L}\right) dx \quad (11)$$

$$\int_0^L f(x)cos\left(\frac{2\pi nx}{L}\right) dx = A_n \frac{L}{2} \rightarrow A_n = \frac{2}{L}\int_0^L f(x)cos\left(\frac{2\pi nx}{L}\right) dx \quad (12)$$

$$\int_0^L f(x)sin\left(\frac{2\pi nx}{L}\right) dx = A_0 \int_0^L sin\left(\frac{2\pi nx}{L}\right) dx + \sum_{n=1}^{\infty} A_n \int_0^L cos\left(\frac{2\pi nx}{L}\right) sin\left(\frac{2\pi nx}{L}\right) dx + B_n \int_0^L sin\left(\frac{2\pi nx}{L}\right) sin\left(\frac{2\pi nx}{L}\right) dx \quad (13)$$

$$\int_0^L f(x)sin\left(\frac{2\pi nx}{L}\right) dx = B_n \frac{L}{2} \rightarrow A_B = \frac{2}{L}\int_0^L f(x)sin\left(\frac{2\pi nx}{L}\right) dx \quad (14)$$

$$\int_0^L f(x)dx = \int_0^L A_0 dx + \sum_{n=1}^{\infty} A_n \int_0^L cos\left(\frac{2\pi nx}{L}\right) dx + B_n \int_0^L sin\left(\frac{2\pi nx}{L}\right) dx \quad (15)$$

$$A_0 = \frac{1}{L}\int_0^L f(x)dx \quad (16)$$

$$f(t) = A_0 + \sum_{n=1}^{\infty} C_n \sin(nt + \Phi_n) \quad (17)$$

$$C_n = (A_n^2 + B_n^2)^{1/2} \quad (18)$$

$$\Phi_n = \tan^{-1}(B_n/A_n) \quad (19)$$

When examining the graphical method, the concept of symmetry arises. Initially, symmetries of the graphs need to be analyzed. The types of symmetry can be classified as: even function symmetry, odd function symmetry, half wave symmetry, quarter wave symmetry.

Even function symmetry is characterized by f(-x) = f(x) When the periodic wave folds to the left around the vertical axis, such that its right-sided curve aligns precisely with its left-sided curve, the function is said to exhibit even function symmetry. Odd function symmetry is defined by the property f(-t) = -f(t). When the curve on the right side of the vertical axis of a periodic wave fold around the axis horizontally (either upward or downward) in a manner that aligns with the curve on the left side, and the two segments coincide, the function is said to exhibit odd function symmetry. Half wave symmetry is defined by the property f (t + π) = - f(t). If a periodic function's half-period segment is shifted horizontally to the right or left by π units and, upon folding around the axis, the two curve segments coincide, then the function exhibits half-wave symmetry. If a periodic wave exhibits both half-wave symmetry and even-wave symmetry, it possesses quarter-wave symmetry. The Fourier series of such waves consists of cosine terms and odd harmonics (Arrillaga et al., 2003; Hart, 2011).

If the non-sinusoidal waveform is symmetrical, the formula that is in Eq. (20-21) is used to calculate its fundamental components and odd harmonics.

$$A_1 = \frac{2}{m}(y_1 \cos\theta_1 + y_2 \cos\theta_2 + \cdots + y_m \cos\theta_m) \quad (20)$$

$$B_1 = \frac{2}{m}(y_1 \sin\theta_1 + y_2 \sin\theta_2 + \cdots + y_m \sin\theta_m) \quad (21)$$

So, the final form of the equation for non-sinusoidal waves is in Eq. (22).

$$f(\theta) = A_1 cos\theta + \cdots + A_n cos(n\theta) + B_1 sin\theta + \cdots + B_n sin(n\theta) \quad (22)$$

While analyzing these waveforms, the graphical analysis method is employed. Initially, the graph divided into vertical and equal segments. Subsequently, the average value for each segment is determined and then these values are expressed as a sum of sine and cosine functions.

Total Harmonic Distortion (THD) is a parameter used to measure the impact of harmonic components in a signal. It is typically expressed as a percentage and can be calculated over current or voltage. A low THD value indicates a signal

with fewer harmonic distortions and a purer signal. Total Harmonic Distortion (THD) is calculated for voltage and current as in Eq. (23-24) (Esposito et al., 2010).

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \quad (23)$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (24)$$

Total demand distortion (TDD) examines the impact of current harmonics on the load that is in Eq. (25). The distortion power factor (PF_{THD}) is the ratio of true power to apparent power due to THD that is in Eq. (26). The total power factor (PF_{TOT}) is the product of the displacement power (PF) factor and the distortion power factor and is in Eq. (28) (Arrillaga et al., 2003; Hart, 2011).

$$TDD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_L} \quad (25)$$

$$PF_{THD} = \sqrt{\frac{1}{1+(THD)^2}} \quad (26)$$

$$PF = \frac{P}{S} = cos(\theta_v - \theta_i) = cos(\varphi) \quad (27)$$

$$PF_{TOT} = PF * PF_{THD} \quad (28)$$

2.2. Development of software

In this study, for the calculation and visualization of harmonically distorted signals, an application is proposed. The application can get the distorted signal parameters from the users both manually entering into the left side of the GUI (Graphical User Interface) of the application that is shown in Figure 1 and also uploading a CSV file by using "Load CSV" button that is top right side of the GUI. CSV file can be obtained from energy analyzers or some of the oscillators. With the parameters, application can plot harmonic components, distorted signal and harmonic spectrum, and it can also calculate THD and PF_{THD}. The users can understand and experience how harmonic distortion could affect the overall signal. Usage steps of the application algorithm as follows:

1. Start the program
2. Enter the harmonic and fundamental parameters in the respected tabs or load a CSV file via "Load CSV" button
3. If parameters are entered manually, press "Generate Harmonic Components" button to see all harmonic components in same time domain
4. Press "Generate Harmonics" to see the distorted signal
5. Press "Plot Harmonic Spectrum Button" to see the harmonic spectrum in bar chart form
6. Press "Calculate THD and PF(THD)" button to see total harmonic distortion and distortion power factor
7. If parameters will be obtained from CSV file, press "Load CSV" button to search the file from storage place
8. Press "Plot Signal From CSV" to see the distorted signal
9. Press "Plot Harmonic Spectrum From CSV" to see the harmonic spectrum in bar chart form
10. Press "Calculate THD and PF(THD) from CSV" to see total harmonic distortion and distortion power factor
11. Press "Clear" button to clear the tabs before entering the new parameters
12. Press "Exit" button to exit the program

In the application, according to entered parameters, harmonic components, distorted signal, and harmonic spectrum plotting are done and they are shown in Figure 2, Figure 3 and Figure 4 respectively. The application do the necessary calculation for THD and PF_{THD} up to 13th harmonic. 13th harmonic is chosen as a limit, because after that the effects of harmonics are relatively negligible. The application only uses odd harmonics, because in three phase systems even harmonics distortion effects are neglectable.

The application is developed in python programming language (Ari and Ustazhanov, 2014). Customtkinter graphical library is used for GUI, mathplotlib is used for signal plotting and pandas is used for data analysis from CSV file. The application is packaged into standalone executable by using Pyinstaller, to distribute to end users (Ari and Ustazhanov, 2014; Seetha et al., 2023). This tool serves as a practical learning aid to students, quick reference tool for engineers and visualization platform for understanding harmonic orders' distortion effect on the main signal. The future improvements

can be adding harmonic filter topologies, showing their effects on the system and filter recommendations based on distorted signal.



Figure 1. GUI of the Application

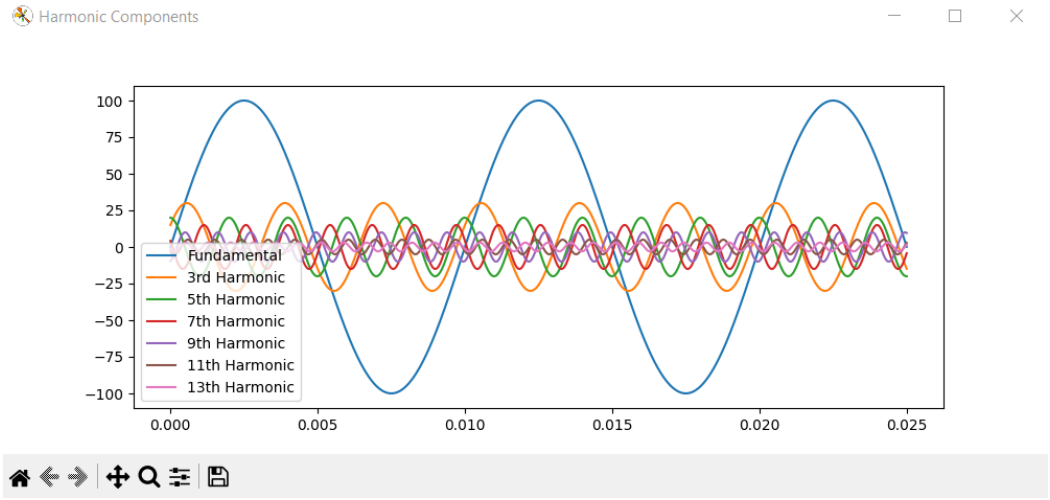

Figure 2. Harmonic Component Plotting

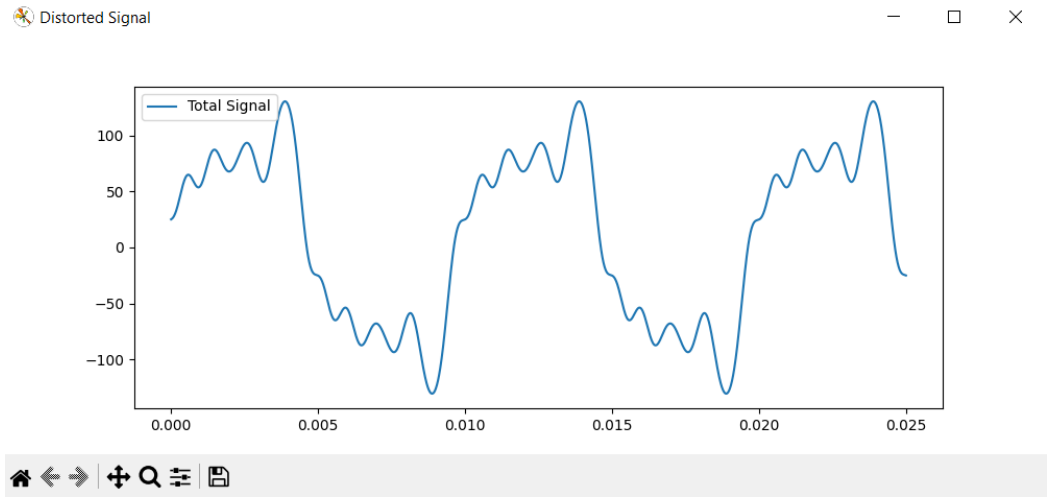

Figure 3. Distorted Signal Plotting

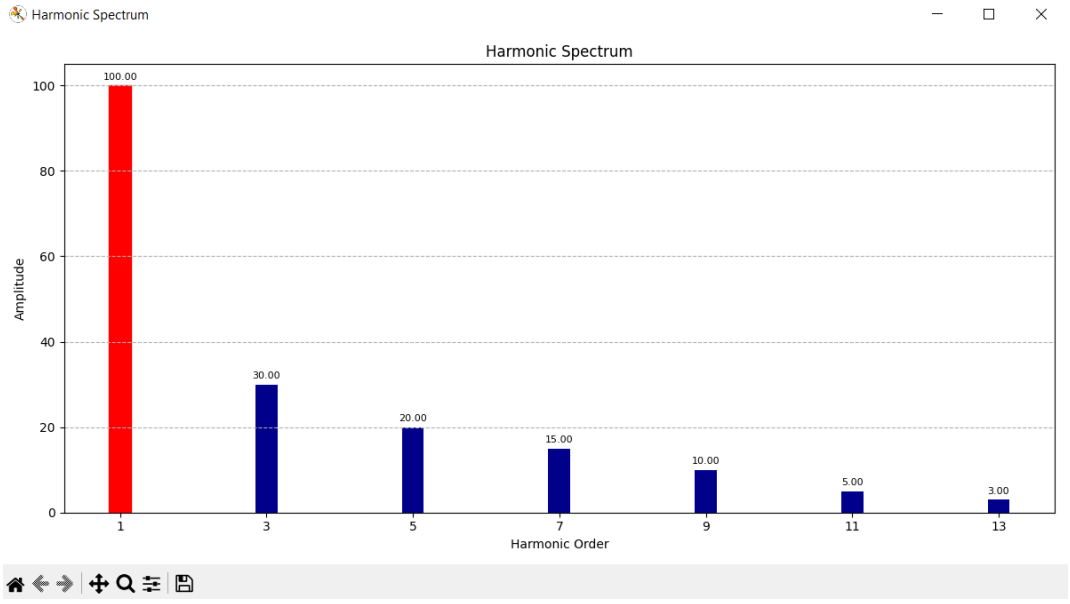

Figure 4. Harmonic Spectrum Plotting

3. DISCUSSION AND CONCLUSIONS

In this study, a comprehensive approach to the calculation and visualization of harmonic distortion in electrical signals has been presented, combining both theoretical part and practical software implementation. The theoretical part of the study covers definitions, causes and effects of harmonics on power quality. It supports these terms with Fourier series analysis and mathematical formulas.

To address these challenges, a Python-based software application was developed, enabling users to enter or import system parameters, visualize harmonic components, analyze waveform distortions, and calculate THD and PF_{THD}. The application has ability to plot results in both time and frequency domains, along with the ability to analyze harmonics up to 13th order. These features provide users with an effective tool for both educational and practical purposes. By featuring an intuitive GUI, the software bridges the gap between theoretical harmonic analysis and hands-on experimentation, making it accessible to a wide range of people, from students to engineers.

Overall, the developed tool and paper provide a deeper understanding of harmonic analysis. Future improvements of the application could be the integration of harmonic filtering modules, automated filter design suggestions, and advanced analysis for unbalanced and non-sinusoidal three-phase systems. These will enhance its utility in modern power system engineering.

REFERENCES

Ari, N. and Ustazhanov, M. (2014). Matplotlib in python. 2014 11th International Conference on Electronics, Computer and Computation (ICECCO), Abuja, Nigeria, pp. 1-6, doi: 10.1109/ICECCO.2014.6997585.

Arrillaga, J., Bradley, D.A., Bodger, P.S. (2003). Power System Harmonics, second ed. John Wiley & Sons, Norwich.

Carretero-Hernandez, A., Martin-Martinez, S., Artigao, E., Gomez-Lazaro, E. (2025). Current harmonic emission of string inverters based on cable length on a large grid-connected PV plant. International Journal of Electrical Power & Energy Systems, Volume 170, 110909, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2025.110909.

Ding, T., Chen, H., Wu, B. and Hu, P. (2018). Harmonic characteristics analysis of PWM-based electric vehicle chargers considering control strategy. 2018 18th International Conference on Harmonics and Quality of Power (ICHQP), Ljubljana, Slovenia, pp. 1-5, doi: 10.1109/ICHQP.2018.8378942.

Esposito, G., Foiadelli F., Roscia M. (2010). Impact of harmonic filters in MV distribution systems. Proceedings of 14th International Conference on Harmonics and Quality of Power - ICHQP 2010, Bergamo, Italy, pp. 1-4, doi: 10.1109/ICHQP.2010.5625362.

Hart, Daniel W., (2011). Power Electronics. McGraw-Hill Companies, Inc, New York.

IEEE Recommended Practice for Monitoring Electric Power Quality (2019). IEEE Std 1159-2019 (Revision of IEEE Std 1159-2009), vol., no., pp.1-98, doi: 10.1109/IEEESTD.2019.8796486.

Li, W., Wang, S., Tu, H., Miao, H., Jiao, N., Tianqi Liu, T. (2025). Utility harmonic impedance estimation based on time series clustering and improved Pettitt method. International Journal of Electrical Power & Energy Systems, Volume 170, 110935, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2025.110935.

Šćekić, L. and Mujović, S. (2022). Long-Term Harmonic Analysis of Grid-Connected Photovoltaic Systems. 2022 20th International Conference on Harmonics & Quality of Power (ICHQP), Naples, Italy, pp. 1-6, doi: 10.1109/ICHQP53011.2022.9808737.

Seetha, H., Tiwari, V., Anugu, K. R., Makka, S., Karnati, R., (2023). A GUI Based Application for PDF Processing Tools Using Python & CustomTkinter. International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 11, Issue I, ISSN: 2321-9653, https://doi.org/10.22214/ijraset.2023.48848

Shelar, S., Bankar, D. and Singh, P. K. (2024). Harmonic Measurement and Analysis in Manufacturing Industry: Case Study. 2024 21st International Conference on Harmonics and Quality of Power (ICHQP), Chengdu, China, pp. 463-467, doi: 10.1109/ICHQP61174.2024.10768848.

Xu, S., Tao, S. and Xu, Y. (2025). Secondary sideband harmonic emission characteristics of individual/multi-parallel grid-connected inverters. International Journal of Electrical Power & Energy Systems, Volume 170, 110816, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2025.110816.

Higher Education and Human Capital as a Catalyst for the Timber Industry: Evidence and Policy Pathways for Sustainable Economic Development in Kosovo

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Abstract: Kosovo's wood-processing and furniture industries have become increasingly visible within the country's manufacturing and export profile, especially after 2020, yet the sector remains constrained by persistent skills gaps, limited R&D capacity, and weak university–industry linkages. This paper examines how higher education and human capital policies can accelerate structural upgrading in Kosovo's timber-based value chain—from primary processing to higher value-added products—while aligning with sustainable forest governance and EU market requirements. The study synthesizes recent sector reports, national policy documents (2022–2030 forestry strategy and 2022–2024 action planning), and labor-market evidence on workforce demand and skills mismatch. The analysis highlights three interlocking constraints: (i) governance and legality challenges in the regional timber trade context, (ii) limited applied education and training pipelines for wood processing and furniture manufacturing, and (iii) insufficient innovation infrastructure that inhibits productivity, quality assurance, and export competitiveness. We propose an integrated policy framework focusing on curriculum modernization, practice-based education, dual training models, applied research co-financed with industry, and market compliance mechanisms (traceability, certification readiness). The paper concludes that higher education is not merely a supportive actor but a strategic lever for Kosovo's timber industry to scale productivity, expand exports, and strengthen sustainable economic development.

Keywords: Kosovo; Timber industry; Higher education; Skills mismatch; Wood processing; Sustainable development.

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1. INTRODUCTION

Human capital is widely recognized as a fundamental driver of economic growth, particularly in resource-based and manufacturing economies undergoing structural transformation. Endogenous growth theory emphasizes that education and knowledge accumulation increase productivity by enhancing innovation, technological adoption, and labor efficiency (Aghion & Howitt, 2009; Romer, 1990). In forest-based industries, these effects are particularly pronounced, as value creation depends not only on raw material availability but also on processing technologies, design capabilities, quality control, and market compliance (Nijnik & Weiss, 2017).

In the Western Balkans, forestry and timber industries have historically played an important role in rural employment and SME development. However, empirical studies indicate that weak governance structures, limited technological upgrading, and insufficient integration of education and industry have constrained competitiveness across the region (Glavonjić & Stevanović, 2021; UNECE & FAO, 2022). Kosovo exemplifies this pattern. Despite substantial forest resources, its timber industry remains heavily oriented toward fuelwood production and basic sawmilling, while higher value-added segments such as furniture manufacturing and engineered wood products remain underdeveloped.

This study investigates how higher education can support the structural upgrading of Kosovo's timber industry and contribute to sustainable economic development. The central research question is: How can higher education and human capital development enhance productivity, innovation, and export capacity in Kosovo's timber sector?

2. CONCEPTUAL BACKGROUND: HIGHER EDUCATION, HUMAN CAPITAL, AND FOREST-BASED INDUSTRIES

The relationship between higher education and industrial development has been extensively examined in the literature. Universities contribute to economic growth by supplying skilled labor, generating applied research, and facilitating knowledge transfer to industry (OECD, 2021). In forest-based economies, education in forestry, wood science, and industrial engineering is strongly associated with higher value-added production and improved resource efficiency (Nijnik et al., 2021).

Recent empirical studies show that countries investing in forestry-related higher education achieve significantly higher economic returns per unit of harvested wood due to better processing efficiency and product diversification

(Hurmekoski et al., 2019; Jonsson et al., 2021). Moreover, university–industry collaboration has been identified as a key mechanism for innovation diffusion in wood-based manufacturing, particularly in SMEs (Hansen et al., 2020).

From this perspective, higher education affects the timber industry through three main channels:

- Skills formation and workforce quality,
- Applied research and technological innovation,
- Institutional and market integration capacity, including sustainability and legality compliance.

3. HIGHER EDUCATION AND TIMBER-RELATED SKILLS IN KOSOVO

3.1 Institutional and educational context

Higher education in Kosovo is predominantly provided by public universities, with forestry and environmental studies embedded within broader academic structures. While these programs provide a theoretical foundation in natural resource management, recent assessments suggest that curricula remain insufficiently aligned with the technological and organizational needs of modern wood-processing industries (World Bank, 2022).

Sector-oriented studies emphasize that Kosovo's timber enterprises, largely SMEs, face difficulties in recruiting graduates with practical competencies in production planning, CAD/CAM systems, CNC operation, and quality management (FEGO, 2022). This reflects a broader skills mismatch, a phenomenon frequently observed in transition economies where education systems evolve more slowly than labor market demands (OECD, 2021).

Table 1. Key Skills Gaps in Kosovo's Timber Industry

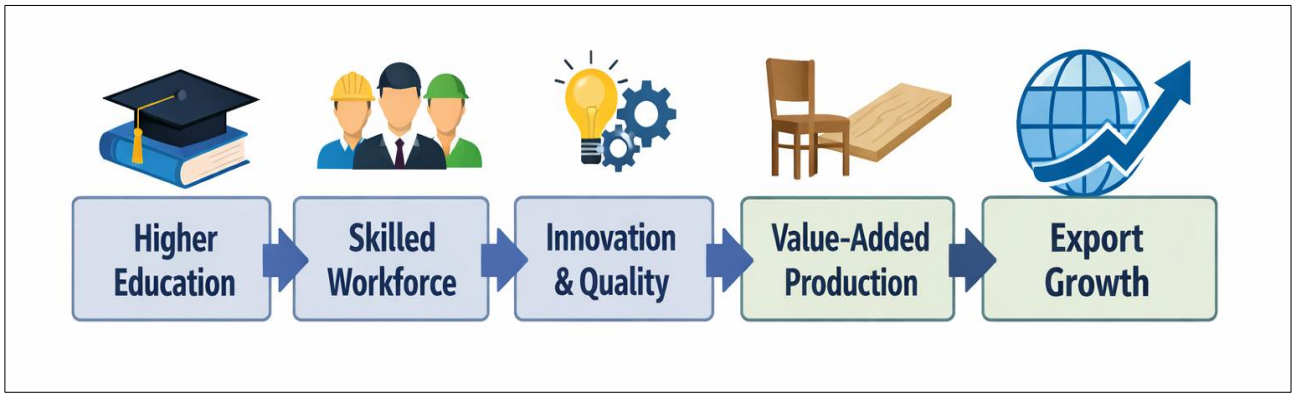
Skill domain	Observed deficiency	Economic impact
Wood processing technology	Limited process optimization skills	Low productivity, material losses
Furniture manufacturing	Insufficient design and CNC expertise	Weak value-added production
Quality & standards	Limited knowledge of certification and compliance	Restricted export access
Management & logistics	Weak cost control and planning	Reduced competitiveness

4. ECONOMIC ROLE OF THE TIMBER INDUSTRY AND HUMAN CAPITAL CONSTRAINTS

Empirical evidence from the Western Balkans suggests that timber and furniture industries can significantly contribute to manufacturing growth when supported by skilled labor and innovation capacity (Glavonjić & Stevanović, 2021). In Kosovo, recent macroeconomic analyses highlight furniture manufacturing as one of the more dynamic export-oriented subsectors, yet its overall contribution remains limited due to structural bottlenecks (European Commission, 2023).

High dependence on imports of finished wood products further illustrates the underutilization of domestic capabilities. Studies on forest-based bioeconomy development emphasize that without skilled engineers, designers, and technicians, countries remain locked into low-value segments of the value chain (Hurmekoski et al., 2019; Nijnik et al., 2021).

Figure 1. Higher Education–Industry Linkages in the Timber Sector



5. POLICY IMPLICATIONS: STRENGTHENING HIGHER EDUCATION FOR TIMBER INDUSTRY DEVELOPMENT

The literature strongly supports the view that coordinated education–industry policies are essential for upgrading forest-based industries (Hansen et al., 2020; OECD, 2021). For Kosovo, several policy priorities emerge:

- Modernization of forestry and wood science curricula with strong industry input,
- Expansion of practice-based learning, internships, and dual education models,
- Development of applied research laboratories for wood technology and product testing,
- Strengthening international academic cooperation (e.g., Erasmus+, Horizon Europe),
- Integration of sustainability, traceability, and legality assurance into education programs.

Such measures align with Kosovo's forestry development strategy and EU integration objectives, while directly addressing the human capital constraints limiting sectoral competitiveness.

6. CONCLUSION

This study demonstrates that higher education represents a critical yet underutilized lever for enhancing the economic contribution and long-term competitiveness of Kosovo's timber industry. Although the country benefits from substantial forest resources and a favorable ecological foundation, sustainable sectoral growth cannot be achieved through resource availability alone. Instead, it depends fundamentally on the development of skilled human capital, the strengthening of applied research capacity, and the establishment of effective and institutionalized linkages between higher education institutions and the timber industry.

The findings indicate that Kosovo's current timber industry structure remains largely concentrated in low value-added activities, such as primary processing and fuelwood production, which limits productivity, export capacity, and resilience against market fluctuations. In this context, higher education has the potential to function not merely as a supplier of labor, but as a strategic driver of industrial upgrading by supporting technological adoption, innovation, quality assurance, and compliance with international market standards. Practice-oriented curricula, dual education models, and applied research platforms can play a decisive role in bridging existing skills gaps and enhancing firm-level capabilities.

Repositioning higher education as an integral component of industrial and forestry policy would enable Kosovo to shift from a resource-based to a knowledge-based development trajectory within the timber sector. Such a transition would contribute to higher value-added production, increased export diversification, improved resource efficiency, and stronger alignment with sustainable forest management principles. Moreover, strengthening education–industry collaboration would generate positive spillover effects, including rural employment stabilization, SME development, and enhanced regional competitiveness.

From a policy perspective, the study underscores the need for coordinated strategies that integrate higher education reform, industrial upgrading, and forest governance. Future research could further enrich this analysis by incorporating firm-level productivity data, longitudinal assessments of education–industry cooperation, and comparative studies across Western Balkan economies. Overall, leveraging higher education as a strategic policy instrument offers Kosovo a viable pathway toward building a competitive, innovation-driven, and sustainable forest-based economy.

Ethics Committee Approval
N/A

Author Contributions
All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Aghion, P., & Howitt, P. (2009). The economics of growth. MIT Press.

European Commission. (2023). Kosovo progress report 2023. Brussels.

FEGO. (2022). Skills needs assessment of the furniture sector in Kosovo. Swisscontact / FEGO.

Glavonjić, B., & Stevanović, T. (2021). Forest-based industries in the Western Balkans: Structural challenges and development perspectives. Drvna Industrija, 72(3), 215–228. https://doi.org/10.5552/drvind.2021.2023

Hansen, E., Panwar, R., & Vlosky, R. (2020). The global forest sector: Changes, practices, and prospects. Forest Policy and Economics, 118, 102221. https://doi.org/10.1016/j.forpol.2020.102221

Hurmekoski, E., Jonsson, R., Nord, T., & Hetemäki, L. (2019). Educated workforce and innovation in the forest bioeconomy. Forest Policy and Economics, 101, 90–99. https://doi.org/10.1016/j.forpol.2019.01.003

Jonsson, R., Rinaldi, F., Pilli, R., Fiorese, G., Hurmekoski, E., & Cazzaniga, N. (2021). The role of education and skills in the forest-based bioeconomy. Sustainability, 13(9), 4891. https://doi.org/10.3390/su13094891

Nijnik, M., & Weiss, G. (2017). Forestry and the bioeconomy: Economic, environmental and social aspects. Forest Policy and Economics, 79, 1–3. https://doi.org/10.1016/j.forpol.2017.03.002

Nijnik, M., Nijnik, A., & Secco, L. (2021). Human capital and innovation in forest-based bioeconomy development. Forest Policy and Economics, 128, 102456. https://doi.org/10.1016/j.forpol.2021.102456

OECD. (2021). Higher education, skills and economic development. OECD Publishing.

Romer, P. M. (1990). Endogenous technological change. Journal of Political Economy, 98(5), S71–S102. https://doi.org/10.1086/261725

UNECE & FAO. (2022). State of Europe's forests 2022. United Nations.

World Bank. (2022). Kosovo: Education and skills for jobs. World Bank Group.

Drying Kinetics and Effective Moisture Diffusivity of Cactus Pear Slices at Different Thicknesses Using a Laboratory-Scale Infrared Dryer

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Abstract: In this study, the drying behaviour of cactus pear (*Opuntia ficus indica*) slices (2, 5, and 8 mm) was investigated using a laboratory-scale infrared (IR) drying device at a constant temperature of 70 °C. Moisture content (MC) values were recorded throughout the drying process, and drying times, effective moisture diffusivity coefficients, and thin-layer drying models were assessed. Drying time was significantly affected by the slice thickness. The total drying times were determined to be 65 ± 5 min for 2 mm slices, 115 ± 7 min for 5 mm slices, and 205 ± 10 min for 8 mm slices. The effective moisture diffusivity coefficients (D_{eff}) calculated using Fick's second diffusion law were (6.33 ± 0.08) × 10^{-11} m²/s for 2 mm, (1.96 ± 0.09) × 10^{-10} m²/s for 5 mm, and (2.84 ± 0.10) × 10^{-10} m²/s for 8 mm. Although the drying time increases with increasing thickness, the increase in D_{eff} values indicates that a higher driving force is generated for moisture transport in thicker samples.

The experimental MR data were applied to four common thin-layer drying models: Page, Midilli–Kucuk, Logarithmic, and Two-term. Among these models, the Midilli–Kucuk model was determined to be the most suitable, as it had the highest coefficient of determination ($R^2 > 0.999$) and the lowest root mean square error (RMSE < 0.01) for all thicknesses. While the Page and Logarithmic models represented the drying kinetics at an acceptable level, the two-term model showed parameter instability.

In conclusion, this study demonstrated that cactus pear slices can be effectively dehydrated using the infrared drying method and that the drying kinetics can be accurately represented using the Midilli–Küçük model. These findings highlight the potential of infrared drying for fruit processing applications.

Keywords: Cactus pear, infrared drying, thin-layer models, effective diffusion coefficient.

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1. INTRODUCTION

Prickly pear (*Opuntia ficus-indica*) is a fruit that grows in semi-arid regions and is notable for its high nutritional and bioactive compound content. However, due to its high moisture content, it tends to spoil quickly and has a limited shelf life. Therefore, drying processes that increase product stability by removing water are of great importance (Gouws et al., 2019).

Among drying technologies, infrared (IR) drying stands out due to its high energy efficiency, short processing time, and ability to preserve product quality. IR energy accelerates both heat and mass transfer by providing direct energy transfer to the food surface. Products dried using this method are generally reported to have better colour, aroma, and nutrient retention(Huang et al., 2021; Bouhile et al., 2025; Rajoriya et al., 2020).

Determining the kinetics of the drying process is critical for understanding the mechanism of moisture removal and for industrial design and optimization. For this purpose, thin-layer drying models (e.g., Page, Midilli–Küçük, Logarithmic, Two-term) are widely used (Kutlu et al., 2015; Goneli et al., 2017). Furthermore, the effective moisture diffusion coefficient (D_{eff}) value provides a quantitative expression of internal moisture transport and allows for the comparison of mass transfer behaviour between samples of different thicknesses (Ergün et al., 2016).

In this study, the drying behaviour of cactus fig slices of different thicknesses (2, 5, and 8 mm) at a constant temperature of 70 °C was investigated in a laboratory-type IR dryer. The moisture content values obtained from the experimental data were applied to various thin-layer drying models, and the most suitable model was determined. Furthermore, effective moisture diffusion coefficients were calculated using Fick's second law, and the effects of slice thickness on drying time and moisture transport were evaluated.

2. MATERIAL AND METHOD

2.1. Material

In this study, cactus fruit (Opuntia ficus-indica) was used as the raw material. The fruits were selected from ripe but unspoiled specimens and, after washing and cleaning, were directly subjected to drying experiments with intact skins. The seeds and peel were not separated, and the whole slices were evaluated with their natural structure preserved. The slices were prepared at three different thicknesses: 2, 5, and 8 mm. The thicknesses were measured using a digital calliper and standardized.

2.2 Drying Experiments

Drying processes were carried out using a laboratory-type infrared (IR) drying apparatus (Radwag MA 50R, Radwag Balances and Scales, Radom, Poland). The experiments were conducted at a constant temperature of 70 °C. In addition to the standard configuration of the device, a perforated metal grid designed by the researchers was used to ensure that the samples were exposed to IR radiation from both sides. This resulted in more homogeneous drying.
At the start of each experiment, the initial mass of the samples was weighed using a precision balance (±0.001 g). Weight changes during drying were recorded at specific time intervals using the device. The drying process was terminated based on the criterion of the sample's mass remaining constant (no difference between three consecutive measurements).

2.3 Mathematical Modelling

Thin-layer models, widely used in the literature to explain the drying kinetics of cactus fruit at different thicknesses, were employed (Table 1). During drying, the weights of the products were measured at specific intervals, and the time-dependent moisture ratio (MR) was determined using Eq. (1).

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad \text{Eq.(1)}$$

Here, MR denotes the dimensionless separable moisture ratio, M_t denotes the moisture value at any time t during the drying process (g water/g dry matter), M_i denotes the moisture value at the start of drying (t=0) (g water/g dry matter), and M_e denotes the equilibrium moisture content value (g water/g dry matter). The M_e value is considered to be 0 because it is quite small compared to the M_t and M_i values, and the drying time is long (Karacabey et al., 2016).

Table 1. Thin-layer drying models describing experimental drying data

Model	Equation	Reference
Page	$MR = \exp(-b*t^n)$	Page, 1949
Logarithmic	$MR = a*\exp(-b*t)+c$	Wang ve ark., 2007
Midilli-Kucuk	$MR= a*\exp(-b*t^n)+c*t$	Midilli ve ark., 2002
Two-term	$MR= a*\exp(-b*t)+c*\exp(-g*t)$	Henderson, 1974

MR: Moisture ratio, t: Time (min), a, b, c, n, g: Model parameters

2.4 Effective Diffusion Coefficient

Fick's second diffusion equation was used to calculate the effective diffusion coefficients (D_{eff}) (Crank, 1975). This is shown in Eq. (2). During the calculations, it was assumed that the diffusion coefficients were constant and that the banana slices had an infinite plate geometry and a homogeneous initial moisture distribution (Doymaz, 2007).

$$\frac{Mt - M_e}{M_i - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-(2n+1)^2 \pi^2 D_{eff} \left(\frac{t}{4L^2}\right)\right) \quad \text{Eq. (2)}$$

Here, L denotes the half-thickness of the product (m), D_{eff} denotes the effective diffusion coefficient (m^2/s), M_e denotes the equilibrium moisture content (g water/g dry matter), M_i denotes the initial moisture content (g water/g dry matter), M_t denotes the moisture value at any time t (g water/g dry matter), and t denotes the time (s) (Azoubel et al., 2010).

2.5 Statistical Analysis

The Root Mean Square Error (RMSE) and R^2 values were examined using the MATLAB R2015a program to determine the agreement between the experimental data recorded during drying and the data predicted by the thin-layer models used for modelling. The calculation of these values is given in Equations 3 and 4.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pred,i} - MR_{exp,i}\right)^2} \quad \text{Eq. (3)}$$

$$R^2 = \frac{\sum_{i=1}^{N}(MR_i - MR_{pred,i}) \times \sum_{i=1}^{N}(MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^{N}(MR_i - MR_{pred,i})^2\right] \times \left[\sum_{i=1}^{N}(MR_i - MR_{exp,i})^2\right]}} \quad \text{Eq. (4)}$$

Here, $MR_{exp,i}$ denotes the experimental separable moisture content, $MR_{pred,i}$ denotes the predicted separable moisture content, MR_i denotes the separable moisture content at any given time, and N denotes the total number of weight measurements.

3. RESULTS AND DISCUSSIONS

The time-dependent change in experimental MR values of cactus fruit slices is shown in Figure 1. The thin-layer drying modelling results are presented in Table 2. The Midilli-Kucuk model was determined to be the best model to explain the drying behaviour of cactus fruit slices with thicknesses of 2, 5, and 8 mm, with the lowest RMSE and highest R-squared values. The Midilli–Kucuk model provided the best fit, consistent with previous studies reporting its high performance in modelling the infrared drying behaviour of fruits (Puente-Diaz et al., 2020; Lahsasni et al., 2004)

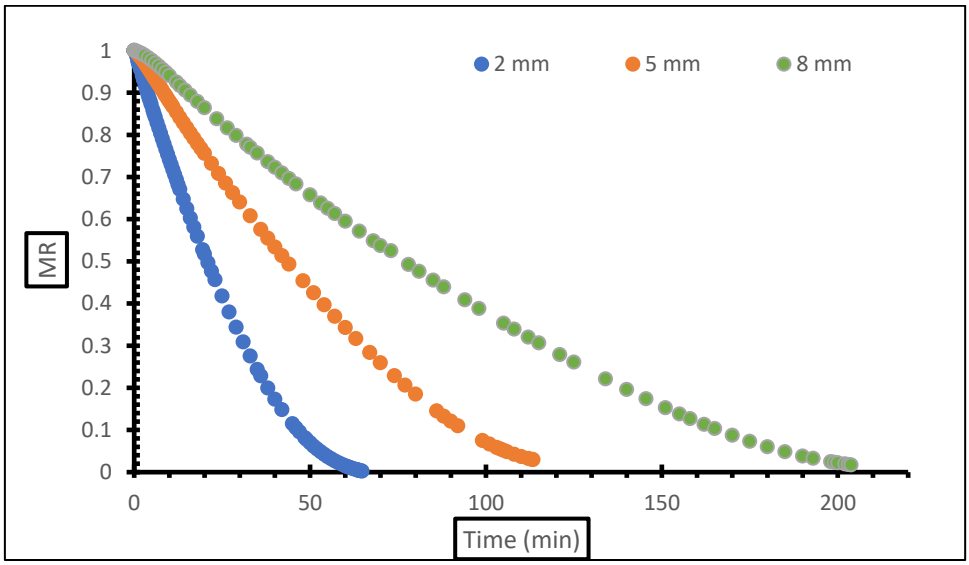

Figure 1. MR changes depending on time during the drying process of cactus fruit slices at different thicknesses

Table 2. Thin-layer modelling results

Model	Cactus fruit thickness	Model parameters	R^2	RMSE
Page	2 mm	b = 0,01272 n = 1,345	0,9956	0,024
	5 mm	b = 0,00503 n = 1,328	0,9960	0,022
	8 mm	b = 0,00198 n = 1,364	0,9950	0,024
Logarithmic	2 mm	a = 1,293 b = 0,0255 c = -0,2713	0,9986	0,014
	5 mm	a = 1,503 b = 0,0098 c = -0,4861	0.9995	0,008
	8 mm	a = 1,512 b = 0,0055 c = -0,4945	0,9995	0,008
Midilli-Kucuk	**2 mm**	**a = 0,9865 b = 0,0153 c = -0.0013 n = 1,23**	**0,9995**	**0,009**
	5 mm	**a = 0,9986 b = 0,0074 c = -0,0013 n = 1,165**	**0,9998**	**0,005**
	8 mm	**a = 1,003 b = 0,0042 c = -0,00078 n = 1,142**	**0,9998**	**0,005**
Two Term	2 mm	a = 24,03 b = 0,0739 c = -23,03 g = 0,0764	0,9956	0,025
	5 mm	a = 6,948 b = 0,0073 c = -5,914 g = 0,0059	0,9989	0,012
	8 mm	a = -0,065 b = 40,26 c = 1,065 g = 0,0112	0,9793	0,051

The experimental MR values of 2, 5, and 8 mm cactus fruit slices and the time-dependent changes in MR values predicted by the Midilli-Kucuk model are shown in Figures 2, 3, and 4, respectively.

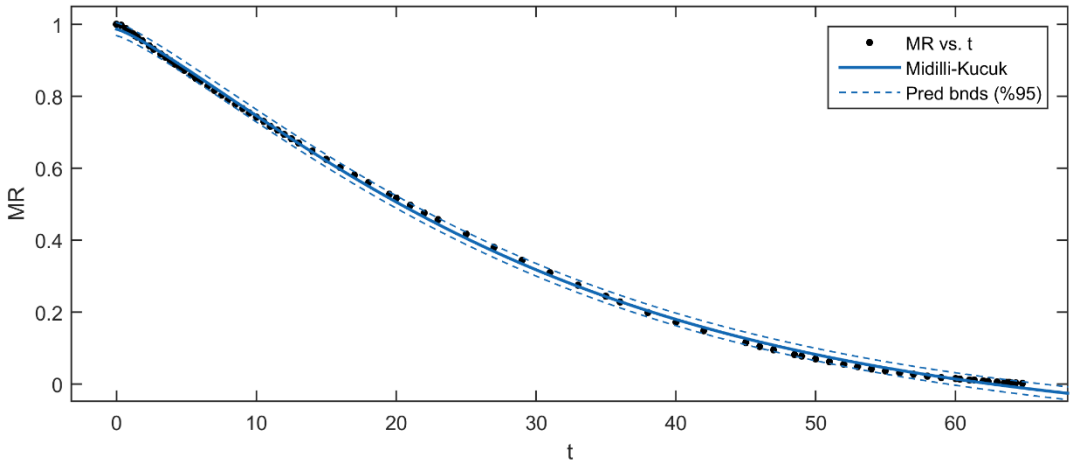

Figure 2. Change in MR values over time (min) for 2 mm cactus fruit slices, as predicted by experimental MR and Midilli-Kucuk model.

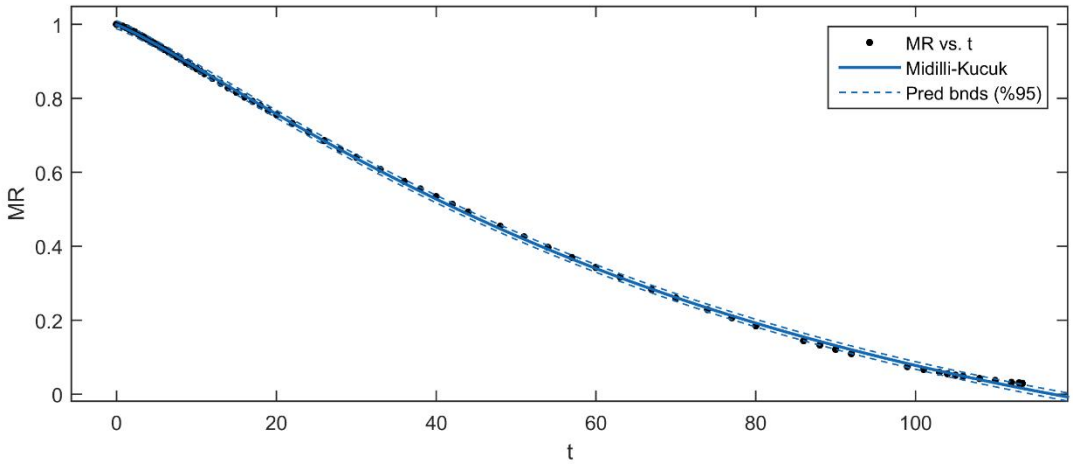

Figure 3. Change in MR values over time (min) for 5 mm cactus fruit slices, as predicted by experimental MR and Midilli-Kucuk model.

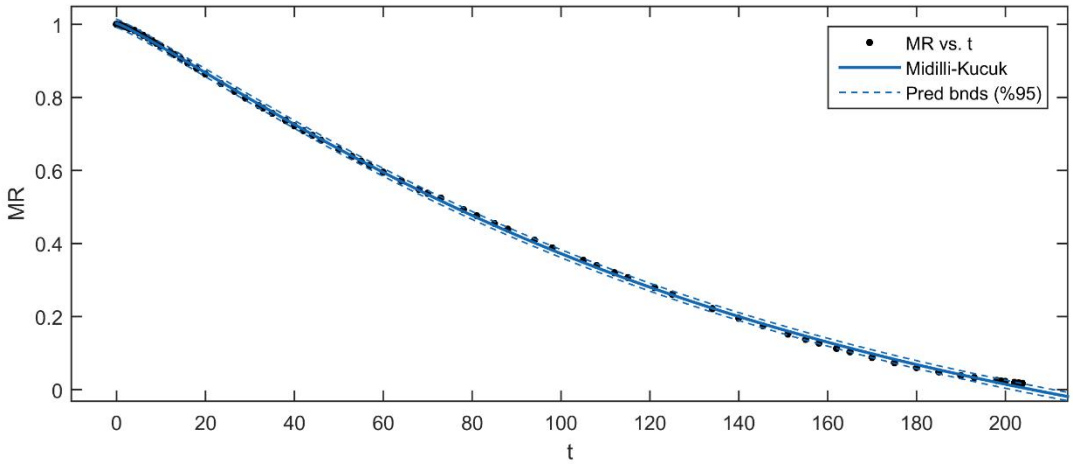

Figure 4. Change in MR values over time (min) for 8 mm cactus fruit slices, as predicted by experimental MR and Midilli-Kucuk model.

The effective diffusion coefficients and drying times for the drying processes were calculated and are listed in Table 3. As shown in Table 3, drying time increased markedly with increasing slice thickness, while the calculated effective moisture diffusivities (D_{eff}) also rose. This trend suggests that thicker slices develop stronger internal moisture gradients, which enhance moisture transport. Similar observations were made in recent studies: for example, Kamble et al. (2022) reported that the effective diffusivity of banana slices (2–8 mm) increased with thickness under isothermal drying conditions. Moreover, in infrared-convective drying of food slices, El-Mesery et al. (2025) found that the Midilli–Kucuk model yielded the highest coefficient of determination and lowest error metrics, and that drying time increased with slice thickness.

Table 3. Effective diffusion coefficients and drying times of cactus fruit slices

Slice thickness (mm)	Drying time (min)	Effective diffusivity (m^2/s)
2	65 ± 5	$(6.33 \pm 0.08) \times 10^{-11}$
5	115 ± 7	$(1.96 \pm 0.09) \times 10^{-10}$
8	205 ± 10	$(2.84 \pm 0.10) \times 10^{-10}$

4. CONCLUSIONS

This study demonstrated that infrared drying is a reliable and efficient technique for dehydrating cactus pear slices. Increasing the slice thickness from 2 mm to 8 mm prolonged the total drying time (65 to 205 minutes), while the effective moisture diffusivity (D_eff) also increased from 6.33×10^{-11} m^2/s to 2.84×10^{-10} m^2/s. This relationship indicates that thicker samples develop stronger internal moisture gradients, which promote moisture migration during drying.

Among the four thin-layer models examined, the Midilli–Küçük model provided the most accurate fit for all thickness levels ($R^2 > 0.999$, RMSE < 0.01), confirming its suitability for describing infrared drying kinetics of cactus pear slices.

In summary, infrared drying offers a fast, energy-efficient, and quality-preserving method for producing dried cactus pear products. Future investigations could focus on optimizing infrared parameters or combining IR with hybrid techniques (such as IR-vacuum or IR-microwave drying) to enhance process efficiency and maintain the nutritional and sensory quality of the final product.

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All authors have read and agreed to the published version of the manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Azoubel, P. M., Baima, M. D. A. M., da Rocha Amorim, M., & Oliveira, S. S. B. (2010). Effect of ultrasound on banana cv Pacovan drying kinetics. *Journal of Food Engineering*, *97*(2), 194-198. https://doi.org/10.1016/j.jfoodeng.2009.10.009

Bouhile, Y., Guo, Y., Wu, B., Dai, J., Song, C., Pan, Z., & , H. (2025). Research progress in the application of infrared blanching in fruit and vegetable drying process.. *Comprehensive reviews in food science and food safety*, 24 1, e70103 . https://doi.org/10.1111/1541-4337.70112.

Crank, J. (1975). The mathematics of diffusion (2nd ed) Oxford University Press, London. https://doi.org/10.1115/1.3245200

Doymaz, I. (2007). Air-drying characteristics of tomatoes. *Journal of Food engineering*, *78*(4), 1291-1297. https://doi.org/10.1016/j.jfoodeng.2005.12.047

El-Mesery, H. S., ElMesiry, A. H., Hu, Z., Zhang, X., & Quaye, E. K. (2025). Modeling and Optimization of Infrared-Convection Drying Parameters and Slice Thickness of Onion Slices: Effects on Drying Kinetics and Physicochemical Quality. *Food Science & Nutrition*, *13*(6), e70437.

Ergün, K., Caliskan, G., & Dirim, S. (2016). Determination of the drying and rehydration kinetics of freeze dried kiwi (Actinidia deliciosa) slices. *Heat and Mass Transfer*, 52, 2697 - 2705. https://doi.org/10.1007/s00231-016-1773-x.

Goneli, A., Araujo, W., Filho, C., Martins, E., & Oba, G. (2017). DRYING KINETICS OF PEANUT KERNELS IN THIN LAYERS. *Engenharia Agricola*, 37, 994-1003. https://doi.org/10.1590/1809-4430-eng.agric.v37n5p994-1003/2017.

Gouws, C., D'Cunha, N., Georgousopoulou, E., Mellor, D., & Naumovski, N. (2019). The effect of different drying techniques on phytochemical content and in vitro antioxidant properties of Australian-grown prickly pears (Opuntia ficus indica). *Journal of Food Processing and Preservation*. https://doi.org/10.1111/jfpp.13900.

Henderson, S.M. (1974). Progress in developing the thin layer drying equation.Trans. ASAE. 17:1167–1172.

Huang, D., Yang, P., Tang, X., Luo, L., & Sundén, B. (2021). Application of infrared radiation in the drying of food products. *Trends in Food Science and Technology*, 110, 765-777. https://doi.org/10.1016/j.tifs.2021.02.039.

Karacabey, E., Baltacioglu, C., Cevik, M., & Kalkan, H. (2016). Optimization of microwave-assisted drying of Jerusalem Artichokes (Helianthus tuberosus L.) by Response Surface Methodology and Genetic Algorithm. Italian Journal of Food Science, 28(1), 121-130. https://doi.org/10.14674/1120-1770/ijfs.v466.

Kamble, M. G., Singh, A., Kumar, N., Dhenge, R. V., Rinaldi, M., & Chinchkar, A. V. (2022). Semi-empirical mathematical modeling, energy and exergy analysis, and textural characteristics of convectively dried plantain banana slices. *Foods*, *11*(18), 2825.

Kutlu, N., İşcİ, A., & DemİrkoI, Ö. Ş. (2015). Thin layer drying models in food systems.

Lahsasni, S., Kouhila, M., Mahrouz, M., Idlimam, A., & Jamali, A. (2004). Thin layer convective solar drying and mathematical modeling of prickly pear peel (Opuntia ficus indica). *Energy*, *29*(2), 211-224.

Midilli, A., Kucuk, H., & Yapar, Z. (2002). A new model for single-layer drying. *Drying technology*, *20*(7), 1503-1513. https://doi.org/10.1081/DRT-120005864

Page, G. E. (1949). Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin layers. Purdue University. https://www.proquest.com/dissertations-theses/factors-influencing-maximum-rates-air-drying/docview/301817819/se-2?accountid=14141

Puente-Díaz, L., Spolmann, O., Nocetti, D., Zura-Bravo, L., & Lemus-Mondaca, R. (2020). Effects of Infrared-Assisted Refractance Window™ Drying on the Drying Kinetics, Microstructure, and Color of *Physalis* Fruit Purée. *Foods*, *9*(3), 343. https://doi.org/10.3390/foods9030343.

Rajoriya, D., Shewale, S., Bhavya, M., & Hebbar, H. (2020). Far infrared assisted refractance window drying of apple slices: Comparative study on flavour, nutrient retention and drying characteristics. *Innovative Food Science and Emerging Technologies*, 66, 102530. https://doi.org/10.1016/j.ifset.2020.102530.

Wang, Z., Sun, J., Liao, X., Chen, F., Zhao, G., Wu, J., & Hu, X. (2007). Mathematical modeling on hot air drying of thin layer apple pomace. *Food Research International*, *40*(1), 39-46. https://doi.org/10.1016/j.foodres.2006.07.017

An Innovative Global Filter for Seismic Reflection Data Based on Frequency Decomposition

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Abstract: Enhancing noise filtering and the quality of seismic imaging remains a central objective in seismic data processing. It continues to face major challenges, particularly in improving the signal-to-noise ratio SNR, preserving the integrity of wavelets, and enhancing the resolution of seismic horizons. We propose a novel global filtering approach for seismic reflection signals, based on a new conceptual framework and an innovative computational method. This method enables the direct extraction of reflected wavelets by addressing the problem from a different perspective. The developed filter is specifically designed to isolate seismic wavelet traces with their true amplitudes by eliminating multiple forms of noise-including both coherent (organized) and incoherent (random) noise as well as spikes, multiples, and interferences. The algorithm operates in the time-space (t-x) domain, applied to a small number of adjacent seismic traces within a moving window. This sliding window sweeps across all offsets, from the nearest to the farthest, enabling wavelet processing with amplitude preservation. Applications of the proposed method to both synthetic and real seismic datasets have demonstrated its significant potential and effectiveness.

Keywords: Wavelet, Noises, Multiples, Interferences, Frequency Decomposition, De-blending.

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1. INTRODUCTION AND PROBLEM STATEMENT

In this section, the work topic should be stated in the previous work on the subject, the purpose of working with the relevant references supported. The entire article will be written in Times New Roman in 10 pt with a single line spacing. The development of effective seismic noise attenuation techniques is a key objective in modern seismic data processing However, improving the signal-to-noise ratio SNR and attenuating strong random noise while preserving wavelets remains a major challenge in enhancing the quality of seismic imaging in geophysics. The development and refinement of noise filtering techniques continue to be a central concern in seismic data processing, as they are essential for increasing SNR, preserving wavelet integrity, and improving the resolution of seismic horizons. These advances enable wavelet processing with preserved amplitudes.

Seismic data filtering is often a limiting factor in extracting meaningful geological information during exploration, development, and interpretation. Noise can mask or distort valid seismic signals, making it crucial to apply appropriate filtering methods during seismic data processing to effectively attenuate such disturbances.

In practice, specific filters are usually applied to target specific types of noise. As a result, we use many filters separately in the processing sequence to attenuate different types of noise such as random noise, spikes, airwaves, ground roll, multiples, and various interferences (Yilmaz Özdoğan and Stephen M. Doherty, 2001 ; Thomas Elboth et al, january 2008).

The innovative approach proposed in this study aims to comprehensively and efficiently filter seismic data by addressing various forms of noise including both coherent (organized) and incoherent (random) noise, spikes, multiples, and interferences.

This innovative method enables the extraction of reflected wavelet series with their true amplitudes by applying the filter in the time-space (t-x) domain to a small set of adjacent seismic traces. Although the traces within a Common Depth Point (CDP) gather are recorded at different spatial positions and acquisition times, they share the same consistent seismic reflection information (wavelets).

The method extracts a common reflected trace within a small analysis window that moves and sweeping through all offset displacements from the nearest to the farthest along the CDP gather. This process ensures amplitude preservation during wavelet extraction.

To evaluate the effectiveness of the proposed approach, we first apply it to synthetic seismic data contaminated with various types of noise and interferences. Subsequently, it is tested on real seismic datasets.

2. THEORY AND METHOD

In a CDP gather, seismic traces are collected from different recorded sources. By comparing adjacent traces within the CDP gather, we can extract their common frequency components, which represent the shared wavelet series present in each trace.

The method operates in the t-x domain and is applied to a group of neighboring traces within a moving window. This window sequentially sweeps across offsets, from the nearest to the farthest (see figure 1), enabling the isolation of consistent wavelet components while filtering out noise.

The comparison of neighboring traces enables the extraction of their common reflected wavelet trace.

The process is primarily based on decomposing each seismic trace into elementary frequency components using mathematical tools such as the Fourier Transform (Robinson E. A., and Treitel, S., 1964; Oppenheim A. V., and Schafer, R. W., 1975; Oppenheim, A.V. et al, 2001).

This is followed by matrix operations to compute a separation operator, which isolates the filtered signal. This method preserves the amplitudes of the shared frequency components and removes unrelated noise elements for each wavelet (Ladjadj, Y. et al, 2025).

Neighboring traces are compared while being sorted by absolute offset. Since the frequency content varies between near and far offsets - due to absorption effects - far offset wavelets tend to be more stretched after dynamic corrections. To prevent wavelet degradation during filtering, a comparison rate parameter is introduced into the filtering algorithm. This parameter helps maintain the original frequency content of each wavelet.

As illustrated in figure 1, an example involves six neighboring traces - three from the left and three from the right - spaced such that the distance covered by three traces on either side equals two inter-trace intervals (i.e., 50 meters total).

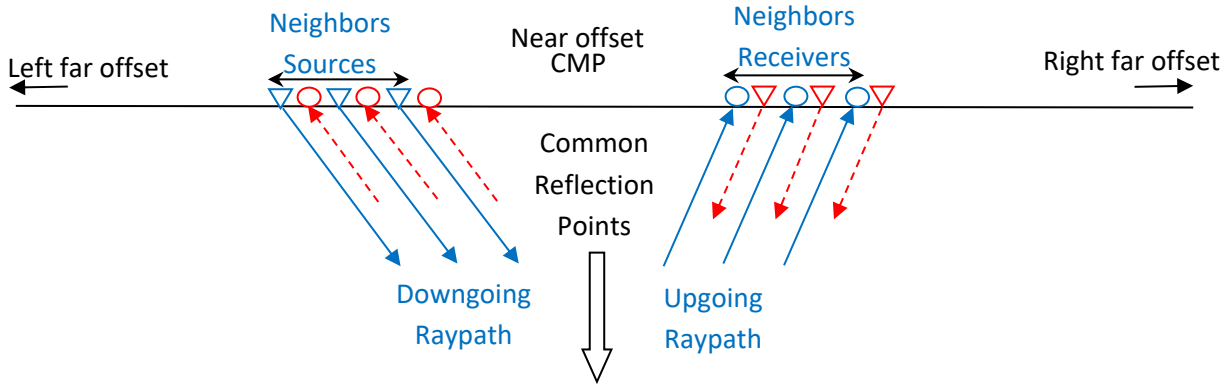

Figure 1. Neighboring traces with the same offset class arriving from both left and right sides.

A small group of neighboring traces - three from the left and three from the right - is used as an example. The spatial distance they occupy is relatively small, which ensures that they share similar surface conditions and acquisition characteristics. However, the recorded noise varies from one trace to another.

By sweeping across all offset displacements in small sequential steps, the method preserves the amplitude of the wavelets during processing.

Although the traces do not share identical surface characteristics, their reflections are sorted by absolute offset, which justifies the application of a common processing solution (figure 2). Comparing these traces enables the extraction of a common trace that represents the reflectivity series.

The effectiveness of the proposed technique is demonstrated through its application on simulated synthetic seismic data, followed by tests on real seismic data that have already undergone static and dynamic corrections.



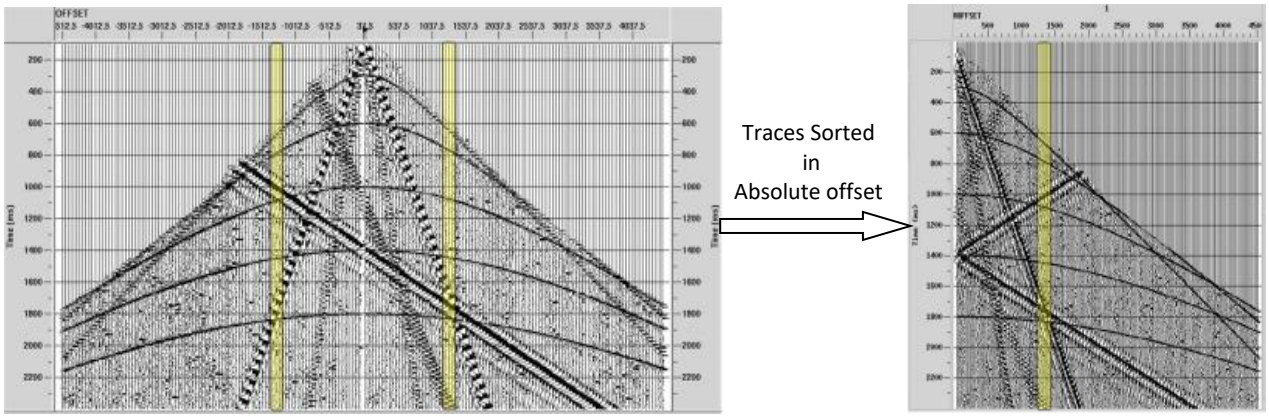

Figure 2. Noisy CDP gather traces sorted from offset to Absolute offset.

3. APPLICATION

To evaluate the effectiveness of the proposed filter, the technique is applied to both synthetic and real seismic datasets.

3.1 Synthetic data

A synthetic CDP gather contaminated with various types of noise was selected. To construct this test model, three primary reflections were first generated, as illustrated in figure 3.

Subsequently, two multiple reflections corresponding to the first and second primary events were added, along with spike noise, random noise, airwaves, ground roll, and linear interferences characterized by varying dips and frequency contents (see figure 3).

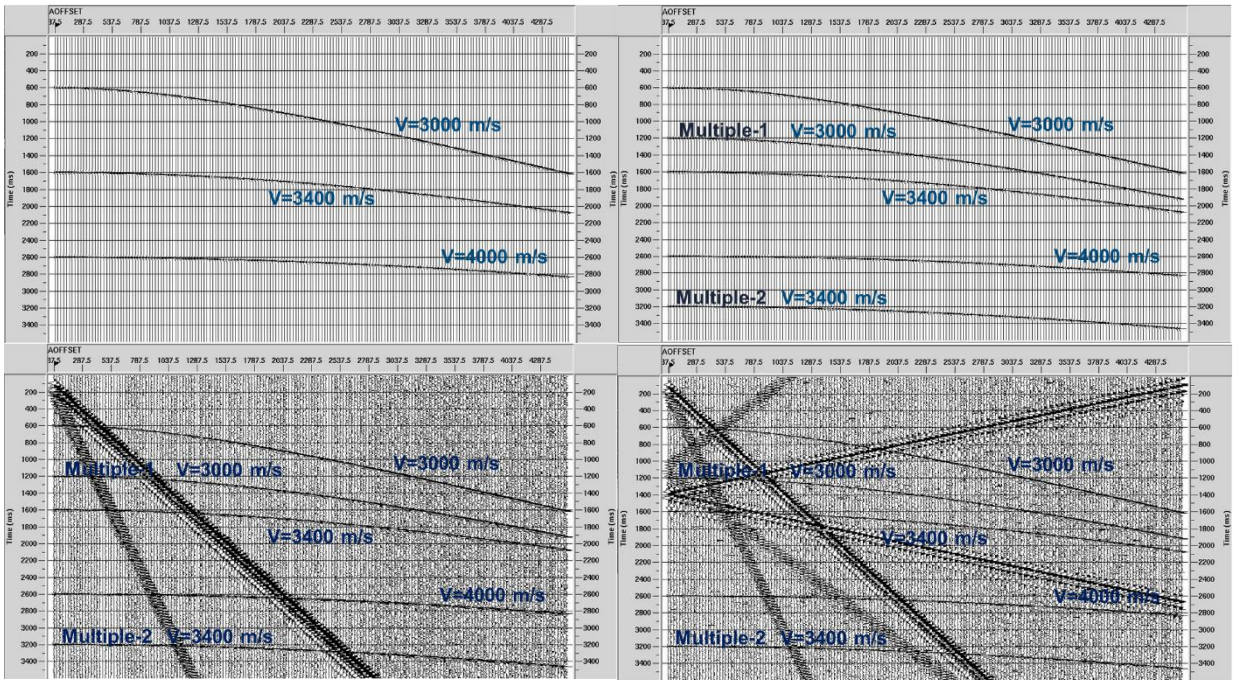

Figure 3. Synthetic CDP gather shows Reflections, Multiples, Random noise, spikes, airwave, ground roll and linear interferences with different deeps and frequencies levels.

In general, specific filters are applied to target and remove particular types of noise. As a result, multiple filters are often used separately throughout the seismic data processing sequence to attenuate various types of noise, such as spikes, airwaves, ground roll, random noise, multiples, and linear interferences. That there is no single algorithm that can remove all types of noise from seismic gathers (Thomas Elboth et al, january 2008).

In the proposed approach, adjacent traces are compared after frequency decomposition within a moving analysis window. By using a CDP gather, traces recorded from different source positions are selected. The comparison of these traces within

the CDP gather allows for the extraction of common frequency components, which are represented by the wavelet series of each trace.

The potential of the proposed technique is demonstrated through its application on a simulated synthetic seismic CDP gather. Normal Moveout (NMO) correction is applied prior to filtering. The filtered result, obtained using a narrow moving window, is illustrated in figure 4.

A comparison of the synthetic seismic model's frequency amplitude spectrum before and after the filter application is performed. The quality control (QC) is carried out by analyzing the difference between the noisy input and the filtered CDP gathers.

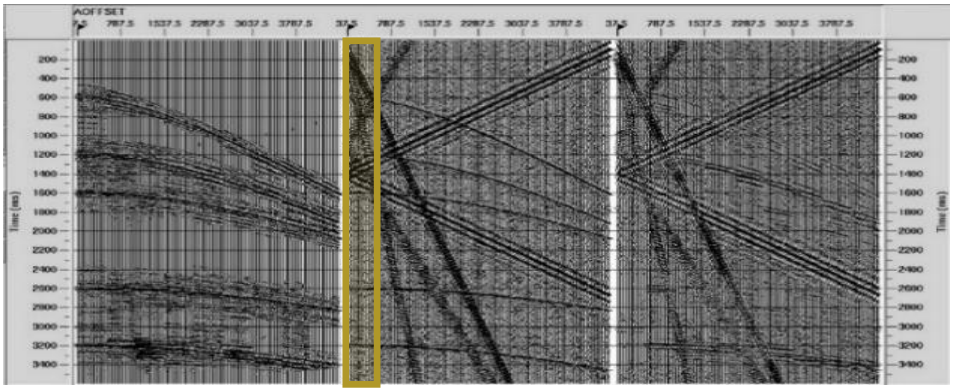

Figure 4. Input & Filtred CDP Gathers & difference between Noisy Input and filtered CDP gathers using narrow window

The window width is progressively increased at each iteration, starting from a narrow window and extending up to the full length of the CDP gather, as illustrated in figures 4, 5 and 6.

Within each window, the algorithm compares neighboring traces and separates the frequency components of the reflected wavelet from those associated with noise. The amplitude and phase of the wavelet are preserved throughout the process (see figures 4, 5 and 6).

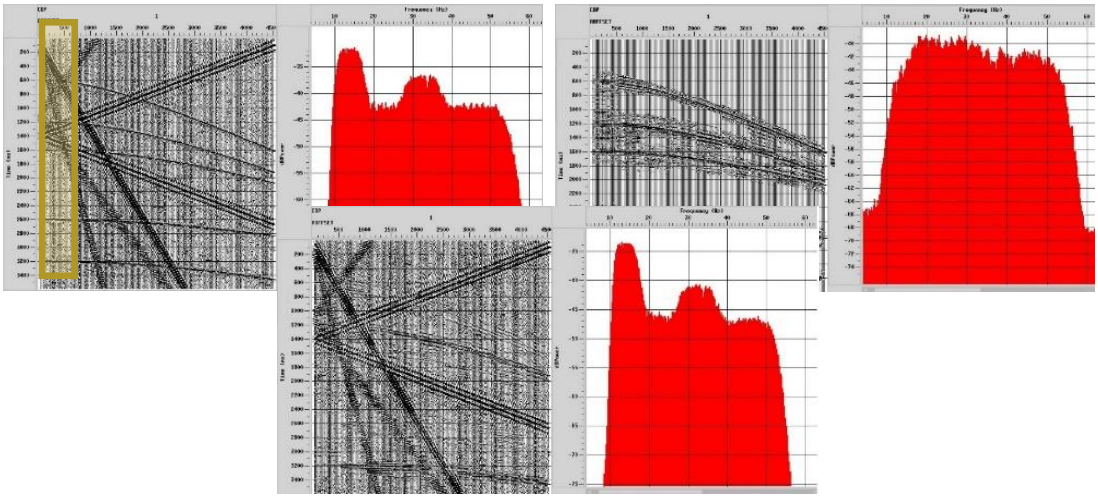

Figure 5. Synthetic seismic CDP gather and its frequency amplitude spectrum:
Noisy Input**,** Filtred and the Difference between them.

The frequency bandwidth varies between near and far traces due to absorption effects, and wavelets at far offsets tend to be stretched after dynamic corrections. To prevent wavelet distortion during the filtering process, a comparison rate parameter is introduced into the filtering algorithm. This parameter helps preserve the frequency content of each wavelet, as illustrated in figure 7.

A wide window allows comparison of all traces together using a 70% comparison ratio, whereas a narrow window focuses on comparing closely neighboring traces (see figure 7).

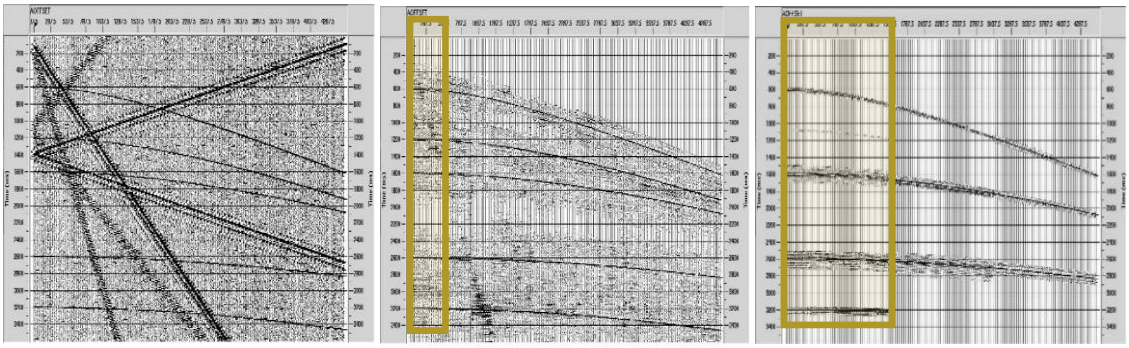

Figure 6. Filtered input using different window size.

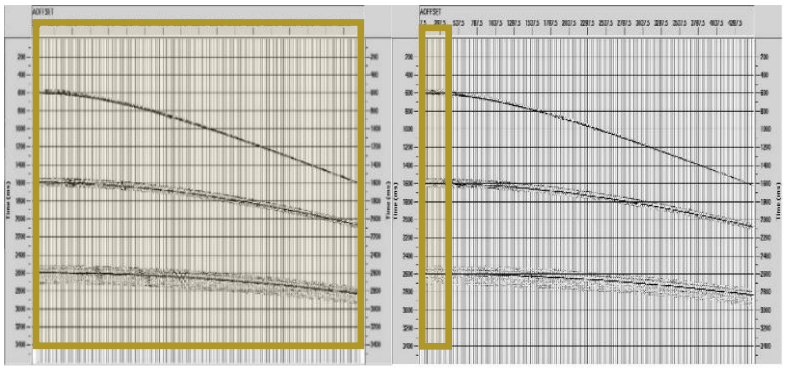

Figure 7. Wide window with reduce comparison ratio applied of 70% and a Narrow window with total comparison.

The algorithm compares neighboring traces within the moving window inside the CDP gather, and separates the frequency components of the reflected wavelet from those of unwanted signals, while preserving the wavelet's amplitude and phase.

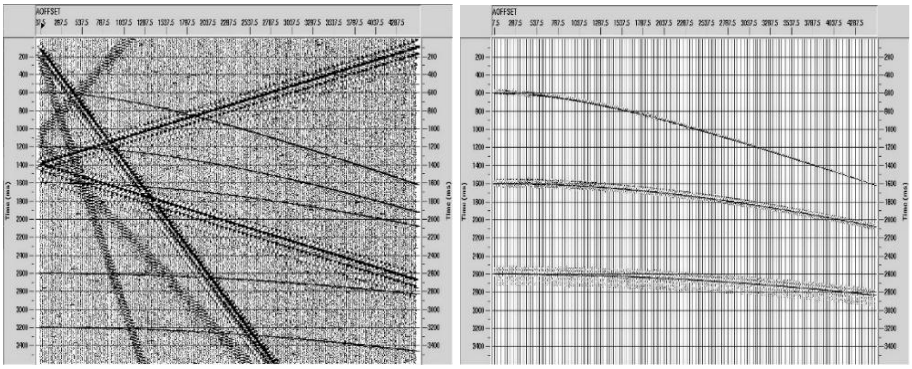

Figure 8. Noisy and Filtered Synthetic CDP gathers sorted in Absolute Offset before and after filter application (two iterations using wide & narrow windows)

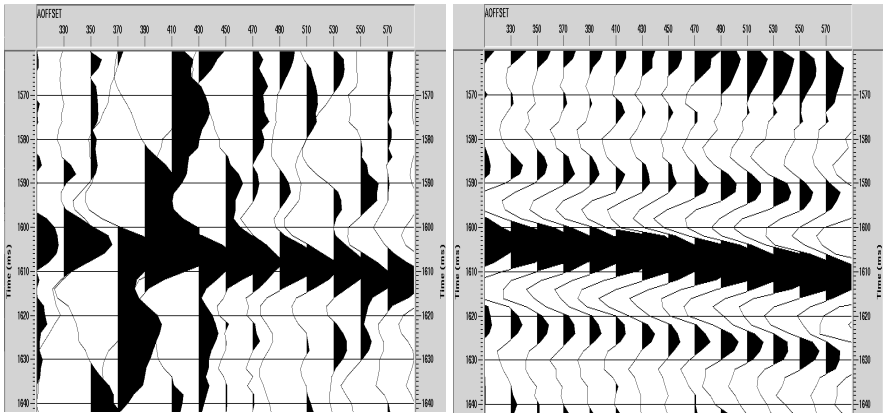

Figure 9. Wavelets form recuperation before and after filter application on the synthetic CDP gather

3.2 Real data

The proposed method was applied to real seismic data contaminated by several strong types of noise. The method successfully attenuated the noise while preserving the amplitude of the seismic signal, as illustrated in figure 10. Figure 10 shows the real data before and after filter application, displayed using individual-trace scaling mode.

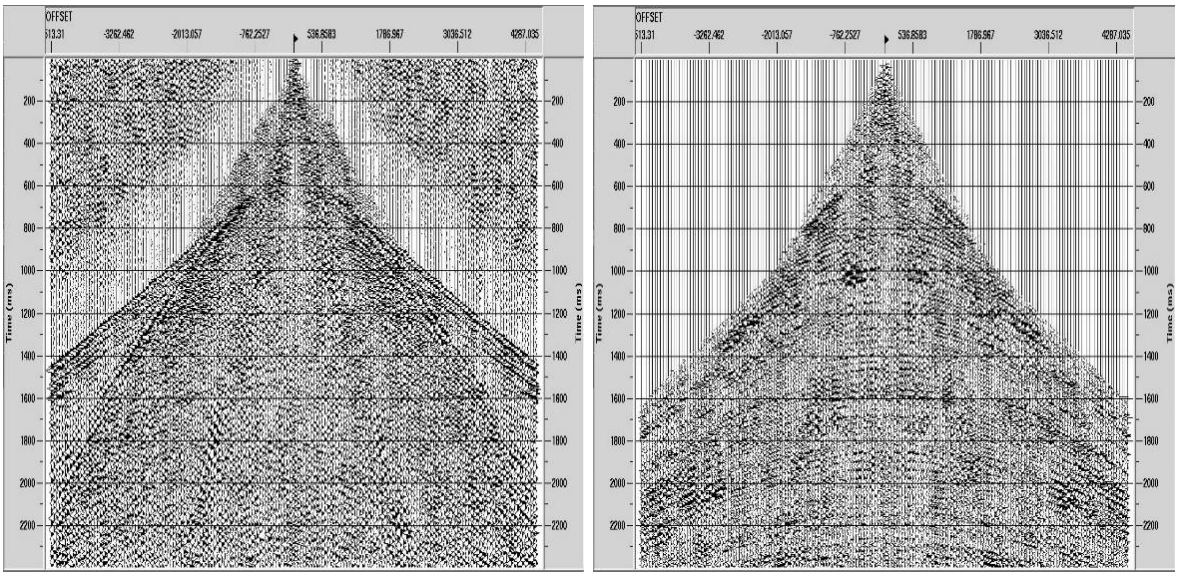

Figure 10. Real data before and after filter application

4. DISCUSSION

The proposed filter preserves this common seismic response while effectively eliminating all types of noise. As a result, both resolution and signal-to-noise ratio SNR are significantly improved for synthetic as well as real seismic datasets.

Furthermore, the proposed method offers advantages in terms of computational efficiency, requiring less manual intervention and enabling faster execution when compared to conventional filtering techniques. This novel approach is designed to comprehensively and efficiently attenuate various noise types, while maintaining the integrity of the seismic wavelet. It provides a clear enhancement in SNR signal-to-noise ratio and overall seismic data resolution.

5. CONCLUSION

To assess the effectiveness of the proposed filtering method, tests were conducted on synthetic seismic data contaminated with various types of noise, including multiples and linear interferences. The method demonstrated a robust capability to attenuate all forms of organized and random noise while preserving the amplitude and phase of seismic reflection wavelets.

One observed limitation arises when using wide computational windows: the comparison between near-offset traces (with higher resolution) and far-offset traces (which are stretched and more attenuated due to absorption) may degrade the

wavelet resolution. To mitigate this issue, an uncertainty parameter was incorporated into the algorithm to preserve the frequency bandwidth during comparisons. As a result, computations performed within narrow windows maintain the resolution of seismic horizons.

Overall, the results confirm the advantages of the proposed approach in enhancing seismic imaging and highlight its potential impact on improving the accuracy of seismic data interpretation.

Moreover, the proposed method reduces the effort required and offers faster execution compared to conventional methods.

6. RECOMMENDATIONS

In full-fold stacking, the inclusion of far-offset traces can degrade the quality of the final stack due to absorption effects and wavelet stretching, which adversely affect the contribution of near-offset traces.

To improve seismic imaging, it is preferable to use the Near Trace Section as the primary representation of the seismic section. This approach avoids issues related to dip dependency and reduces the need for complex preprocessing steps such as top muting, Dip Moveout (DMO), and Pre-Stack Time Migration (PSTM).

Post-stack migration applied to the Near Trace Section is often sufficient to achieve satisfactory imaging results.

The proposed filter is specifically designed for processing the seismic data recorded by the High Productivity and high-density Vibroseis Acquisition.

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to Halliburton for providing the SeisSpace software, which greatly contributed to the completion of this study. This software was installed at the university as part of a research and scientific development cooperation agreement.

FURTHER DISCLOSURE

Findings has been presented in the:

1. JST12 - June 24-26, 2025 - Oran, Algeria: "SONATRACH Scientific and Technical Days."
2. SEG_Workshop - December 10-12, 2024 – Abu Dhabi, UAE: "Addressing the Challenges in Processing Data for Land and Shallow Water in the Middle East."

REFERENCES

Ladjadj, Y., Berguig, M. C., Gaci, S., (August 2025). An Innovative Method For Computing Static corrections using seismic reflection horizons analysis. JSE **2025**, 34(2).
https://doi.org/10.36922/JSE025240016

Oppenheim, A. V., and Schafer, R. W., (1975). Digital signal processing. 211-218: Prentice-Hall.

Oppenheim, A.V., Schafer, R.W. and Buck, J.R., (2001). Discrete-Time Signal Processing.

Özdoğan, Y., Doherty, S. M., (2001). Seismic Data Analysis: Processing, Inversion, and Interpretation of seismic data. Vol 2 Society of Exploration Geophysicists.

Robinson, E. A., and Treitel, S., (1964). Principles of digital filtering. Geophysics, 29, 395-404.

Thomas, E. et al, (January 2008). De-noising seismic data in the time-frequency domain. SEG technical program.

Preliminary Studies for a Smart Garment Design: Realization of an Electronic Warning System against Excessive UV Exposure and Possible Implementation to a Smart Garment

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Abstract: Solar radiation that reaches to the earth's surface contains a continuous spectrum of electromagnetic radiation, including ultraviolet (UV) light (290-400 nm), visible light (400-760 nm), and infrared (760-4000 nm). The UV lights which are not filtered by the atmosphere usually cover most of the UVA and some UVB lights. Normally, adequate amounts of UV exposure can be beneficial for humans by inducing D vitamin production. However, excessive exposure to UV lights can result with several health problems like skin cancer, sunburn and inflammation, skin-reddening and photo-aging. Therefore, people should be protected from long-time exposures to UV. Especially elder people should adopt a balanced approach to sun exposure. UV protective textiles can help to reduce side-effects of UV exposure. In this term, the design and the coverage of the fabric and the clothing become very important for the degree of protection. The uncovered areas of the body maintain affected from exposure. Implementing wearable electronics to the textiles can enhance the avoidance from excess UV exposure. By considering all these facts, the main aim of this study was to develop a wearable warning system which gives easy-to-understand and audible signals in case of excessive UV exposure. The system was developed to be lightweight, compact and user-friendly. The system mainly consisted of a reliable UV sensor, a microcontroller, a battery, a battery charger, an OLED screen, a voltage regulator, and a buzzer, to detect and evaluate the UV exposure and produce warning signals. The selected UV sensor could detect the 280-390 nm light most effectively that covered most of the UVA (tanning rays) and part of the UVB (burning rays) spectrum. OLED screen was used as software developing and debugging aid, but also can be used as an additive human machine interface (HMI) hardware for prototype. The results of the developed system were also verified by using a commercial UV measurement instrument (Lutron YK-35UV). Both the hardware and the software of the electronic warning system were successfully developed. The dimensions of the final system were about 10 cm in length and 2.5 cm in width. The system components were gathered together to fit on a textile based elastic wrist band or to be implemented on a hat or an upper garment. Possible drawings and patterns were created to implement the system on a smart textile product. The developed system was also tested under real life conditions. The correlation analysis between the developed system and commercial test device verified the performance of the developed system. In addition, vocal warnings could be taken from the system when the pre-determined UV exposure levels were exceeded.

Keywords: UV sensor, wearable technology, UV exposure, warning system, smart textiles.

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1. INTRODUCTION

The electromagnetic spectrum is the complete range of electromagnetic radiation, which is classified according to wavelength or frequency (Norgard and Best, 2017). It extends from long-wavelength radio waves to short-wavelength gamma rays.

Ultraviolet (UV) radiation covers a portion of the electromagnetic spectrum between visible light and X-rays (wavelengths from approximately 290 to 400 nanometers (nm)) (Zwinkels, 2023). These UV bands is invisible for people however it can be dangerous for human health although the right amount is necessary for D vitamin synthesis (McKenzie et al., 2005; Wright and Weller, 2015). When exposed to excessive UV lights, it can result with several health problems such as skin cancer, photo-aging, sunburn, inflammation, and skin-reddening. Previous studies showed that 90 % of skin cancers can be prevented by UV protection like avoiding from sun exposure, wearing protective clothing and using sunscreens (Sivakumar et al, 2013; Hossain and Rahman, 2015; Robinson et al, 2021).

Especially elder people and children should adopt a balanced approach to sun exposure (Neale et al, 2023). UV protective textiles can help to reduce side-effects of UV exposure. In this term, the design and the coverage of the fabric and the clothing become very important for the degree of protection. The uncovered areas of the body maintain affected from exposure (Aguilera et al, 2023; Khan et al, 2020). The usage of smart garments or wearable electronics can help the wearer to avoid from excessive UV exposure. Here, the main problem may be washing the wearable system or the smart

garment equipped with electronic devices (Akkan et al, 2022; Kirstein et al, 2005). Therefore, the durability of the smart systems should be secured by using waterproof cases (Akkan et al, 2022) or attachable/detachable systems (Kirstein et al, 2005; Kara et al, 2017).

There are some smart garment examples with UV detecting capabilities in the literature. In one of them, a UV sensor was mounted on the right chest pocket of a multifunctional fall/winter jacket (Lee and Baek, 2021). Haghi et al (2020) produced a hardware prototype of wrist-worn monitoring device. Puente-Mansilla et al (2016) and Robinson et al (2021) designed wearable systems connected with smartphones.

Different from the literature, a plug-on/plug-of wearable system was developed within this study. The main aim of the study was to measure the UV level by a wearable electronic system and create vocal warning signals when the pre-determined UV exposure levels were exceeded. The system was developed to be lightweight, compact, consistent and user-friendly, and was suitable for versatile usages that can be used with any kinds of upper clothes.

2. MATERIALS AND METHODS

2.1. Materials

The electronic hardware comprised a battery, a battery charger, a voltage regulator, a microcontroller, an OLED screen, an UV sensor, and a buzzer. The purpose of the system was to detect and evaluate the UV exposure and to produce vocal warning signals. The selected UV sensor (ML8511) demonstrated the greatest sensitivity to light within the 280-390 nm range, which encompasses the majority of UVA and a portion of UVB spectrum.

The commercial UV measurement system was a Lutron YK-35UV. It was used to verify and tune the data that was measured via designed and developed UV detection system.

2.2. Methods

The electronic system was assembled according to the schematic given in Figure 1. According to it, all the buzzer, OLED screeen, debug module connection and battery module were assembled due to certain ports of the microcontroller. 5V Li-Po battery charger is used to charge battery when needed. The system was gathered together in a compact form of 10 x 2.5 cm.

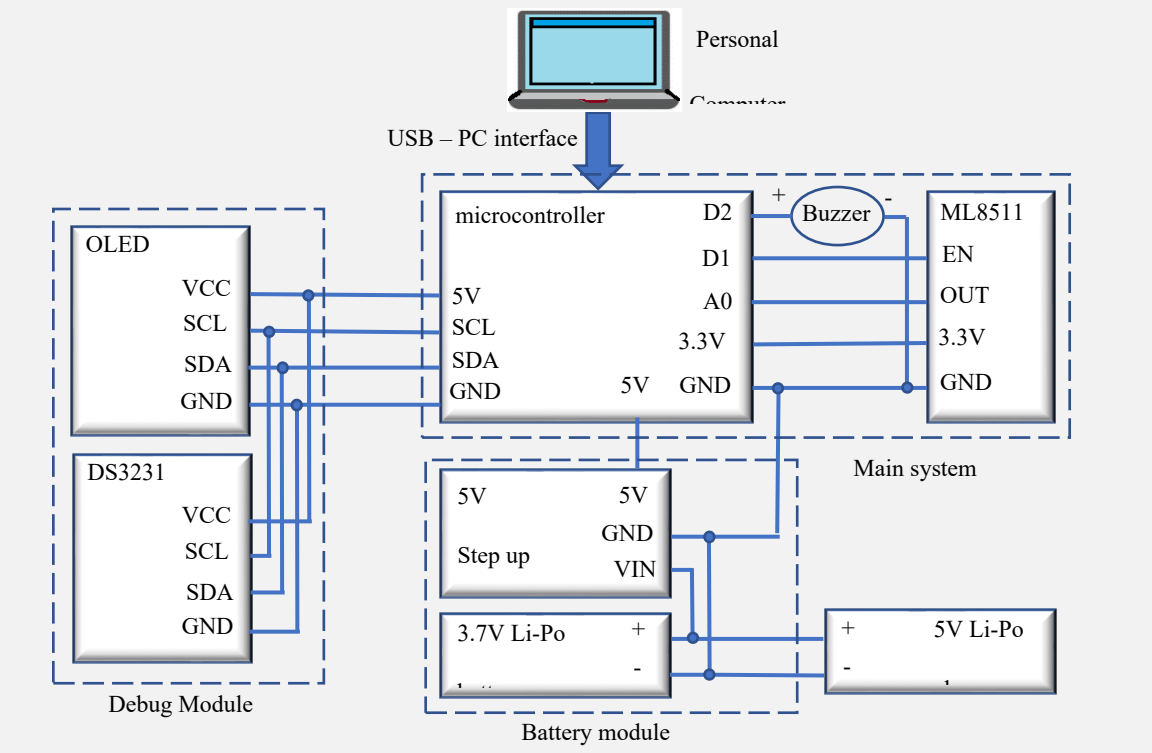

Figure 1. Schematic of the developed electronic system

The hardware was programmed via an USB PC interface. The flowchart type algorithm of the software is given in Figure 2. The UV exposure was determined according to a multiple averaging approach to eliminate sudden UV sensor direction changes and allows for stable measurements with high long-term accuracy.

The experiments were designed to measure the UV level and tune the sensor. The UV level was measured via both the developed electronic system and the commercial UV measurement device (Lutron YK-35UV).

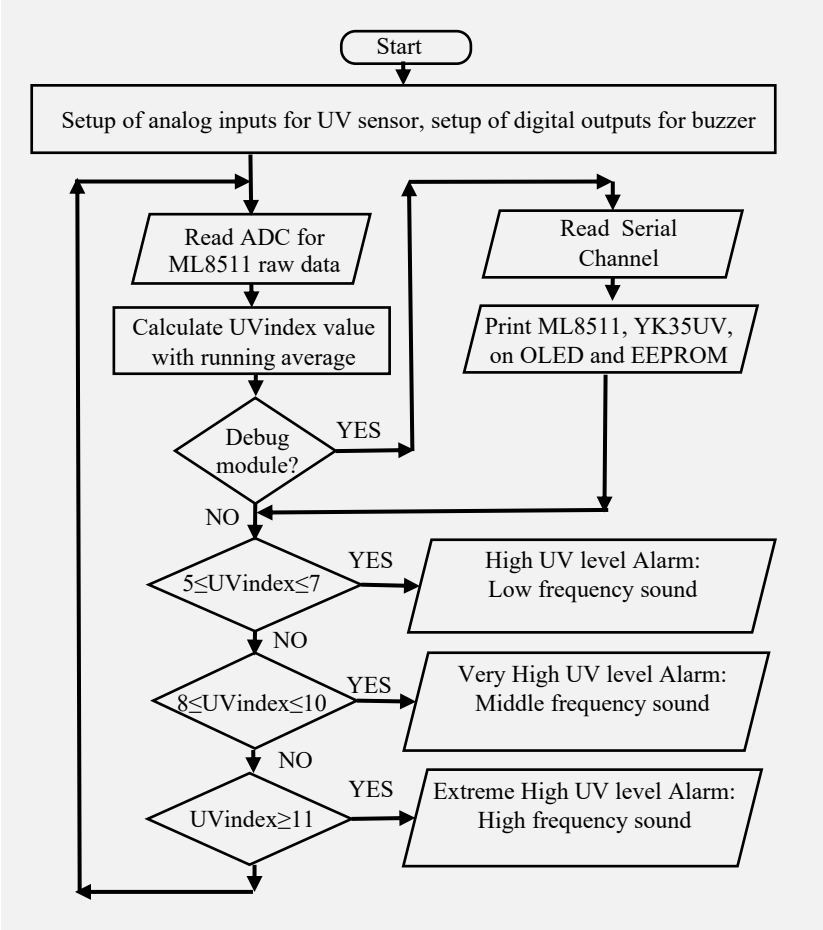

Figure 2. Flowchart of the developed software

After building the electronic system prototype and verifying its results, the design studies were performed to implement the electronic system to textiles. Textiles were selected as the base structure for the electronic system, because they are an indespensible part of daily life and sport activities such as trekking and jogging. For the pretrials of the smart garment design, a case was firstly developed to carry and protect the hardware. The case was designed to provide the montage of the electronic system to any desired garments, accesories or to be used as a wrist band. The designs of the smart textiles were created by Designer 9 (Gerber Artworks Expert).

3. RESULTS

3.1 Building and verification results of the electronic UV measurement and warning system

The electronic system was gathered together to form a long and thin structure that can fit on a wrist band, hat or shoulder of a garment. All the system components were mounted on a flexible plastic ribbon to carry it easily and position on the demanded place. The back view of the final system is given in Figure 3.a. The microcontroller, buzzer, UV sensor, motor, regulator and charging socket were placed on the upper side of the system. The nickel plates were placed on each ends of the ribbon's back-side. A corresponding ribbon with magnets was used to fix the system to the desired position (Figure 3.b). In the following parts, the corresponding nickel plates were designed to be implemented to the carrier case instead of the ribbons for easier usage.

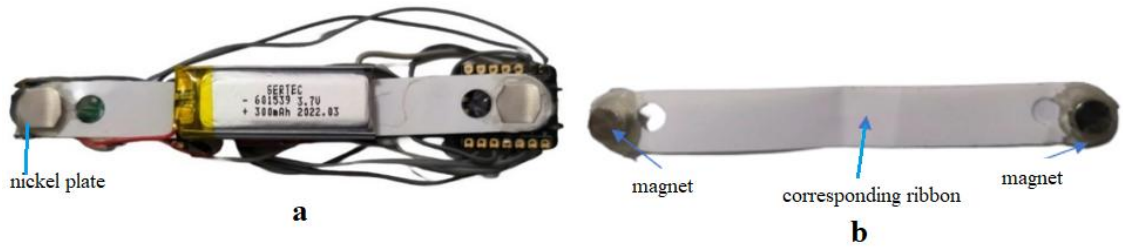

Figure 3. The final views of the developed system a) Back view of the system on the ribbon b) the corresponding ribbon with magnets for fixing the system to garments

As mentioned in the methods part, the developed UV detecting and warning system was tested in real-life conditions. To verify and tune the UV sensor, the experiment was repeated under same conditions with a commercial UV meter. The UV indexes obtained from these two systems are visualised as graphics. The experimental results of the developed system and the commercial UV meter are given in Figure 4.

340 data was collected for each ML8511 (UV sensor of the developed system) and YK-35UV (commercial UV meter) for each 12 seconds that corresponded to 4080 seconds (68 min) interval. The correlation analysis between the developed system and the commercial UV meter showed that results of the adjusted ML8511 correlated highly with the commercial measurement device (correlation coefficient: 0.853). The data of the commercial UV meter was about 2 times of the developed system. When the multiplying factor was removed, it can be clearly seen that the data has similar behaviour.

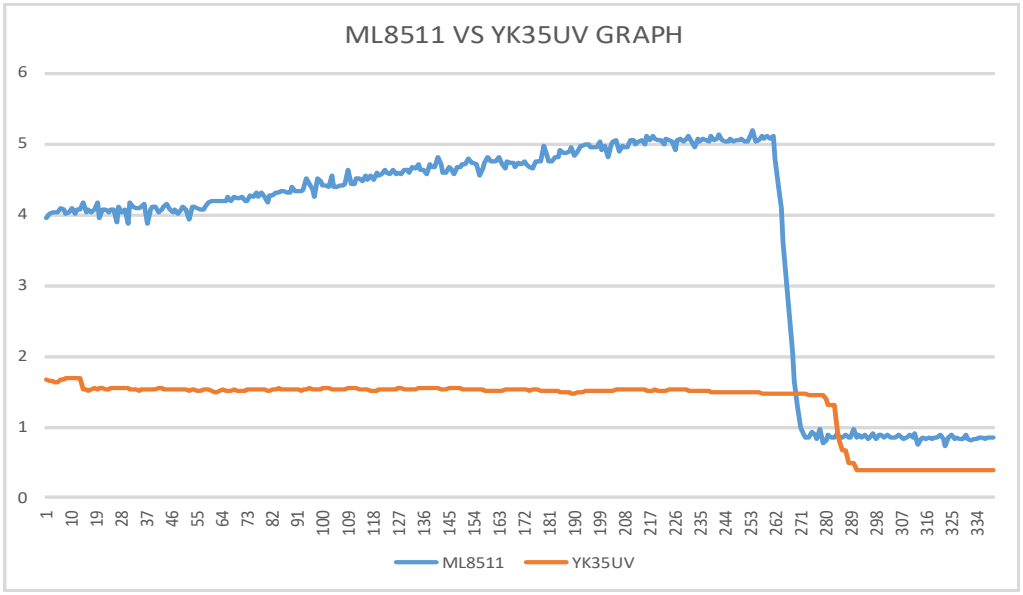

Figure 4. The sensors versus data number graphs

3.2 Possible smart garment designs

3.2.1 Design of the carrier for the electronic system

The carrier case for the electronic system was designed to protect the system from external factors, hide the electronic system modules/cables and provide a more aesthetic look.

The case had two pieces as shown in Figure 5: one top piece and one lower piece. The electronic system would be inserted within these two fabric pieces. The upper piece had a transparent window or a hole that would fit on the UV sensor module (Figure 6). Therefore, the UV would not be blocked by the fabric. The edges of this window would be secured by stitching. The nickel plates would be placed on each ends of the fabric. This was designed to fix the final system to garments with the help of the corresponding ribbon with magnets. The edges of the top and lower pieces of the case would be assembled by stitching as shown in the Figure 5.

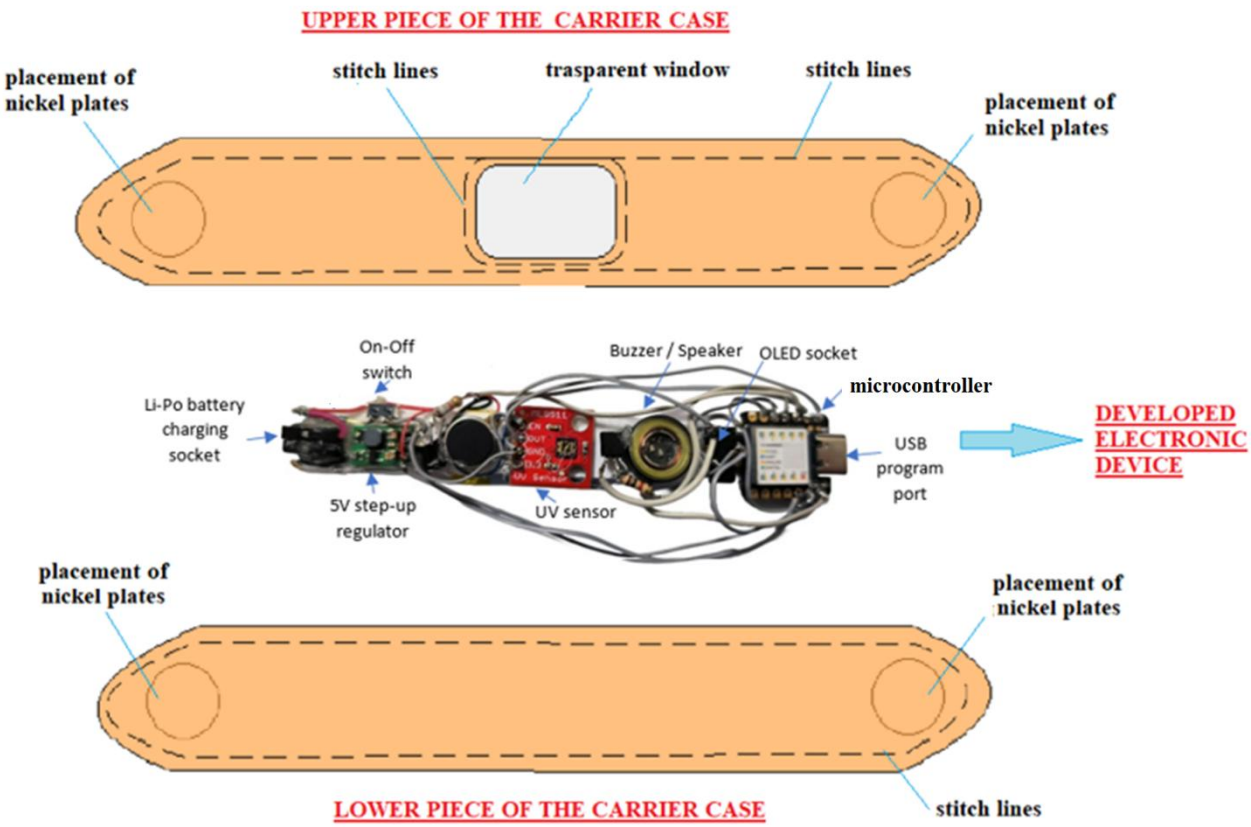

Figure 5. The technical sketch of the designed carrier case for the developed electronic system

Figure 6 shows the technical sketch of the final form of the case (top view) after implementing the electronic system and stitching the case.



Figure 6. The technical sketch of the final form of the case (top view) after implementing the electronic system and stitching the case

3.2.2 Smart garment designs (wrist band, hat and t-shirt)

The electronic system was designed as an easy plug on-plug off system to be applied to upper garments, hats or to be used for wrist band. The plugging-on and -off processes was planned to be made via the nickel plates on the case and the corresponding ribbon with strong magnets. This would provide to separate the electronic system easily before washing the textile structures. In addition, this would provide to implement the electronic system to different garments such as t-shirts, jackets, hats etc. and functionalise them easily.

The first smart wearable system design consisted of an elastic wrist band (Figure 7). In this design, the case structure was altered to have Velcro tapes on the case ends for the closure (Figure 7.a). Top and lower pieces of the elastic wrist band would be sealed by stitching like the pre-designed carrier case. Instead of nickel plates and corresponding ribbon with magnets, Velcro tapes were utilised to form a closed loop to be used as a wrist band. The electronic system was designed on a flexible ribbon (Figure 3 and 5) therefore, it will bend easily to form the loop structure in Figure 7.b. The placement of the electronic system will allow to place the UV sensor to the open window on the top piece. The main limitation of this wrist band design would be the change of the direction of the UV sensor during walking/running. This sources from the movement of the arm of the wearer during activity.

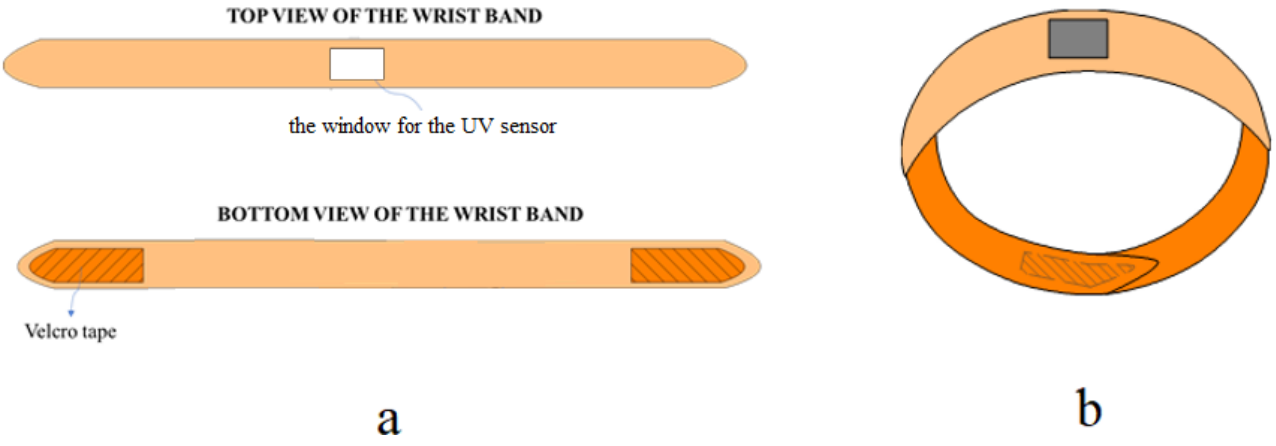

Figure 7. The technical sketch of the wrist band
a) top and lower pieces of the wrist band b) closed loop form of the wrist band

The second design for the implementation of the electronic system was to place it on the shoulder of a top garment as shown in Figure 8. The front and top view of the placement of the system on a t-shirt are given in the figure. This kind of approach provides measuring sun/UV rays from a constant angle. The case can be designed to have alternative colors and patterns to provide extra harmony with the clothing. The plug-on/ plug-off structure of the case allows to use the developed electronic system with any top wear.

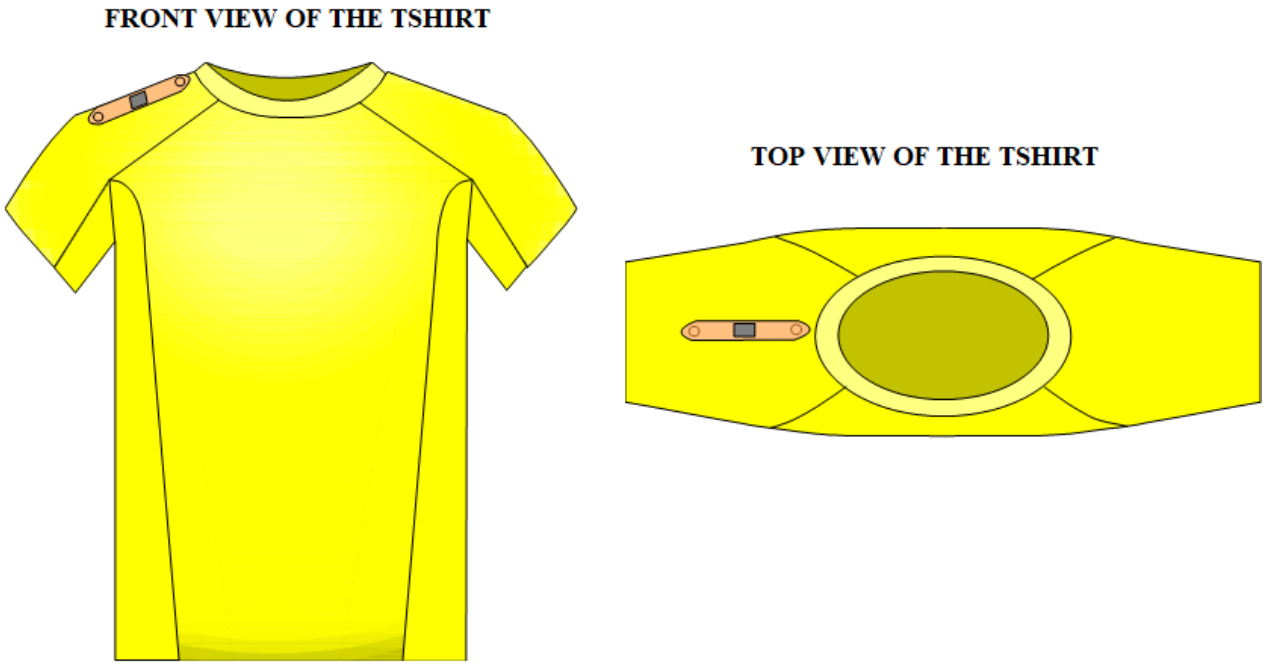

Figure 8. The technical sketch of the implementation of the electronic system on a t-shirt

The last design of the implementation of the electronic system is on a hat. The example design of the implementation of the system on a sports cap is given in Figure 9. The electronic system can be placed on the top front or the top of the cap as shown in the figure by means of the carrier case (Figure 9) and corresponding ribbon with magnets (Figure 3.b). As for the t-shirt design, the case's color/pattern design can be changed and the most suitable case can be used according to the color/pattern of the hat to provide an aesthetic and harmonic look. The advantage to implement the system on a hat is taking the sun and UV rays from the same direction during all activity.

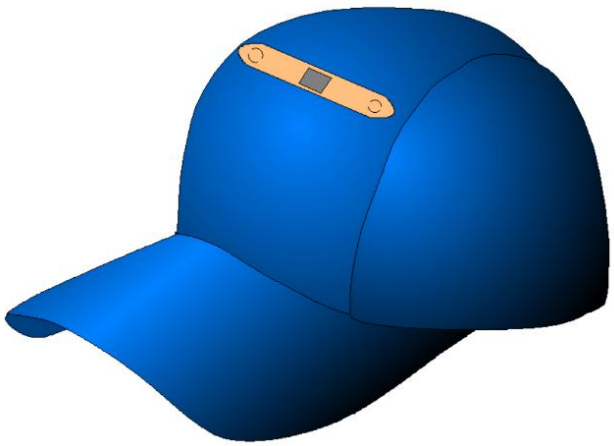

Figure 9. The technical sketch of the implementation of the electronic system on a sports cap

4. DISCUSSION AND CONCLUSIONS

The main aim of this study was to design and realize an electronic system that could measure UV exposure of the wearer and create a vocal warning signal according to the level of UV index by means of a smart garment. The electronic system was designed to be easy to use, easy to understand and attachable/detachable to top garments, hats or wrist bands.

The vocal warning signals were successfully taken from the developed system and the UV measurement results correlated highly with the commercial UV meter. Different from the literature, this system provided vocal warning signals to the wearer so that the wearer needn't look at a screen constantly to see the UV index values. This provides easy-to-understand warnings to elder people, children and sportsmen so assist them to avoid from excessive UV exposure.

Within the context of this work, all the concept design of the wearable warning system, hardware and software were developed successfully. The textile-based carrier case was designed to attach the electronic system to wearables without further modification and the final form was useful for training, sports, sunbathing and other activities. This easy attachment was provided by means of Velcro tapes and/or nickel plates and strong magnets. This eliminated the disadvantages of direct smart garment designs such as cleaning/washing of the garments, the obligation to use the same clothing for the targeted function, the difficulties during hardware implementation (usage of appropriate conductive yarns, connecting problems etc.).

One of the textile designs consisted of a t-shirt design where the electronic system was placed on the shoulder. This was allowing the sensor to take measurements from the same angle during the activity. In addition, the flexibility of the system allows to mount the electronic system to the chest or back side of the garment, due to the nature of the current activity (walking direction, sitting, turning back to sunlight etc.).

Ethics Committee Approval
N/A

Peer-review
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Author Contributions
Conceptualization: T.A., S.K.; Investigation: T.A., S.K., L.Ö.A.; Material and Methodology: T.A., S.K., L.Ö.A.; Supervision: T.A., S.K., L.Ö.A.; Visualization: T.A., S.K.; Writing-Original Draft: T.A., S.K., L.Ö.A.; Writing-review & Editing: T.A., S.K., L.Ö.A.; Other: All authors have read and agreed to the published version of manuscript.

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REFERENCES

Aguilera, J., Navarrete-de Gálvez, E., Sánchez-Roldán, C., Herrera-Ceballos, E., & de Gálvez, M. V. (2023). Sun-protective Properties of Technical Sportswear Fabrics 100% Polyester: The Influence of Moisture and Sweat on Protection against Different Biological Effects of Ultraviolet (UV) Radiation. Photochemistry and Photobiology, 99(1), 184-192.

Akkan, T., Kara, Ş., Ağin, B., Yeşilpinar, S., & Şenol, Y. (2022). Examination of waterproof pockets as protective carriers for smart garments. Tekstil ve Muhendis, 29(126), 80-87.

Haghi, M., Danyali, S., Thurow, K., Warnecke, J. M., Wang, J., & Deserno, T. M. (2020). Hardware prototype for wrist-worn simultaneous monitoring of environmental, behavioral, and physiological parameters. Applied Sciences, 10(16), 5470.

Hossain, M. A., & Rahman, M. (2015). A review of nano particle usage on textile material against ultra violet radiation. Journal of Textile Science and Technology, 1(03), 93.

Kara, S., Yesilpinar, S., Senol, Y., & Akkan, T. (2017). Design of an electronically equipped sailing garment for improved safety. Industria Textila, 68(1), 23-30.

Khan, A., Nazir, A., Rehman, A., Naveed, M., Ashraf, M., Iqbal, K., ... & Maqsood, H. S. (2020). A review of UV radiation protection on humans by textiles and clothing. International Journal of Clothing Science and Technology, 32(6), 869-890.

Kirstein, T., Cottet, D., Grzyb, J., & Tröster, G. (2005). Wearable computing systems–electronic textiles. Wearable electronics and photonics, 177-197.

Lee, H., & Baek, K. (2021). Developing a smart multifunctional outdoor jacket with wearable sensing technology for user health and safety. Multimedia Tools and Applications, 80, 32273-32310.

McKenzie, R. L., Liley, J. B., & Björn, L. O. (2009). UV radiation: balancing risks and benefits. Photochemistry and photobiology, 85(1), 88-98.

Neale, R. E., Lucas, R. M., Byrne, S. N., Hollestein, L., Rhodes, L. E., Yazar, S., ... & Olsen, C. M. (2023). The effects of exposure to solar radiation on human health. Photochemical & Photobiological Sciences, 22(5), 1011-1047.

Norgard, J., & Best, G. L. (2017). The electromagnetic spectrum. In National Association of Broadcasters Engineering Handbook (pp. 3-10). Routledge.

Puente-Mansilla, F., Boza-Quispe, G., Lapa-Velasquez, G., Matos-Avalos, C., & Rosales-Huamani, J. (2016, September). A wearable UV sensor and accessible smartphone application for blind people. In 2016 IEEE International Symposium on Consumer Electronics (ISCE) (pp. 81-82). IEEE.

Robinson, J. K., Patel, S., Heo, S. Y., Gray, E., Lim, J., Kwon, K., ... & Rogers, J. A. (2021). Real-time UV measurement with a sun protection system for warning young adults about sunburn: prospective cohort study. JMIR mHealth and uHealth, 9(5), e25895.

Sivakumar, A., Murugan, R., Sundaresan, K., & Periyasamy, S. (2013). UV protection and self-cleaning finish for cotton fabric using metal oxide nanoparticles.

Zwinkels, J. (2023). Light, electromagnetic spectrum. In Encyclopedia of color science and technology (pp. 1062-1069). Cham: Springer International Publishing.

Furniture Design and Interior Decoration as Strategic Drivers of Tourist Satisfaction: Evidence from Hotels and Hospitality Buildings in Montenegro

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Abstract: Tourism is a dominant sector in Montenegro's economy, with hotels and hospitality buildings playing a central role in shaping destination image and visitor experience. In contemporary tourism markets, the quality of interior environments—particularly furniture design and spatial decoration—has become a strategic determinant of tourist satisfaction and competitive differentiation. This study examines the relationship between furniture design, interior environment quality, and tourist satisfaction in hotels in Montenegro. Drawing on interdisciplinary literature from tourism studies, interior architecture, and industrial design, the paper proposes a conceptual model linking furniture design quality to perceived hotel experience and behavioral outcomes. The findings highlight that furniture elements are not merely functional components but experiential and symbolic assets that enhance comfort, reinforce local identity, and contribute to sustainable tourism development. The study concludes that design-oriented strategies integrating furniture, interior decoration, and local materials can significantly strengthen Montenegro's tourism competitiveness and destination branding.

Keywords: Tourism design; Furniture design; Hotel interiors; Tourist satisfaction; Montenegro

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1. INTRODUCTION

Tourism constitutes one of the most significant pillars of economic development in Montenegro, accounting for a substantial share of national income, employment, and foreign exchange revenues. Over the past decade, Montenegro has strategically positioned itself as a high-quality Mediterranean destination, emphasizing experiential tourism, cultural heritage, and premium accommodation facilities. Within this context, the built environment—particularly hotel interiors—has emerged as a critical factor shaping tourist perceptions and overall destination image (Buhalis & Foerste, 2015).
Recent tourism research emphasizes that tourists increasingly evaluate destinations through holistic experiences rather than isolated services or attractions (Pine & Gilmore, 2019). Interior design quality, furniture comfort, aesthetic coherence, and material authenticity significantly influence perceived service quality, emotional responses, and satisfaction levels (Han et al., 2019). For destinations such as Montenegro, where tourism experiences are closely connected to place identity and natural landscapes, furniture design and interior decoration offer a powerful medium for integrating local culture, sustainability principles, and experiential value.

This study aims to analyze the strategic role of furniture design and interior decoration in hotels and hospitality buildings in Montenegro. The central research question guiding this study is: **How do furniture design and interior decoration influence tourist satisfaction and contribute to sustainable tourism development in Montenegro?**

2. CONCEPTUAL FRAMEWORK AND HYPOTHESES

Based on servicescape theory and experience economy literature, this study proposes a conceptual model linking furniture design quality to tourist satisfaction through mediating experiential variables.

- H1: Furniture design quality has a positive effect on perceived interior environment quality in hotels.
- H2: Perceived interior environment quality positively influences tourists' perceived hotel experience.
- H3: Perceived hotel experience has a significant positive effect on overall tourist satisfaction.
- H4: Tourist satisfaction positively affects behavioral outcomes, including revisit intention and recommendation.

3. METHODOLOGY

3.1 Sample and Data Collection

Data were collected from 147 international tourists staying in 4- and 5-star hotels located in Budva, Kotor, and Tivat between June and September 2024.

- Gender: 52% female, 48% male
- Average age: 36.4 years
- Origin: EU (61%), Balkans (23%), Other (16%)
- Average stay: 4.7 nights

3.2 Measurement Scales

All constructs were measured using **5-point Likert scales** adapted from validated studies.

4. RESULTS

4.1 Reliability and Validity Analysis

Cronbach's alpha values indicate high internal consistency.

Table 1. Reliability Analysis

Construct	Cronbach's Alpha
Furniture Design Quality	0.88
Interior Environment Quality	0.86
Perceived Hotel Experience	0.90
Tourist Satisfaction	0.91
Behavioral Intentions	0.87

All values exceed the recommended threshold of 0.70 (Hair et al., 2019).

4.2 Confirmatory Factor Analysis (CFA)

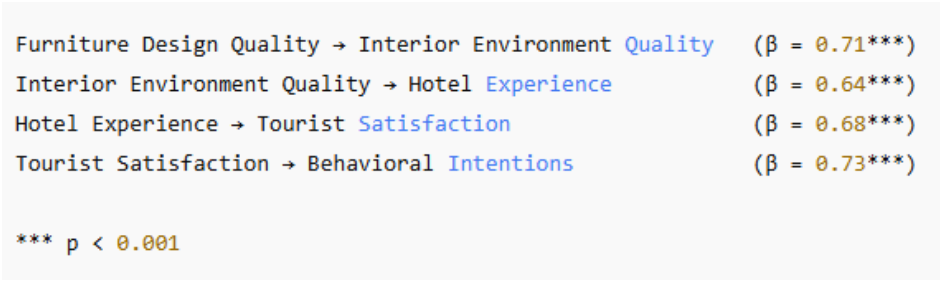
The CFA results confirm good model fit.

Table 2. Measurement Model Fit Indices

Fit Index	Value	Recommended
χ^2/df	2.21	< 3.0
CFI	0.94	> 0.90
TLI	0.93	> 0.90
RMSEA	0.062	< 0.08

4.3 Structural Equation Modeling Results

Figure 1. Structural Model Results (Standardized Path Coefficients)



All hypothesized relationships are statistically significant, supporting **H1–H4**.

4.4 Explained Variance

- Interior Environment Quality: **$R^2 = 0.50$**
- Hotel Experience: **$R^2 = 0.41$**
- Tourist Satisfaction: **$R^2 = 0.46$**
- Behavioral Intentions: **$R^2 = 0.53$**

These values indicate strong explanatory power for the proposed model.

5. DISCUSSION

The findings of this study provide robust empirical evidence that furniture design and interior decoration play a decisive role in shaping tourist satisfaction and behavioral intentions in Montenegro's hotel sector. The statistically significant relationships identified in the structural model confirm that furniture design quality constitutes a foundational determinant of perceived interior environment quality, which subsequently influences tourists' experiential evaluations and satisfaction levels.

Consistent with servicescape theory, the results demonstrate that physical elements of the hotel environment—particularly furniture-related attributes such as ergonomics, material quality, and aesthetic coherence—serve as key stimuli shaping tourists' emotional and cognitive responses (Line et al., 2018). The strong path coefficient between furniture design quality and interior environment perception suggests that tourists perceive furniture not as an isolated element but as an integral component of the overall spatial experience. This finding extends prior hospitality research by empirically highlighting furniture design as a central experiential variable rather than a secondary aesthetic feature.

Moreover, the significant effect of perceived hotel experience on tourist satisfaction reinforces the experience economy perspective, which emphasizes emotional engagement and memorability as critical drivers of value creation in tourism (Pine & Gilmore, 2019). In the context of Montenegro, where tourism competitiveness increasingly depends on experiential differentiation, furniture design emerges as a strategic medium through which hotels can convey quality, authenticity, and local identity.

The strong relationship between tourist satisfaction and behavioral intentions further underscores the economic relevance of interior design decisions. Higher satisfaction levels translate into increased revisit intention and positive word-of-mouth communication, which are particularly vital for small and destination-sensitive tourism economies such as Montenegro. These results align with earlier studies linking physical environment quality to loyalty outcomes in hospitality settings (Han et al., 2019; Ali et al., 2016).

Overall, the discussion highlights that furniture design operates at the intersection of design, tourism management, and destination branding. By empirically validating this role, the study contributes to the literature by integrating industrial design considerations into mainstream tourism satisfaction models.

6. MANAGERIAL AND POLICY IMPLICATIONS

The findings of this study generate several important implications for hotel managers, designers, furniture manufacturers, and tourism policymakers in Montenegro.

From a managerial perspective, hotel operators should recognize furniture design and interior decoration as strategic investments rather than cost-driven procurement decisions. The strong effects observed in the model suggest that prioritizing ergonomic comfort, durable materials, and coherent aesthetic concepts can significantly enhance perceived service quality and guest satisfaction. Managers are encouraged to collaborate closely with professional designers and furniture producers during renovation and new-build processes to ensure that interior environments support experiential quality and brand positioning.

For designers and furniture manufacturers, the results highlight the growing demand for design solutions that integrate functionality, aesthetics, and sustainability. In Montenegro, the incorporation of locally sourced materials—particularly wood—combined with contemporary design language can strengthen authenticity and cultural resonance. Such approaches not only enhance tourist experience but also support local manufacturing ecosystems and value-added production.

From a policy perspective, the study suggests that interior design quality should be considered an integral component of national tourism development strategies. Tourism authorities could incorporate design and furniture quality criteria into hotel classification systems, quality labels, or sustainability certification schemes. Encouraging collaboration between tourism stakeholders, design institutions, and furniture producers may foster innovation, improve quality standards, and enhance Montenegro's international competitiveness.

Additionally, policy instruments such as incentives for sustainable furniture use, support for design-driven SMEs, and integration of design education into tourism and hospitality programs could further strengthen the sector's human capital and innovation capacity.

7. CONCLUSION

This study empirically demonstrates that furniture design and interior decoration are critical determinants of tourist satisfaction and behavioral intentions in Montenegro's hotel sector. The results confirm that furniture design quality significantly influences interior environment perception, which in turn shapes perceived hotel experience and overall satisfaction. These relationships highlight furniture design as a strategic interface between physical space and tourist experience.

In a tourism-dependent economy such as Montenegro, where destination image and experiential quality are central to competitiveness, the strategic integration of furniture design into hospitality development offers substantial economic and symbolic benefits. By moving beyond a purely functional view of furniture and embracing design-driven, sustainability-oriented approaches, hotels can enhance guest satisfaction, strengthen destination branding, and support long-term tourism sustainability.

The study contributes to the literature by empirically integrating industrial design variables into tourism satisfaction models and by providing context-specific insights for Montenegro. While the findings are robust, future research could extend this work through comparative cross-country studies, longitudinal designs, or investigations into the role of locally produced furniture in sustainable tourism branding.

Overall, positioning furniture design and interior decoration as core strategic assets—rather than peripheral aesthetic elements—offers Montenegro a viable pathway toward a more competitive, experience-driven, and sustainable tourism economy.

Ethics Committee Approval
N/A
Author Contributions
All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

REFERENCES

Ali, F., Hussain, K., & Ragavan, N. A. (2016). Memorable customer experience: Examining the effects of customers' experience on memories and loyalty in the hospitality industry. Journal of Hospitality Marketing & Management, 25(6), 1–22.
https://doi.org/10.1080/19368623.2016.1172535

Buhalis, D., & Foerste, M. (2015). SoCoMo marketing for travel and tourism: Empowering co-creation of value. Journal of Destination Marketing & Management, 4(3), 151–161.
https://doi.org/10.1016/j.jdmm.2015.07.002

European Commission. (2023). Montenegro 2023 progress report. Publications Office of the European Union.

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2019). A primer on partial least squares structural equation modeling (PLS-SEM) (2nd ed.). Sage Publications.

Han, H., Moon, H., & Hyun, S. S. (2019). Physical environment and customer loyalty: The moderating role of perceived service quality. International Journal of Hospitality Management, 77, 1–10.
https://doi.org/10.1016/j.ijhm.2018.06.012

Line, N. D., Hanks, L., & Kim, W. G. (2018). An expanded servicescape framework as the driver of place attachment and word-of-mouth. Journal of Hospitality & Tourism Research, 42(3), 476–499.
https://doi.org/10.1177/1096348016645535

Norman, D. A. (2013). The design of everyday things (Revised and expanded ed.). Basic Books.

Pine, B. J., & Gilmore, J. H. (2019). The experience economy: Competing for customer time, attention, and money (Updated ed.). Harvard Business Review Press.

Richards, G. (2018). Cultural tourism: A review of recent research and trends. Journal of Hospitality and Tourism Management, 36, 12–21.
https://doi.org/10.1016/j.jhtm.2018.03.005

Tasci, A. D. A., & Gartner, W. C. (2007). Destination image and its functional relationships. Journal of Travel Research, 45(4), 413–425.
https://doi.org/10.1177/0047287507299569

Timothy, D. J. (2011). Cultural heritage and tourism: An introduction. Channel View Publications.

UNWTO. (2020). Tourism and the sustainable development goals – Journey to 2030. World Tourism Organization.

Vezzoli, C., Kohtala, C., & Srinivasan, A. (2018). Product–service system design for sustainability. Journal of Cleaner Production, 183, 1–14.
https://doi.org/10.1016/j.jclepro.2018.02.001

A COPRAS-Based Assestment of Smart Cities

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Abstract: In recent years, the smart city concept has emerged as a strategic global response to the accelerating pace of urbanization and the mounting demand for sustainable, resilient, and efficiently managed urban environments. As cities continue to grapple with complex challenges such as climate change, population growth, and infrastructure strain, there is a growing need for tools that can quantitatively assess and compare urban performance across diverse regions. This study applies the Complex Proportional Assessment (COPRAS) method to evaluate and rank the smart city performance of 48 major cities worldwide. The assessment framework is built upon seven carefully selected indicators: gross domestic product (GDP) per capita, investment in research and development, number of startups, ICT readiness, share of renewable energy in total consumption, recycling rate, and CO_2 emissions per capita. These indicators reflect a balanced combination of economic vitality, innovation capacity, environmental sustainability, and technological infrastructure. The data set is derived from the 2024 Global Power City Index (GPCI), published by the Mori Memorial Foundation. Results of the analysis reveal that cities such as New York, San Francisco, and London consistently perform at the top of the index, demonstrating strong cross-dimensional smartness. In contrast, cities like Johannesburg, Cairo, and Buenos Aires exhibit lower scores across several categories. This research offers valuable insights for urban planners, policymakers, and decision-makers by presenting a structured, multi-criteria evaluation that can support more informed strategic planning for smart and sustainable urban development.

Keywords: Smart city, multi-criteria decision-making, MCDM, COPRAS.

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1. INTRODUCTION

To address the challenges posed by rapid urbanization and to ensure sustainable economic and social progress, the development of smart cities has become a primary focus. Currently, over half of the global population resides in urban areas (Manville et al., 2014), resulting in various negative externalities such as pollution, traffic congestion, inadequate waste management, excessive energy consumption, housing shortages, and increasing social inequality. It is projected that by 2050, approximately 70% of the world's population will inhabit cities (UN-Habitat, 2020), further intensifying resource scarcity and the deterioration of urban infrastructure. In the literature on smart cities, there are numerous definitions. Some of these include: “A smart city is a global research and urban strategy that aims to improve the quality of life for citizens in metropolitan areas and address the complex challenges posed by increasing urbanization through innovation and advanced technologies (Dameri and Ricciardi, 2015)”; “Smart cities are hybrid models that combine democratic open innovation with centralized urban assistance, and monitoring (Letaifa, 2015)” and, "We define 'smart cities' as livable cities for their inhabitants and sustainable for their environment, where ubiquitous sensors and devices enable more efficient city management processes, smoother information system flows, and/or optimized infrastructure utilization (Marek et al., 2017)”.

The smart city paradigm has arisen in response to these issues, utilizing big data, artificial intelligence (AI), and the Internet of Things (IoT) to improve urban management and the quality of life for residents (Batty, 2019)(Allam et al., 2020). The growing significance of digital transformation at urban sizes is reflected in the notable expansion of the worldwide smart city sector. But even with these technological advancements, there is still a significant lack of scholarly research on the assessment and comparison of smart cities, especially when looking at them from a multifaceted angle that integrates societal, technological, economic, and environmental aspects (Harrison and Donnelly, 2019)(Mora et al., 2020).

To address this gap, our research utilizes the 2024 Global Power City Index to assess and compare the smartness levels of prominent global cities (Mori Memorial Foundation, 2024). The GPCI provides a comprehensive evaluation based on various criteria such as economy, research and development, livability, environment, and accessibility (Unal and Alptekin, 2023). This research aims to systematically compare urban performance using MCDM techniques, thereby enhancing our understanding of the elements that contribute to the advancement of smart cities and offering valuable insights for urban planners and policymakers.

This study is organized as follows: The next section outlines the steps of the proposed COPRAS methodology in detail. Section 3 demonstrates an application of the proposed research methodology and results, and finally, Section 4 provides the concluding remarks.

2. MATERIAL AND METHOD

The COPRAS method is introduced to be used for multi-attribute decision making (Zavadskas et al., 1994). It mainly focuses on deriving relative weight and utility of each alternative. This utility can be converted in terms of ranks. The steps of COPRAS method are given below:

Step 1: Determine the alternatives and the required evaluation criteria. There are m alternatives denoted as $A_i = \{A_1, A_2, \ldots, A_m\}$, which are evaluated under n criteria, $C_j = \{C_1, C_2, \ldots, C_n\}$.
Step 2: Construct the decision matrix that denote the evaluation of alternatives with respect to criteria and the weight matrix of criteria.
Step 3: Normalize the decision matrix. The normalization is computed by dividing each entry by the largest entry in each column.
Step 4: Compute the weighted normalized decision matrix by multiplying the normalized decision matrix with the weight of each criterion.
Step 5: Separate criteria as benefit and cost criteria.
Step 6: Compute the sum of criteria value for benefit-related criteria (Pi).
Step 7: Compute the sum of attributes value for cost-related criteria (Ri).
Step 8: Calculate the relative weight of each alternative as

$$Q_i = P_i + \frac{R\sum_i R_{imin}}{R_i \sum_i^{\sum} \frac{R_{min}}{R_i}} \quad (1)$$

Step 9: Assign the priority of the alternatives (Ni) using (2) and rank the alternatives.

$$N_i = \frac{Q_i}{Q_{max}} \quad (2)$$

3. CASE STUDY AND RESULTS

To evaluate the smartness levels of major international cities, the 2024 Global Power City Index (GPCI), created by the Mori Memorial Foundation is utilized. The data related to the cities are given in Table 1.

Table 1. The data related to the cities

City	GDP per capita	R&D Expenditure	Number of Startups	ICT Readiness	Renewable Energy Rate	Waste Recycle Rate	CO2 Emissions per Capita
Amsterdam	46	2.8	10.1	59.5	22	47.8	72.6
Bangkok	11.1	1.5	0.7	28.5	38.6	34.9	83.3
Barcelona	22.9	1.3	8.2	49.2	35.4	33	82.6
Beijing	10.2	13.2	2.3	80.4	20.6	65.9	65.2
Berlin	18.9	12.2	20.1	77.7	33.1	80.2	86.9
Boston	70.5	28.6	11.9	100	16.2	40.3	30.4
Brussels	32	6.7	0.9	57.1	18.1	55.7	78.1
Buenos Aires	11.6	0.2	1.6	7.7	16.4	10.4	84.1
Cairo	0.5	0.7	3.7	17.2	12.2	3.3	99.7
Chicago	36.2	47.7	14	100	16.2	40.3	65.6
Copenhagen	45.3	3.6	3.9	81.9	87.9	36.5	86.1
Dubai	13.5	6.2	34.6	60.9	0	8.3	68.9
Dublin	61.5	1.1	4.1	54.9	23.9	50.8	82
Frankfurt	42.5	4.2	1.5	77.7	33.1	80.2	66.8
Fukuoka	13.3	4.9	0.1	60.1	14.1	33.2	84.9
Geneva	47.3	1.6	0.8	66.7	52.4	50.3	92.9
Helsinki	24.7	2.2	2.6	74.4	84.4	43.8	85.4
Hong Kong	18.4	7.5	9.9	54	0.2	49.4	93.4

Istanbul	5.9	4.4	8.9	21	32.2	21	87.6
Jakarta	6.9	0	6.5	24.5	57.7	12.6	83.2
Johannesburg	1.7	0.3	0.9	0.5	12.2	0	82.4
Kuala Lumpur	11.2	0.2	2.4	47.6	7.1	56.7	60.1
London	30	30.7	100	87.9	26.3	44.7	97.2
Los Angeles	36.1	69.14	29.5	100	16.2	40.3	65.7
Madrid	15.2	2.9	8.3	49.2	35.4	33	89.5
Melbourne	25.3	10.1	7.4	76.7	17	34.9	70.3
Mexico City	7.7	0.4	5.1	6.7	18.9	17.2	90.4
Milan	25.4	2.5	10.6	51.9	39.5	49.6	81.8
Moscow	11.4	3.9	0	37	4.4	21.5	49.3
Mumbai	0	0.1	20.5	0	54.7	28.3	100
New York	42.3	100	92.4	100	16.2	40.3	89.4
Osaka	21.3	12.5	1.1	60.1	14.1	33.2	74.3
Paris	50.9	15.7	23.6	67	24.2	41.7	74
San Francisco	100	25.9	69.4	100	16.2	40.3	0
Sao Paulo	5.2	2	13.5	13.6	96.22	4.8	95.9
Seoul	14.4	33	10.7	76.3	3.2	94.6	94.1
Shanghai	9.6	15.6	6.3	80.4	20.6	71.9	67.4
Singapore	34.1	14.8	38.1	84.4	1.2	94.5	86.2
Stockholm	29.1	5.9	7.7	75.3	100	34.8	93.7
Sydney	29.9	10	12.9	76.7	17	34.9	64.5
Taipei	12	5.9	1.1	60.9	2.1	100	76.9
Tel Aviv	23	9.9	11.4	64.7	9.7	11.9	88.6
Tokyo	29.2	44.8	29	60.1	14.1	42.3	94.3
Toronto	20.1	5.3	19.3	80.3	34.1	33.4	75.2
Vancouver	21.5	1.2	8.4	80.3	34.1	33.4	73.3
Vienna	22.4	7.1	2.5	44.4	66.6	70	87.7
Washington, DC	96.4	35.1	7.7	100	16.2	40.3	3.7
Zurich	79.5	5.2	6.4	66.7	52.4	50.3	85.6

All criteria except CO2 emission per capita is identified as benefit criteria and the weights of the criteria are considered as same. Qi and Ni values are computed employing (1) and (2), and the ranking of the alternatives are determined. The results are given in Table 2.

Table 2. Ranking of the alternatives

Cities	Q_i	N_i	**Rank**
Amsterdam	47.05	48.11	24
Bangkok	28.83	29.47	40
Barcelona	37.50	38.34	31
Beijing	48.15	49.23	22
Berlin	60.55	61.91	12
Boston	66.88	68.38	6
Brussels	42.63	43.58	30
Buenos Aires	11.98	12.24	46
Cairo	9.40	9.61	47

Chicago	63.60	65.03	10
Copenhagen	64.78	66.23	9
Dubai	30.88	31.57	39
Dublin	49.08	50.18	21
Frankfurt	59.80	61.15	13
Fukuoka	31.43	32.13	37
Geneva	54.78	56.01	18
Helsinki	58.03	59.33	15
Hong Kong	34.85	35.63	34
Istanbul	23.35	23.88	43
Jakarta	27.05	27.66	41
Johannesburg	3.90	3.99	48
Kuala Lumpur	31.30	32.00	38
London	79.90	81.70	3
Los Angeles	72.81	74.45	5
Madrid	36.00	36.81	32
Melbourne	42.85	43.81	29
Mexico City	14.00	14.31	45
Milan	44.88	45.88	27
Moscow	19.55	19.99	44
Mumbai	25.90	26.48	42
New York	97.80	100.00	1
Osaka	35.58	36.38	33
Paris	55.78	57.03	16
San Francisco	87.95	89.93	2
Sao Paulo	33.83	34.59	35
Seoul	58.05	59.36	14
Shanghai	51.10	52.25	20
Singapore	66.78	68.28	7
Stockholm	63.20	64.62	11
Sydney	45.35	46.37	26
Taipei	45.50	46.52	25
Tel Aviv	32.65	33.38	36
Tokyo	54.88	56.11	17
Toronto	48.13	49.21	23
Vancouver	44.73	45.73	28
Vienna	53.25	54.45	19
Washington, DC	73.93	75.59	4
Zurich	65.13	66.59	8

According to the results of the COPRAS method, which was applied to evaluate the smartness levels of 48 global cities based on seven key indicators—GDP per capita, R&D expenditure, number of startups, ICT readiness, renewable energy rate, waste recycle rate, and CO_2 emissions per capita—New York, San Francisco, and London emerged as the top-performing cities, exhibiting the highest composite scores. In contrast, Johannesburg, Cairo, and Buenos Aires ranked lowest in overall smartness.

4. DISCUSSION AND CONCLUSIONS

This study contributes to the expanding body of literature on smart city evaluation by presenting a comparative analysis of 48 global cities based on seven key performance indicators related to economic strength, innovation capacity, digital readiness, environmental sustainability, and urban efficiency. Utilizing the COPRAS, we systematically ranked the smartness levels of these cities using reliable data sourced from the 2024 Global Power City Index (GPCI), developed by the Mori Memorial Foundation.

The results show that New York, San Francisco, and London are the smartest cities according to the 7 criteria, respectively, while the opposite is valid for Johannesburg, Cairo, and Buenos Aires.
Future research could extend this study by employing various fuzzy MCDM methods to compare the results from an alternative perspective, allowing for a more comprehensive analysis of the findings.

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Conflict of Interest / Çıkar Çatışması
The authors have no conflicts of interest to declare.

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REFERENCES / KAYNAKLAR

Allam, Z., & Jones, D. S. (2020). Future (post-COVID) digital, smart and sustainable cities in the wake of 5G and the Internet of Things. Smart Cities, 3(2), 137–152. https://doi.org/10.3390/smartcities3020009

Batty, M. (2019). Defining smart cities. In Smart cities: Big data, civic hackers, and the quest for a new utopia (pp. 7–27). The MIT Press.

Dameri, R., & Ricciardi, F. (2015). Smart city intellectual capital: An emerging view of territorial systems innovation management. Journal of Intellectual Capital, 16(4), 860–887.

Harrison, C., & Donnelly, I. A. (2019). A theory of smart cities. Proceedings of the 55th Annual Meeting of the ISSS - 2011, Hull, UK, 55(1).

Letaifa, S. (2015). How to strategize smart cities: Revealing the SMART model. Journal of Business Research, 68(7), 1414–1419.

Manville, C., Cochrane, G., Cave, J., Millard, J., Pederson, J. K., Thaarup, R. K., ... & Kotterink, B. (2014). Mapping smart cities in the EU. European Parliament, Directorate-General for Internal Policies.

Marek, L., Campbell, M., & Bui, L. (2017). Shaking for innovation: The (re)building of a (smart) city in a post-disaster environment. Cities, 63, 41–50.

Mora, L., Deakin, M., & Reid, A. (2020). Strategic principles for smart city development: A multiple case study analysis of European best practices. Technological Forecasting and Social Change, 153, 119302. https://doi.org/10.1016/j.techfore.2020.119302

Mori Memorial Foundation. (2024). Global Power City Index 2024 (GPCI 2024). Retrieved from https://mori-m-foundation.or.jp/english/ius2/gpci2/index.shtml

UN-Habitat. (2020). World cities report 2020: The value of sustainable urbanization. United Nations Human Settlements Programme. Retrieved from https://unhabitat.org/World-Cities-Report-2020

Unal, M., & Alptekin, G. I. (2023). Using multi-criteria decision-making for smart city evaluation and ranking. Kent Akademisi, 16(4), 2538–2552.

Zavadskas, E. K., Kaklauskas, A., & Sarka, V. (1994). The new method of multicriteria complex proportional assessment of projects. Technological and Economic Development of Economy, 1(3), 131–139.

An innovative method for computing static corrections using seismic reflection horizons analysis

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Abstract: Seismic exploration faces significant challenges due to the physical parameters and geometric complexity of near-surface layers, making their modeling essential for accurately calculating static corrections. These corrections are crucial for preserving the image of geological structures represented by seismic reflectors. However, obtaining key physical parameters, such as the replacement velocity of the substrate and the velocities and thicknesses of near-surface layers, remains challenging. This study proposes a novel approach that addresses the issue in an alternative way. The innovative calculation method allows the direct computation of static corrections, relying solely on the structural analysis of seismic horizons in the near-trace section. Notably, this approach does not require prior knowledge of the weathered zone model. The application of this method to both simulated and real reflection seismic data demonstrates its potential and effectiveness. The static corrections derived from this approach significantly improve seismic image quality and eliminate abnormal regional static corrections compared to calibrated refraction static corrections. Furthermore, this method does not require calibration with borehole data, simplifying the process and representing a significant advantage over traditional methods. In summary, this innovative approach provides an effective solution to the challenges of near-surface layer modeling, delivering substantial improvements quantitatively-through time and effort savings, and reduced error-and qualitatively by enhancing data quality, ensuring consistency with geological realities, and enabling more reliable geological interpretations.

Keywords: Static corrections; Weathered zone model; Near-surface layers; Near-surface structures; Near-trace section; Seismic horizons; Frequency decomposition.

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1. INTRODUCTION AND PROBLEM STATEMENT

In seismic exploration, the heterogeneity and anisotropy associated with velocity variations, along with the geometric and lithological complexity of near-surface layers, significantly influence the arrival times of seismic waves. As a result, these factors affect imaging characteristics such as continuity, coherence, resolution, and particularly the shape of seismic horizons and the geological information obtained [1-4].

Computing static corrections is a processing operation that involves aligning the source and receiver points on the same reference plane. This is achieved by filling the gap between the datum plane and the bedrock of low-velocity layers with a replacement velocity close to or equal to that of the consolidated layer [1,4].

The refraction statics method is the most used approach for determining static corrections in seismic processing centers. It calculates statics by modeling near-surface layers, a process that remains challenging. Existing methods utilize the travel times of refracted waves to generate a model of the weathered zone (WZ) for computing static corrections. However, these refraction statics methods require picking the first arrivals on seismic reflection records, which consumes time and necessitates significant human intervention. Near-surface structures often coexist with low-quality first arrivals, particularly in scenarios involving complex geometries, which complicates the picking process [5]. Constructing accurate surface models requires high-quality first arrivals; however, results from the refraction method based on these data are not always satisfactory. Therefore, calibrating static corrections with borehole information is essential to achieve reliable values [6]. In regions with poor-quality refractors and terrestrial areas with intricate surface features, the correction process is often complicated, making it time-consuming. To tackle these challenges, automatic picking techniques for first arrivals have been developed [7-11]. However, low-quality first arrivals frequently coincide with complex near-surface structures, further complicating the picking procedure [5]. Additionally, surface conditions and the characteristics of the near-surface layer—such as heterogeneity, anisotropy, discontinuities, geological uplifts, velocity inversions, and variations in interface shape and dip—affect the recorded refraction waves. These factors contribute to the difficulties in modeling the WZ [1,4].

The challenges faced when using refracted waves from reflection seismic acquisition underscore the limitations of static refraction corrections and raise the question of whether these first arrival waves are truly suitable for modeling the WZ. In this work, we introduce a novel technique for computing primary static corrections from the travel time of reflected waves, eliminating the need for first arrival picking and the requirement to model the WZ. This technique utilizes near-

trace sections to facilitate the rapid and straightforward identification of seismic horizons (reflectors) affected by static anomalies. The potential, performance, and effectiveness of this method are confirmed and validated through its application to simulated data, followed by real seismic data.

It is well established that one of the quality control procedures for static corrections involves verifying the data from seismic sections post-stacking [6]. Using this criterion, the quality control was conducted on seismic profile data measuring 68 kilometers, characterized by clearly variable surface conditions and morphology.

The seismic sections of the profile were processed using two static correction solutions: the proposed technique and the diminishing residual matrices (DRM) refraction statics method [12]. A comparison of the results was then performed on both obtained seismic sections.

This comparison demonstrates that the proposed method significantly reduces the errors associated with the DRM approach. Consequently, the results highlight the advantages of this new technique and provide a comprehensive evaluation of its impact on the interpretation of seismic data.

2. METHODOLOGY

Sedimentary basins have generally undergone multiple tectonic phases, significantly altering sedimentation patterns and basin morphology. The impact of tectonic forces on the formation and evolution of geological layers and sedimentary environments highlights the geological deformations from the Paleozoic to the Cenozoic eras [13,14]. Consequently, geological layers did not form simultaneously. These layers have experienced syn-sedimentary deformations, resulting in geological interfaces that are globally uncorrelated and linearly independent of one another. This characteristic serves as a valuable criterion for evaluating the accuracy of the structural image represented by the seismic reflection horizons in the near-trace section. Thus, in a zero-offset seismic section without applied static corrections, it can be observed that all seismic horizons, from top to bottom, are influenced by the same deformation. This deformation manifests as a common curve among the seismic horizon curves in the zero-offset seismic section, corresponding to the total static corrections. Consequently, calculating this common curve provides the requisite static corrections for accurate interpretation.

This study aims to extract this common curve, or common solution, from the seismic horizons selected on the near-trace section. The principle of the method is illustrated on simulated data, corresponding to a geological model with three synthetic horizons, before and after removing the common curve (**Figure 1**).

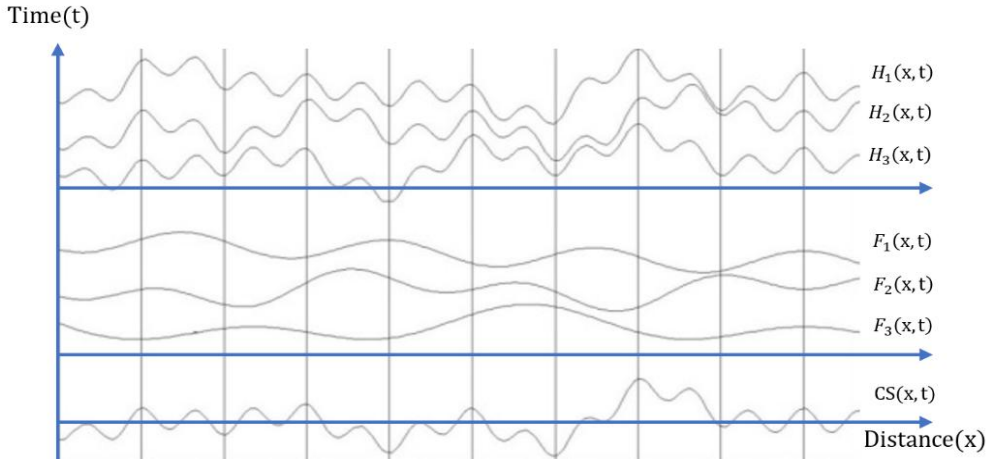

Figure 1. Synthetic model of seismic horizons on the near-trace section, with and without effects of elevation and near-surface layers. Abbreviation: CS: Common solution.

$$\begin{cases} H_1(x,t) = F_1(x,t) + CS(x,t) \\ H_2(x,t) = F_2(x,t) + CS(x,t) \\ H_3(x,t) = F_3(x,t) + CS(x,t) \end{cases} \quad (I)$$

In **Equation I**, H_1, H_2, and H_3 refer to the horizons before application of static corrections (time geological model), F_1, F_2, and F_3 refer to the horizons after application of static corrections, CS refers to the common solution (static corrections model), and (x,t) is the spatiotemporal localization.

The process applied the Fourier transform to the mathematical functions representing the horizon curves selected on the seismic section of the near-trace section into several frequency classes [4,15-17]. Then, these frequency classes were constructed and used as matrix data to calculate the separation operator matrix and, consequently, the common solution curve, $CS(x,t)$.

The computational procedure for calculating static corrections is summarized in **Table 1**.

Table 1. The algorithm to calculate static correction using seismic reflection horizons

Input	Data input and preprocessing
1	Construction of a near-trace seismic section with no applied static corrections
2	Selection of significant seismic horizons
3	Spectral decomposition of selected horizons
4	Matrix computing
4.1	Construction of a binary matrix, the "separation operator," by normalizing and stacking all the frequency classes
4.2	Obtaining the common matrix through outer multiplication of the separation operator with each decomposed horizon
4.3	The common curve is the stacking of all columns of the common matrix.
4.4	The total statics curve is obtained by averaging stacks of all common curves
End	Separation of source and receiver statics

3. RESULTS

3.1. Application to simulated data

To demonstrate the potential of the suggested technique, it was applied to simulated data. For this purpose, a four-layer model was constructed and a known static anomaly containing high- and medium-frequency components was introduced. The obtained results are shown in **Figure 2**. The separation operator was applied to all the decomposed selected horizons. The obtained curves of the common solutions were consistent and comparable. The average stack of all common solutions was considered to improve the solution accuracy.

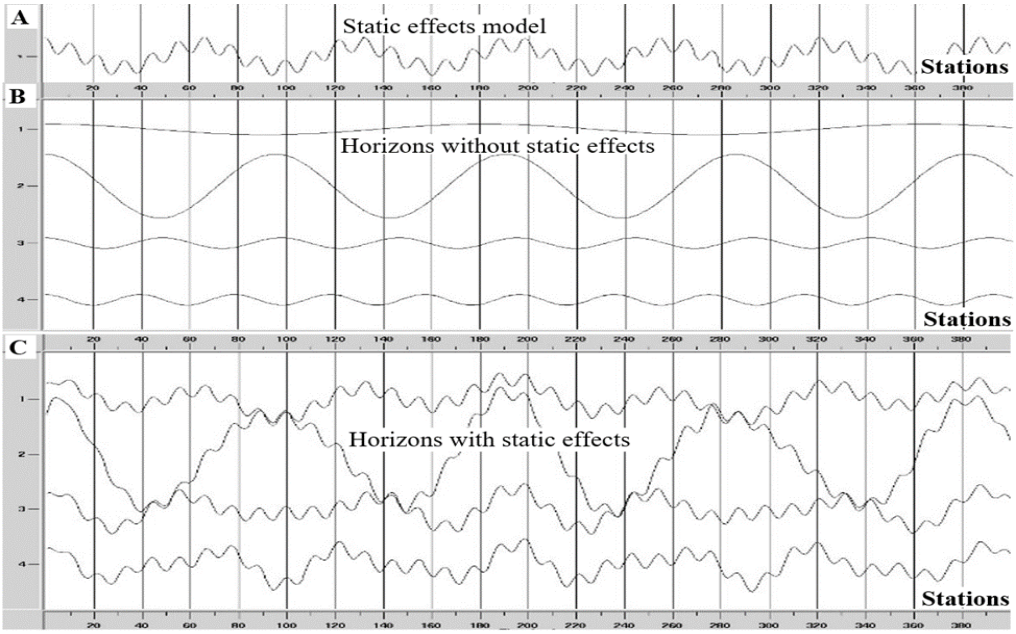

Figure 2. Model of synthetic seismic horizons on near-trace section. (A) Static anomalies model at 15 Hz summing to 90 Hz. (B) Horizons unaffected by statics at 5 Hz, 10 Hz, 20 Hz, and 25 Hz. (C) Horizons with static effects.

The effectiveness of the method was further validated through a comparison of the original (theoretical) static model and the static corrections calculated post-separation. This comparison revealed a negligible discrepancy between the two curves, as illustrated by the error curve. Additionally, the successful application of this method on simulated data confirmed its high calculation accuracy, highlighting its reliability and potential for application to real seismic data processing.

3.2. Application to real data

The shape of the time seismic horizons in the near-trace section indicated good geological interfaces deformed by the effects of surface elevation and the properties of the near-surface layers (**Figure 3**). A near-trace seismic section was constructed by selecting the near-offset traces without applying static corrections, using data that had already been preprocessed. Five seismic horizons were identified and picked from top to bottom (**Figure 3**).

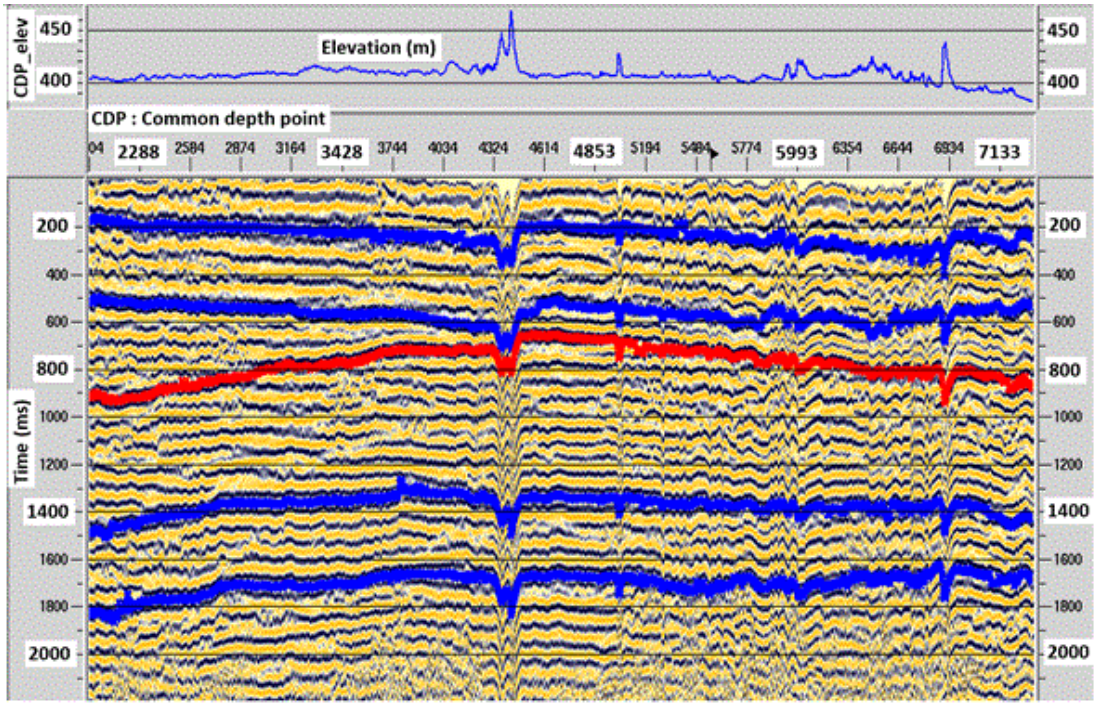

Figure 3. Seismic reflection horizons interpreted on the near-trace section without applying static corrections.

The common curve was determined based on the spectral decomposition of seismic horizons selected on a near-trace section. The elementary decomposition of each seismic horizon curve was performed within a common frequency band, established through the spectral frequency analysis of all horizon curves.

The curves were converted into traces with an inter-common medium point of 12.5 m, and the sampling rate was set to 2 milliseconds to adapt to the frequency range (0.1–60 Hz) for software processing. High frequencies exhibited low amplitudes, which helped determine the maximum frequency limit for effective processing. The frequency analysis of each horizon revealed that high-frequency components have low amplitudes (**Figure 4E**), aiding in determining the optimal maximum frequency and the overall frequency band for the subsequent elementary frequency decomposition.

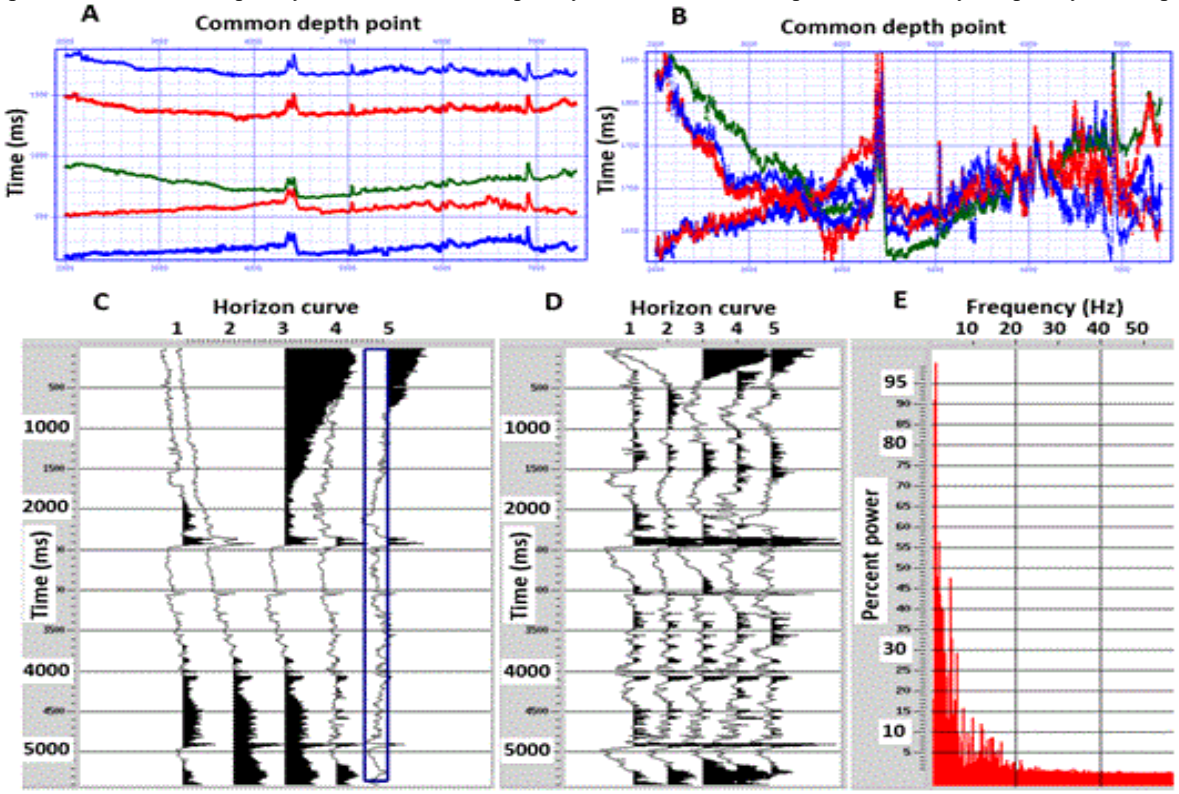

Figure 4. Conversion and processing of horizon curves. (A) Selected horizon curves. (B) Superposition of selected horizon curves. (C) Horizon curves converted into traces. (D) Traces with common frequency band. (E) Frequency spectrum of all the traces (Percent power).

Each curve was decomposed into elementary frequencies and sorted into frequency classes. The selected horizon curves, non-stationary signals, were individually decomposed using the short-time Fourier transform and then categorized into their respective frequency classes.

Each elementary trace was normalized, and a separation operator matrix was constructed. The common curve was then obtained by multiplying the operator matrix by each decomposed horizon matrix. The total statics curve was calculated as the average stack of all resulting curves. The common curve, derived from all horizons, was generated through element-by-element matrix multiplication of the normalized frequency elementary components, followed by summation to produce a common global solution curve (**Figure 5**).

When applied to all selected horizons, the operator matrix yielded consistent and comparable results with acceptable accuracy. To enhance the precision of the total static correction, the average of all common solution curves was computed.

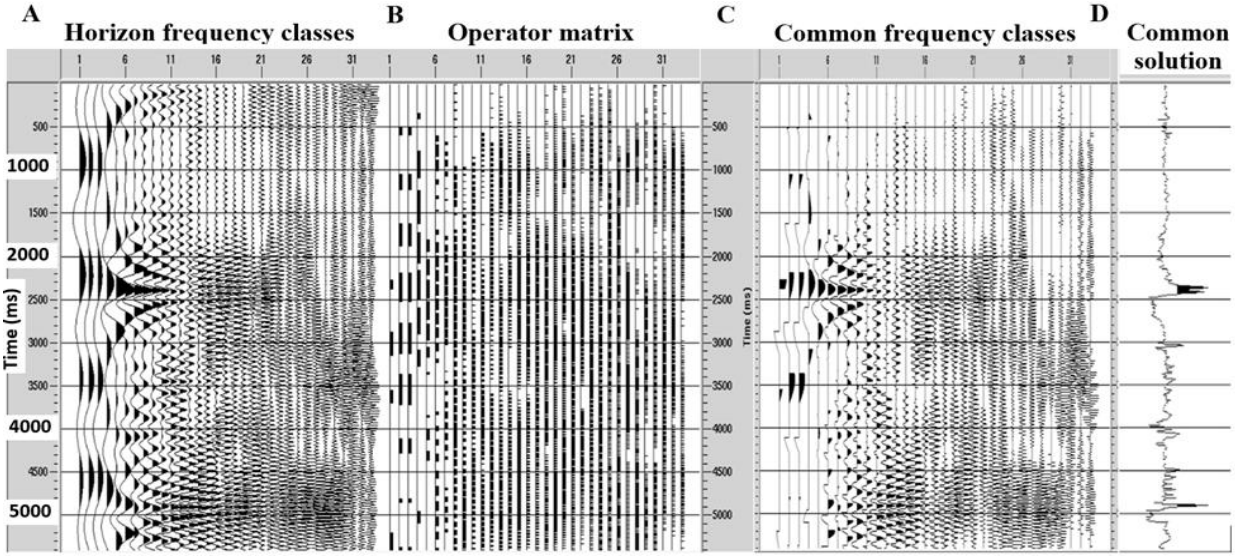

Figure 5. Decomposed horizons matrix, the separation operator matrix, and the common solution pre-stack matrix and post-stack curve. (A) Decomposed horizons. (B) Separation operator. (C) Pre-stack common solution. (D) Common solution curve.

An approximate calculation (**Equations II**–**IX**) was proposed to separate the source and receiver static corrections from the total static corrections by using the elevations of the source and receiver to deduce a mean velocity. It considers the difference between source and receiver elevations, as well as the mean elevation of the entire seismic line (Z_{mean}).

$$\delta_z = Z_r - Z_s \quad \text{(II)}$$

where δ_z is the difference between source and receiver elevations (in meters), Z_s is the source elevation (in meters), and Z_r is the receiver elevation (in meters).

$$Z_m = (Z_s + Z_r)/2 \quad \text{(III)}$$

where $Z_m = Z_{CMP}$, in which $Z_m$is the mean elevation between the source and the receiver (in meters), also referred to as the common midpoint elevation (Z_{CMP}). $Z_{CMP}$is the elevation of the common medium point between the source and the receiver (in meters).

$$V_m = 2(Z_m - Z_{mean})/CS_T \quad \text{(IV)}$$

where V_m is the average velocity between the mean elevation Z_m and the reference elevation Z_{mean}.

$$\delta_T = {}^{\delta_z}/_{V_m} \quad \text{(V)}$$

where δ_T is the time difference between the source and the receiver static corrections (in seconds).

$$CS_T = 2(Z_m - Z_{mean})/V_m \quad \text{(VI)}$$

where CS_T is the total static correction (in meters), and Z_{mean} is the mean elevation of the entire seismic line (400 meters).

$$CS_T = CS_S + CS_R \quad \text{(VII)}$$

$$CS_S = (CS_T - \delta_T)/2 \quad \text{(VIII)}$$

$$CS_R = CS_T - CS_S \quad \text{(IX)}$$

Where CS_S is the source static correction, and CS_R is the receiver static correction.

We present a novel technique for computing static corrections directly from the travel times of reflected waves. This approach calculates total static corrections by identifying seismic reflection horizons on the near-trace section. The static

corrections for both the source and the receiver are derived from elevation values. To illustrate the effectiveness and efficiency of this method, the results were compared with those obtained from refraction statics based on the DRM method (**Figures 6–9**).

The suggested technique was applied to a 68-kilometer seismic profile, and the results obtained were compared to those derived using the DRM-based refraction statics method [12]. The refraction statics solution was computed by picking the first arrivals in the offset range of 150 m to 1100 m, using V0=800 m/s and V1=2,400 m/s (**Figure 6**).

The curves of the refraction static corrections and the proposed corrections displayed a similar global trend; however, notable differences were observed in the regional, medium, and short wavelengths (**Figures 6&7)**. The differences in values (10 to 20 ms) between the static curves from the receivers over distances ranging from 10 km to 20 km (**Figure 7**) suggest the presence of significant errors that could result in misleading and erroneous structural interpretations, thereby distorting the overall geological interpretation.

This comparison demonstrated that the proposed method significantly reduced the errors associated with the DRM method (**Figures 6** & **7**). Additionally, it enhanced the quality of seismic data and ensured accurate interpretation of geological structures (**Figures 8** & **9**). Consequently, the results highlighted the advantages of the proposed approach and offered a comprehensive evaluation of its impact on the interpretation of seismic data.

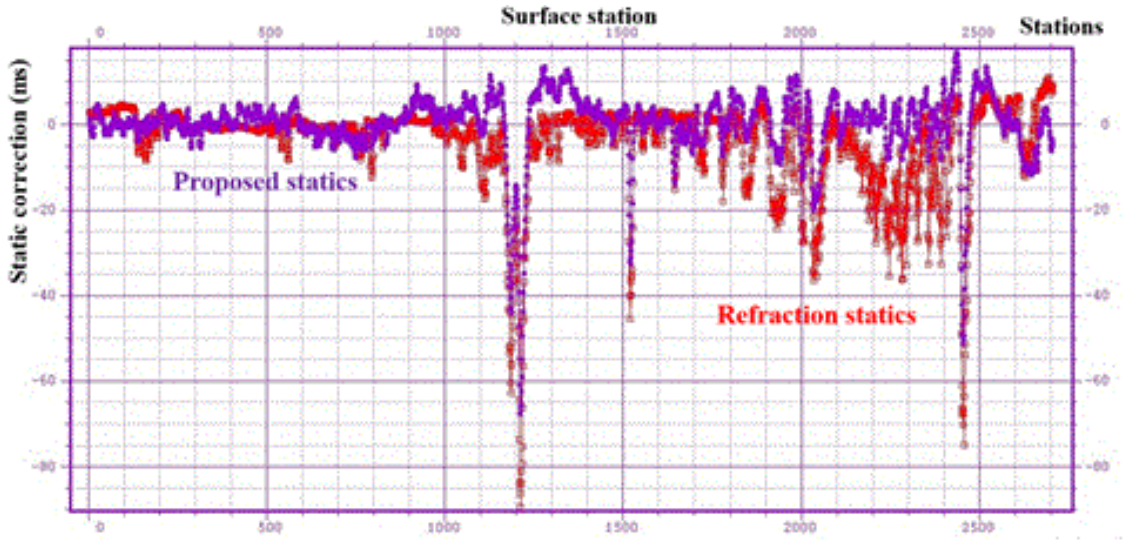

Figure 6. Comparison of static correction curves obtained using the proposed method (purple) and the refraction method (red).

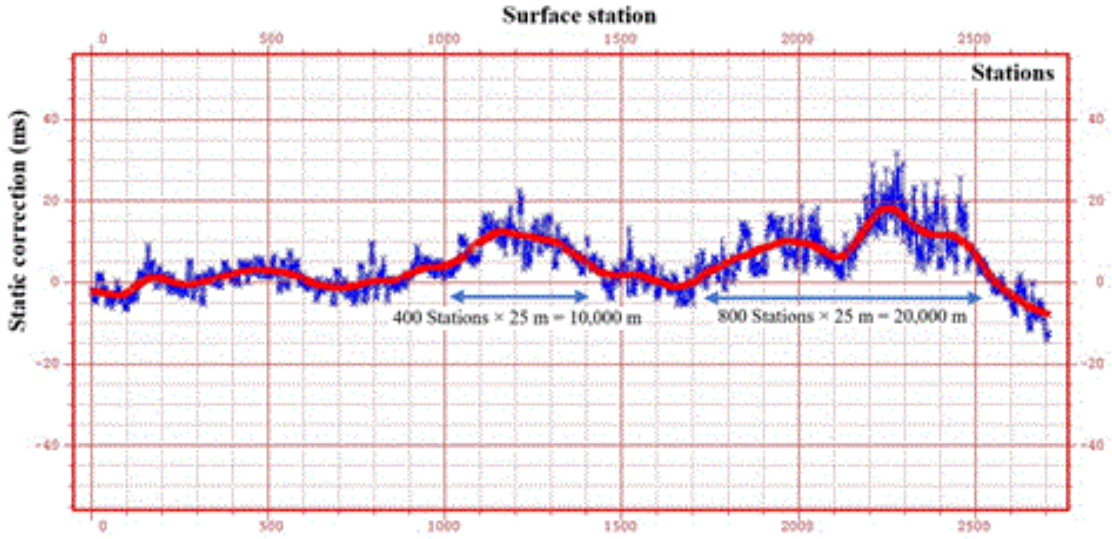

Figure 7. The difference between the static curves obtained from the proposed method and the refraction method, presented with smoothing (red) and without smoothing (blue).

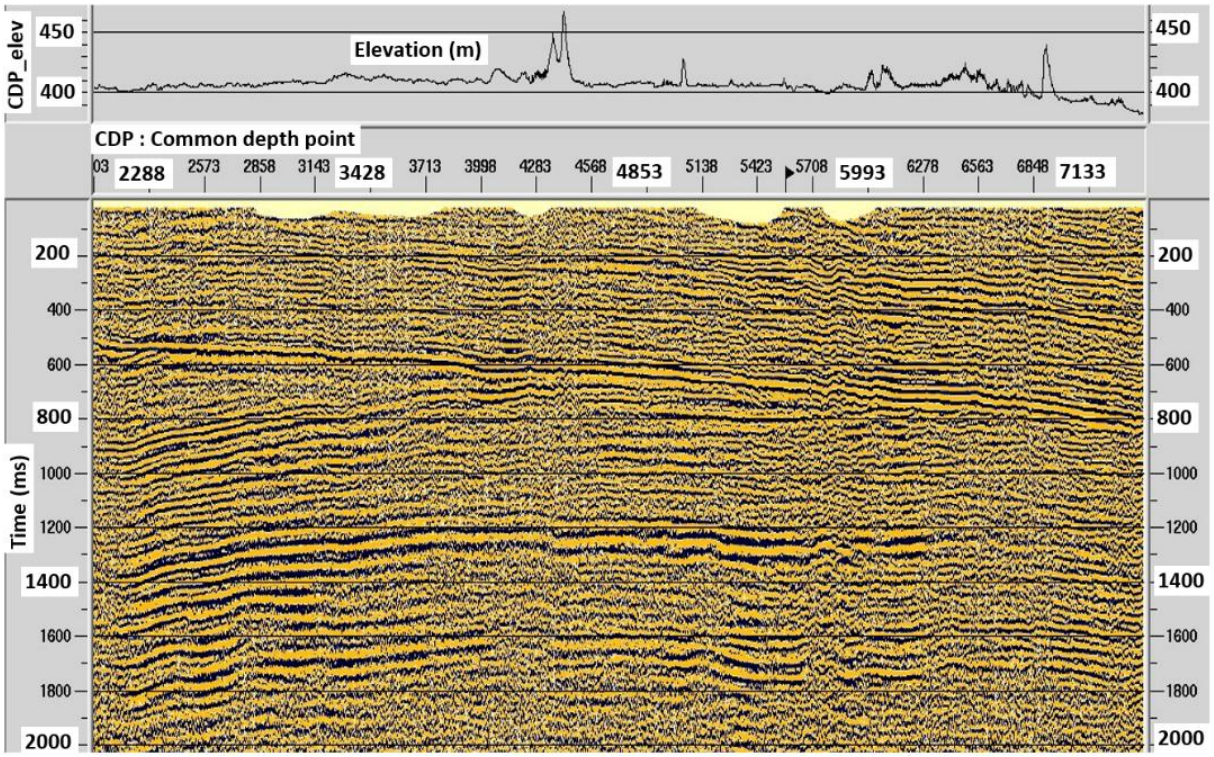

Figure 8. Seismic section processed using refraction static corrections. CDP_elev refers to CDP elevation.

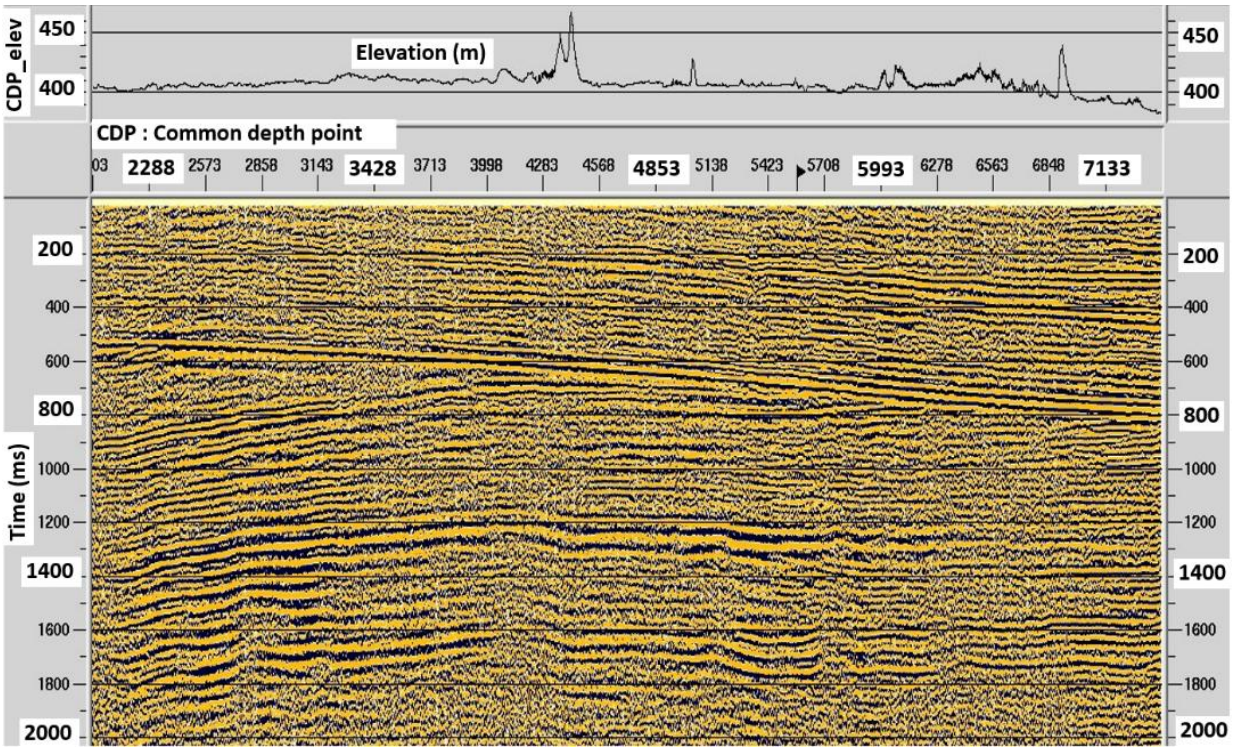

Figure 9. Seismic section processed using the proposed static corrections. CDP_elev refers to CDP elevation.

One quality control procedure for static corrections involves checking the data on the seismic section after stacking [6]. The proposed method improved the seismic image and provided more precise and accurate static corrections. The horizons were clearer in the seismic section obtained. In addition, the comparison with calibrated refraction statics revealed significant improvements in seismic imaging and regional static anomalies removal (**Figures 6** & **7**).

Unlike static corrections derived from refraction methods, which require calibration with borehole data to correct regional trends, the suggested method eliminates the need for such calibration. This improved accuracy enhances continuity, coherence, resolution, and the representation of geological structures, making this approach highly efficient for seismic data processing.

A comparison of the results showed that this method provided more accurate static corrections, significantly reducing errors and enhancing the quality of seismic horizons in terms of continuity, energy, resolution, and signal-to-noise ratio across the entire seismic section (**Figures 8** & **9**).

4. DISCUSSION

In this study, we proposed an innovative method for calculating static corrections by analyzing horizons in the near-trace section, thereby eliminating the need for prior modeling of the near-surface layers.

The impact of heterogeneity and discontinuous structures near the surface on seismic wave velocity is evident in the variations observed in the travel times of reflected seismic waves. The method is based on accurately identifying these horizons in a zero-offset section (prior to applying static corrections). The total static correction is derived by extracting the common deformation curve shared among the horizons. However, regardless of the complexity of the near-surface structures, if the seismic horizons cannot be clearly identified after advanced processing and filtering, the method will not be applicable and will be considered a limitation. The application of the proposed methodology to simulated data demonstrated its effectiveness, showing excellent agreement with theoretical models and thereby validating the robustness of the technique. This robust performance on simulated datasets provided a solid foundation for its application to real-world seismic data. However, while the results obtained from the real data offered valuable insights, they also revealed certain limitations, particularly under challenging conditions. These observations raise important considerations regarding the method's reliability in less-than-ideal acquisition or geological contexts.

The results obtained from both simulated and real seismic data demonstrated that the proposed approach significantly outperformed traditional methods, particularly refraction statics, in terms of both accuracy and efficiency. When applied to real data, it yielded a notable enhancement in seismic image quality by effectively mitigating regional anomalies typically observed with calibrated static corrections. This improvement is critical for ensuring the continuity and consistency of seismic horizons, which are fundamental for reliable geological interpretation. Compared to calibrated refraction statics, the method produced substantial gains in image clarity, including enhanced structural continuity and resolution. Moreover, eliminating the need for borehole calibration streamlines the processing workflow while delivering clearer and more coherent seismic sections than conventional techniques.

Although the results are promising, it is essential to acknowledge certain limitations of the study. One of the main sources of error lies in the data quality, particularly when the data presents a low signal-to-noise ratio. In such cases, powerful filtering is required to clarify reflected seismic horizons, complicating their analysis and shape tracking.

In summary, this method demonstrated that the proposed method offers an efficient and reliable solution for calculating static corrections in seismic exploration. By simplifying the process and improving the quality of seismic images, it addresses one of the main challenges in seismic exploration: the modeling of complex and heterogeneous near-surface layers. Traditional methods, such as refraction statics, heavily rely on the quality of first arrivals, which can be problematic in challenging geological environments [5,6]. The proposed method circumvents the need for first arrival picking and near-surface layers modeling, which are both time-consuming and prone to human error.

Although this study has demonstrated the applicability of our methodology, it is essential to continue refining this approach to maximize the impact of the results in the field. It would be relevant to develop this method to integrate the study and analysis of discontinuous and segmented seismic horizons in the case of sedimentary basins with complex and rugged geology. Furthermore, it is essential to further develop this method to be suitable for three-dimensional studies. These complementary avenues of research could strengthen the robustness of the method and broaden its scope of application.

5. CONCLUSION

The innovative method developed for calculating static corrections represents a significant advancement in seismic exploration methodologies. Based on the reality of geological structures, this approach utilized images of seismic horizons to directly estimate total static corrections without relying on prior information from the WZ model. This independence streamlined the correction process and enhanced the reliability of seismic interpretations.

The technique analyzes time seismic horizons (reflectors) selected from the near-trace section. By correcting for variations in surface elevation, the velocities of near-surface layers, and the bedrock (replacement velocity), the method effectively addresses the regional components of static corrections. This analysis prevents the introduction of fictitious structures, ensuring the final seismic images remain true to geological reality.

A comparison of the results showed that this method provides more accurate static corrections, and improves the seismic imaging and the quality of seismic horizons in terms of continuity, coherence, energy, resolution, signal-to-noise ratio, while respecting the reality of geological structures over the entire seismic section, making this approach efficient for seismic data interpretation (**Figures 8** & **9**).

Additionally, utilizing the near-trace section for horizon selection reduces the effort required for first arrival picking. This expedites the process and minimizes human error, resulting in faster execution than conventional methods. This advancement is achieved without needing borehole data surveys, increasing efficiency and accessibility, particularly in challenging terrains.

Overall, the results highlight the advantages of this method in improving seismic imaging and its impact on data interpretation. The proposed static corrections are more reliable than traditional techniques, particularly in complex geological settings.

The methodological advances introduced in this study encompass several key innovations and offer a robust and efficient alternative for computing static corrections in seismic exploration. It overcomes key limitations of traditional techniques. Firstly, directly calculating static corrections eliminates the need for prior knowledge of the WZ model. Additionally, the study removes the necessity for picking first arrivals and avoids calibration with borehole data, which reduces human error, simplifies the process, and lowers costs. The method is also independent of complex near-surface structures, effectively addressing discontinuity, heterogeneity, and anisotropy challenges in the near-surface layers. Moreover, it demonstrates efficiency in execution, achieving faster processing times through near-trace sections. Lastly, the quality and reliability of seismic images are enhanced by adhering to the structural geological reality.

Furthermore, this innovative method represents a substantial advancement in seismic exploration, contributing to more reliable and efficient geological assessments.

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REFERENCES

1. Cox M. *Static Corrections for Seismic Reflection Surveys*. Thousand Oaks: SEG Books; 1999. doi: 10.1190/1.9781560801818

2. Marsden D. Static corrections: A review. Part I. *Geophys Lead Edge*. 1993a;12(1):43-49. doi: 10.1190/1.1436912

3. Marsden D. Static corrections: A review. Part II. *Lead Edge*. 1993b;12(2):115-120. doi: 10.1190/1.1436936.

4. Yilmaz Ö, Stephen MD. *Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data*. Vol. I&2. Thousand Oaks: SEG Books; 2001.

5. Tlalka S, Sobocinski R. Modelling for Statics Correction. In: *75th EAGE Conference and Exhibition*, London, UK; 2013. p. 10-13.

6. Tlalka S. *Static Corrections in Challenging Cases*. India: Society of Petroleum Geophysicists; 2010.

7. Boschetti F, Dentith MD, List RD. A fractal-based algorithm for detecting first arrivals on seismic traces. *Geophysics.* 1996;61:1095-1102. doi: 10.1190/1.1444030

8. Coppens F. First arrival picking on common-offset trace collections for automatic estimation of static corrections. *Geophys Prospect.* 1985;33:1212-1231. doi: 10.1111/j.1365-2478.1985.tb01360.x

9. Molyneux JB, Schmitt DR. First-break timing: Arrival onset times by direct correlation. *Geophysics.* 1999;64:1492-1501. doi: 10.1190/1.1444653

10. Mousa WA, Al-Shuhail A, Al-Lehyani A. A new technique for first-arrival picking of refracted seismic data based on digital image segmentation. *Geophysics.* 2011;76:V79- V89. doi: 10.1190/geo2010-0322.1

11. Zhang H, Thurber C, Rowen C. Automatic P-wave arrival detection and picking with multiscale wavelet analysis for single-component recordings. *Bull Seismol Soc Am.* 2003;93:1904-1912. doi: 10.1785/0120020241

12. Gülünay N. The diminishing residual matrices method for surface-consistent statics: A review. *Geophysics*. 2017;82(4):V257-V274. doi: 10.1190/geo2016-0602.1

13. Allen PA, Allen JR. *Basin Analysis: Principles and Application to Petroleum Play Assessment*. 3rd ed. United States: Wiley and Blackwell; 2013.

14. Ladjadj Y. *Structural Study of the Lower Chellif Basin Based on Gravimetric, Magnetic, and Seismic Data. (Thesis Title Translated from French). Master's Thesis*. Ferhat Abbas University-Sétif 1; 2018. Available from: https://dspace.univ-setif.dz:8888/jspui/handle/123456789/2448.

15. Robinson EA, Treitel S. Principles of digital filtering. *Geophysics*. 1964;29:395-404.

16. Buttkus B. *Spectral Analysis and Filter Theory in Applied Geophysics*. Berlin, Heidelberg: Springer; 2000. doi: 10.1007/978-3-642-57016-2

17. Oppenheim AV, Schafer RW. *Discrete-Time Signal Processing*. 3rd ed. United Kingdom: Pearson; 2013.

The Impact of Real-Time Fashion Systems on Sustainability in Turkey

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Abstract: Real-Time Fashion Systems (RTFS) and blockchain technology have gained attention in the context of environmental sustainability, particularly in sectors with high resource intensity such as fashion. The current study explores how these digital innovations could be leveraged to reduce ecological pressures within Turkey's apparel industry. Drawing from survey responses and scenario simulations, the analysis indicates measurable reductions in carbon emissions, energy demand, and production costs when RTFS-based models are considered. A decision tree model was applied to uncover key behavioral drivers among consumers, with price sensitivity emerging as the primary determinant of eco-friendly purchasing. Additional factors, including awareness of sustainability and familiarity with RTFS, were also shown to influence decisions. These results point to the potential of combining technological and behavioral strategies to accelerate sustainability transitions in the textile sector. Enhancing consumer engagement and promoting transparency in production practices are discussed as necessary steps toward broader adoption.

Keywords: Real-Time fashion systems, blockchain, sustainability, fashion industry, Turkiye.

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1. INTRODUCTION

The fashion industry is one of the leading contributors to global environmental degradation, responsible for nearly 10% of carbon emissions worldwide (Remington, 2020). The fast fashion model accelerates this impact through rapid production cycles and high consumption, resulting in excessive energy use and textile waste (Hacıola & Atılgan, 2024).

Technological solutions such as Real-Time Fashion Systems (RTFS) and blockchain have emerged as promising tools to address these sustainability challenges (Lee, 2021). RTFS optimizes production using artificial intelligence and digital tools, minimizing waste and reducing energy consumption. Blockchain enhances supply chain transparency and traceability, allowing verification of sustainable practices.

In Turkey, the fashion industry faces similar environmental pressures, including 10–15% cut-and-sew waste (Enes & Kipöz, 2019) and increased regulatory pressure under the EU Green Deal. In response, many manufacturers have adopted practices including the use of organic cotton, recycled textiles, and emission-reducing technologies.

Although some studies examine these technologies separately, research integrating consumer behavior with RTFS and blockchain applications remains limited. This study aims to bridge that gap by evaluating the effects of RTFS and blockchain on sustainability in the Turkish fashion industry, combining survey data with scenario-based modeling.

2. MATERIAL AND METHOD

2.1. Research design

This study adopts a mixed-method approach combining quantitative survey analysis and scenario-based simulation to evaluate the impact of Real-Time Fashion Systems (RTFS) and blockchain technologies on sustainability in Turkey's fashion industry.

2.2. Data collection

2.2.1. Survey

A structured online survey was conducted with 100 participants across Turkey. The questionnaire covered three areas:

- Demographics: gender, age, and income level.
- Awareness: familiarity with sustainable textile products and RTFS.
- Purchasing behavior: willingness to buy eco-friendly products and price sensitivity.

The dependent variable was defined as eco-friendly purchasing behavior (1 = Purchase, 0 = No Purchase).

2.2.2. Simulation data

Scenario modeling was conducted using hypothetical data obtained from the literature. Comparative metrics were established as follows:

- Traditional fashion: 10 kg CO_2 emissions, 1000 kWh energy consumption, 100 units of cost.
- RTFS scenario: 4 kg CO_2, 700 kWh, 85 units of cost.

These figures were used to calculate potential gains in sustainability through RTFS and blockchain integration.

2.3. Data analysis

2.3.1. Decision tree modeling

A decision tree model was developed to determine the factors influencing eco-friendly purchasing behavior. The independent variables were:

- X_1: Sustainability awareness (1 = Yes, 0 = No)
- X_2: RTFS perception (1 = Yes, 0 = No, 2 = Neutral)
- X_3: Price sensitivity (1 = Yes, 0 = No)

The dataset was split into 80% training and 20% testing subsets. The Gini index was used to construct the tree, and model performance was evaluated using a confusion matrix and ROC-AUC score.

2.3.2. Scenario-based impact calculations

The sustainability impact of RTFS was measured with the following formulas:

- Carbon footprint reduction (%):

$$\frac{Traditional\ carbon\ footprint - RTFS\ carbon\ footprint}{Traditional\ carbon\ footprint}\ x\ 100 \quad (1)$$

- Energy efficiency improvement (%):

$$\frac{Traditional\ energy\ consumption - RTFS\ energy\ consumption}{Traditional\ energy\ consumption}\ x\ 100 \quad (2)$$

- Cost reduction (%):

$$\frac{Traditional\ cost - RTFS\ cost}{Traditional\ cost}\ x\ 100 \quad (3)$$

3. RESULTS

The demographic profile of the survey respondents demonstrates a balanced distribution across age groups and income levels. Female participants accounted for 60.3% of the sample, while 39.7% identified as male. The largest age segment was the 45 and over group (37.7%), followed by the 18–24 group at 36.4%, with smaller proportions represented by the 25–34 and 35–44 brackets. Regarding income, 70.2% of participants fell within the middle-income category, with 18.5% categorized as low-income and 11.3% as high-income earners.

When assessing awareness of sustainability, 51.7% of participants reported having prior knowledge of eco-friendly textile products. Social media emerged as the dominant source of information, influencing 68.2% of those aware, whereas traditional media such as television accounted for only 4%. The remaining participants cited their personal environment (10.6%) or other channels (17.2%) as sources of information.

In terms of purchasing behavior, a strong inclination toward sustainable products was observed. Approximately 79.5% of respondents stated that eco-friendliness influenced their buying decisions, and 66.2% indicated a willingness to pay up to 10% more for such products. Among the attributes prioritized when selecting sustainable goods, quality was the leading factor at 45.05%, followed by price (34.45%), environmental impact (15.25%), and brand reputation (5.25%).
Participants' perceptions of RTFS and blockchain technologies were also evaluated. A majority, 64.2%, viewed RTFS positively in terms of environmental contribution. Additionally, 79.5% expressed increased trust in companies employing blockchain due to its capacity to enhance supply chain transparency and credibility.

The decision tree model yielded several insights into the classification performance and predictive power of the variables used in the analysis. According to the confusion matrix, the model correctly classified 13 instances as true positives (class 1) and 8 instances as true negatives (class 0), while 3 cases were identified as false positives and 6 as false negatives. The overall classification accuracy of the model was calculated at 70%, with a ROC-AUC score of 0.70, indicating a moderate level of discriminative ability. Figure 1 shows the ROC curve.

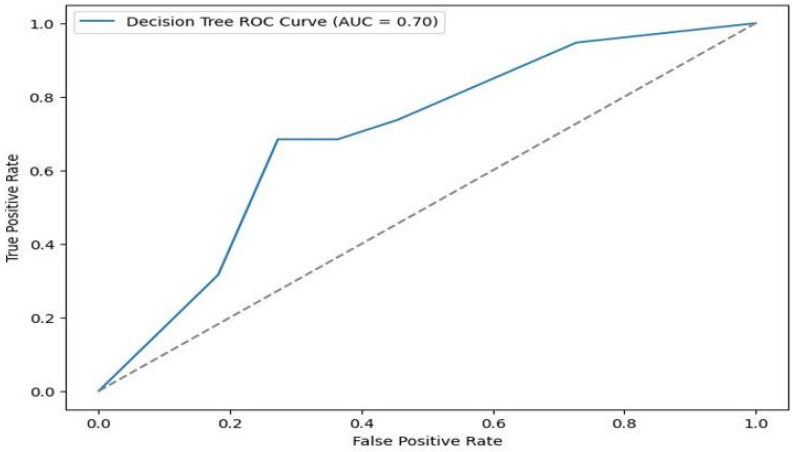


Figure 1. ROC curve

The classification report further details the model's performance across both classes. For the positive class (1), the precision was 81%, recall was 68%, and the F1-score was 74%. For the negative class (0), the model achieved a precision of 57%, a recall of 73%, and an F1-score of 64%. The macro average F1-score was 0.69, while the weighted average F1-score reached 0.71, based on a total of 30 instances evaluated. The classification report is detailed in Table 1.

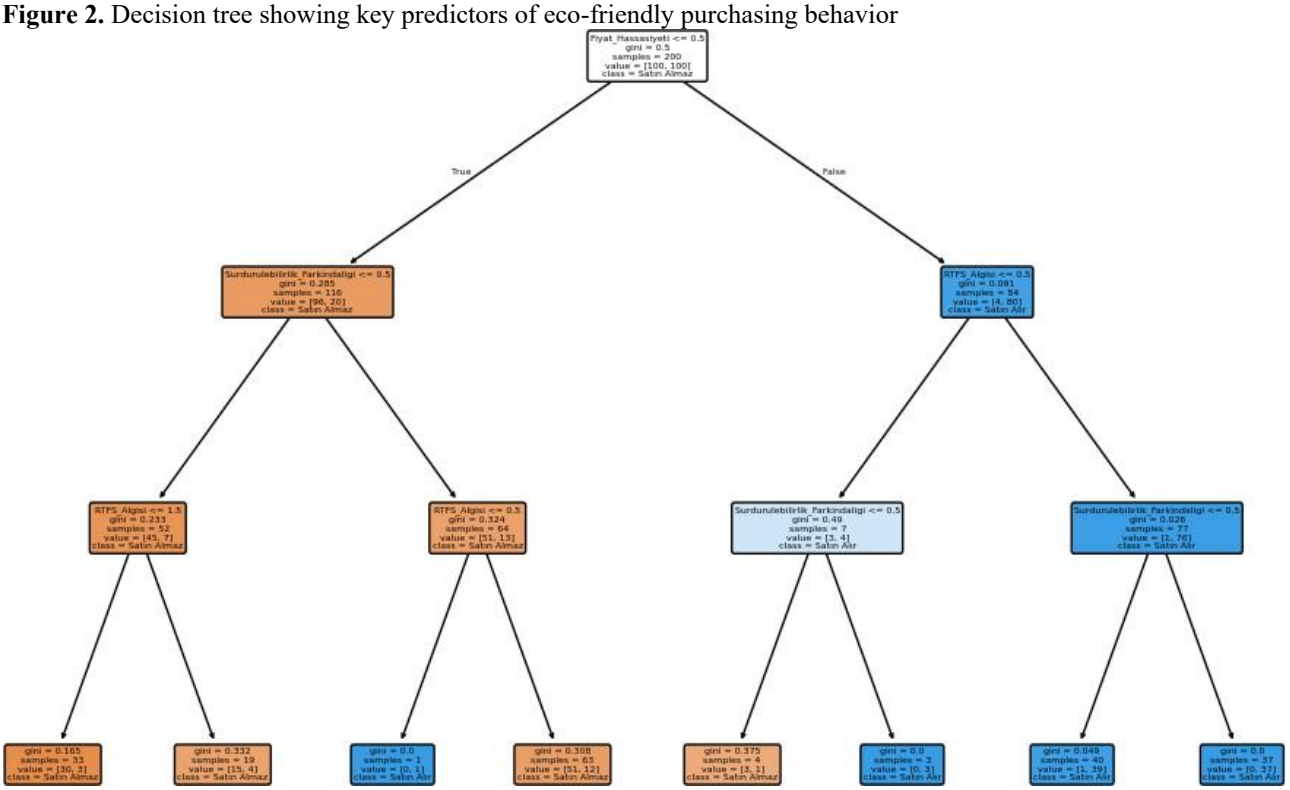
Table 1. Classification Report

	Precision	Recall	F1-Score	Support
0 (Negative)	0.57	0.73	0.64	11
1 (Positive)	0.81	0.68	0.74	19
Accuracy			0.70	30
Macro Average	0.69	0.71	0.69	30
Weighted Average	0.72	0.70	0.71	30

Regarding the structure of the decision tree, the root node was identified as Price Sensitivity, highlighting it as the most influential predictor of eco-friendly purchasing behavior. Subsequent branches included Sustainability Awareness and RTFS Perception, which contributed to the decision pathways by separating observations based on their categorical thresholds.

The structure of the decision tree, as illustrated in Figure 2, visually reinforces the finding that price sensitivity is the primary determinant of eco-friendly purchasing behavior. It is positioned as the root node of the tree, followed by sub-branches based on sustainability awareness and perception of RTFS. These variables collectively guide the classification path according to defined thresholds and contribute to the model's predictive accuracy.

Figure 2. Decision tree showing key predictors of eco-friendly purchasing behavior



4. DISCUSSION AND CONCLUSIONS

The analysis highlights the role of digital transformation in advancing sustainability within the Turkish fashion sector. By integrating RTFS and blockchain technologies, notable gains were observed in terms of reducing environmental impact and operational inefficiencies. Consumer data further emphasize the influence of pricing, awareness, and technological perception in shaping sustainable purchasing habits.

Rather than relying solely on technological adoption, the findings underscore the importance of aligning digital strategies with behavioral dynamics. While environmental awareness is growing among consumers, price considerations continue to play a dominant role in purchasing decisions. The results suggest that promoting digital transparency and improving public understanding of RTFS applications may facilitate broader adoption of sustainable practices.

In light of these observations, fostering collaboration among industry stakeholders, including producers and consumers, appears critical. Tailored strategies that blend technological capability with user-oriented communication may contribute significantly to the sector's transition toward environmentally responsible production models.

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Conflict of Interest / Çıkar Çatışması
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REFERENCES

Enes, E., & Kipöz, Ş. (2019). Turkey fashion industry's cut-and-sew waste problem and its waste management strategies. *Journal of Textiles and Engineer*, 26(113), 97–103. https://doi.org/10.7216/1300759920192611311

Hacıola, Y., & Atılgan, T. (2024). An analysis of fast fashion and fast fashion retailing in Turkey's ready-to-wear sector. *DergiPark Makale Arşivi*. https://dergipark.org.tr

Lee, Y. K. (2021). Transformation of the innovative and sustainable supply chain with upcoming real-time fashion systems. *Sustainability*, 13(1081). https://doi.org/10.3390/su13031081

Remington, C. (2020). Reducing the carbon footprint in textile manufacturing. *Ecotextile News*. Retrieved January 24, 2020, from https://www.ecotextile.com/sponsored-content/reducing-the-carbon-footprint-in-textilemanufacturing.html

Digital traceability and tracking system in sterilization containers

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Abstract: Sterilization containers are critical in ensuring sterility and reducing infection risks in the processing of medical equipment. These containers support the continuity of sterilization processes, especially in hospitals and surgical areas. The counter module integrated into conventional container systems in this study records each sterilization cycle performed in the autoclave devices, enabling systematic maintenance planning and quality assurance. With its ergonomic and seal-oriented design, the container prevents contamination while ensuring optimum sterilization efficiency. In addition, with its wireless data transfer feature, the maintenance periods of vital parts of the container can be monitored and analyzed in real time. In this study, an innovative sterilization container with integrated counter module and mobile application compatibility has been developed to ensure the sustainability of container systems used in sterilization processes and to minimize leakage risks by performing technical service maintenance on time

Keywords: Smart sterilization containers; counter module; wireless data transfer; autoclave device; digital traceability

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1. INTRODUCTION

Sterilization is a critical process that ensures that medical materials are free from microorganisms and infection risks are minimized. Disinfection and sterilization practices, which are the cornerstone of infection control policies in hospitals, are indispensable for the safety of health services. In order for a medical device to be defined as "STERILE", the probability of a single microorganism remaining after the sterilization process must be ≤ 10-6. This value, defined as the Sterility Assurance Level, expresses the numerical value desired to be reached after sterilization (PERÇİN, t.y.). The sterilization containers used in this process ensure not only the preservation of sterility, but also the safe transportation and storage of materials.

Historically, the development of sterilization technology began with Antonie van Leeuwenhoek's observation of microorganisms and extended to modern methods. In 1862, Louis Pasteur suggested that microorganisms cause diseases and that heat could be used to kill bacteria (*Louis Pasteur | Biography, Inventions, Achievements, Germ Theory, & Facts | Britannica*, 2025). The pasteurization process developed by Pasteur showed that bacteria could be destroyed more effectively with moist heat and was an important breaking point for the science of sterilization(“The History of Sterilisation Part 2”, 2025). Looking at the studies in this field in the following years, Charles Chamberland developed a pressurized steam autoclave in 1876. The autoclave optimized the sterilization process thanks to high pressure and temperature, and this method began to be widely used in the health sector. In the 1930s, the modern autoclave was developed by German and American engineers with temperature, vacuum and pressure control systems. Today, autoclave systems are recognized as an economical, non-toxic and effective sterilization method (Frieden, 2017), (Joslyn, 1991).

Central Sterilization Units (CSUs) used in this field play a vital role in the process of cleaning, sterilizing and making medical devices ready for reuse (Arslanoğlu & Urk, 2015). However, sterilization safety is not limited to the CSU. Transporting sterile materials to operating rooms and maintaining sterile conditions until the moment of use is also of great importance. At this point, sterilization containers prevent contamination and protect the materials from external factors. The reuse of medical devices is a special process that requires control of various preparation stages and consists of six stages: pre-disinfection, cleaning, packaging, sterilization, release of the sterilization load and storage or delivery directly to the department (Daoudi vd., 2023). The cost of failures in sterilization processes is quite high. Studies show that infectious complications occur in approximately 2% of surgical operations in the United States (AORN, 2019; Evans, 2009). The cost of these infections can exceed $90,000, especially in arthroplasty cases (AORN, 2019).

In container systems used in autoclave devices, monitoring the condition of critical components and optimizing maintenance processes are of great importance for the reliability and efficiency of the sterilization process. One of the main problems frequently encountered in these systems is the limited lifetime of the sealing gaskets. Seals can be subject to mechanical deformations such as wear and tear during use (*Medical Device Sterilization Methods and Information | Analog Devices*, 2025). Such degradation can lead to containers that should be kept sterile after the autoclave process being exposed to air leakage from the external environment, resulting in loss of sterility due to the passage of particles or microorganisms (*Medical Device Sterilization Methods and Information | Analog Devices*, 2025). It should be noted that this problem is not limited to gaskets. For example, the replacement cycles of long-life Teflon filters are often ignored or

not monitored by users. This can lead to a reduction in the performance of filtration systems and therefore loss of efficiency of the sterilization process. Daoudi et al. (2023) found in their study that containers with valves are 64% more prone to water leakage and loss of integrity than containers with filters (Daoudi vd., 2023). Failure to perform timely maintenance or replacement of critical components a negative impact on the quality of sterilization processes (*Medical Device Sterilization Methods and Information | Analog Devices*, 2025).

In this context, the lack of an integrated mechanism to monitor the lifetime of the components used in container systems constitutes one of the main technical problems encountered in sterilization processes. Therefore, continuous monitoring of the condition of these components and their timely maintenance or replacement is a critical requirement for the reliability of autoclave devices and the efficiency of sterilization processes.

In this study, an innovative sterilization container system has been developed to make sterilization processes more reliable and traceable. The developed system aims to optimize the maintenance processes of vital parts and provide digital traceability by recording and analyzing each sterilization cycle. Thanks to the mobile application integration, users can follow the sterilization processes instantly. This 3 approach contributes to the quality of healthcare services by facilitating maintenance processes as well as increasing the sealing safety of the sterilization container. Figure 1 and Figure 2 show the container components that are periodically maintained. In addition, a technical service maintenance report is generated for these container components through the mobile application, enabling the health of the container components to be monitored in a digital and sustainable way.



Figure 1. Cap gaskets used for sealing



Figure 2. Sterilization container systems lid filters

2. MATERIAL AND METHOD

Counter Module

The counter module is an innovative technology designed to monitor and manage sterilization containers in accordance with modern requirements. As shown in Figure 3, the module consists of components such as microcontroller, bimetal thermostat, heat resistant battery and wireless communication unit to record sterilization cycles and provide information about these processes to the user. The main function of the module is to count the number of cycles by sending a signal to the microcontroller via the bimetal thermostat when a certain temperature threshold value is reached during sterilization and to save this data in its memory. The microcontroller is a mini computer on a single integrated circuit containing a CPU, RAM, some types of ROM and I/O ports, which acts as the control center of the system and ensures the reliability of sterilization processes by processing temperature data (Hussain vd., 2016). The heat-resistant

battery is able to withstand high temperature conditions for a long time, meeting the energy needs of the module and providing efficiency in terms of energy management. When the sterilization process is completed, a reader unit is attached to the counter module and wireless communication is established with mobile applications, allowing users to access

sterilization cycle data. The developed mobile application allows the data to be analyzed, interpreted and edited when necessary. This is a critical advantage, especially in terms of monitoring the lifetime of parts that require periodic maintenance and optimizing maintenance plans. The compact design of the meter module saves the internal volume of the container while increasing operational efficiency. The developed system offers ease of use and reliability by digitalizing sterilization processes.

Communication Module

As shown in Figure 3, the communication module in the sterilization container plays an important role in transferring the data recorded by the counter module. The counter module records data by counting each sterilization cycle and this data is transmitted to the communication module through the UART (Universal Asynchronous Receiver-Transmitter) interface. Embedded systems, microcontrollers and computers often use UART as an inter-device hardware communication protocol (Peña & Legaspi, 2020).

The communication module receives data via UART and wirelessly establishes a Bluetooth connection with mobile devices. This enables real-time monitoring and analysis of the sterilization container cycle count and other important data via the mobile app. The Bluetooth connection enables data to be easily transferred, helping users to identify maintenance requirements in a timely manner. For example, once a certain number of cycles has been reached, the status of components such as seals or filters that require maintenance can be tracked via the mobile app. The use of UART and Bluetooth ensures reliable and efficient data transmission and ensures that maintenance is performed at the right time. These developed wireless communication features make significant contributions to increasing the efficiency and safety of sterilization processes.

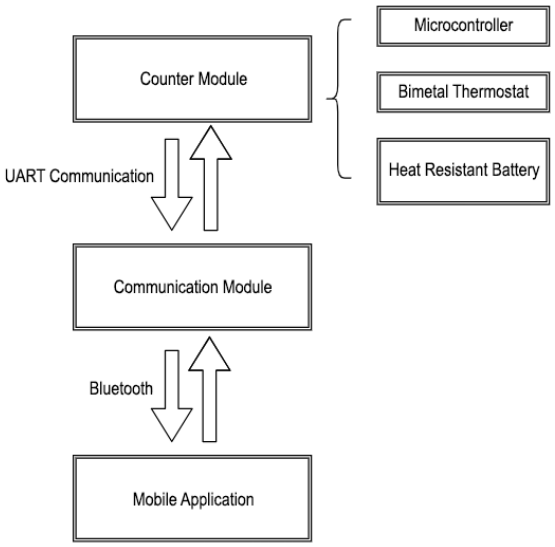

Figure 3. Main components and flowchart of the designed system

Mobile Application

As shown in Figure 4, the mobile application, which is one of the main components of this system, operates through the wireless Bluetooth connection provided by the communication module. Through the Bluetooth connection, the mobile application instantly provides the user with the number of cycles of the sterilization container, the history of the operations performed and the maintenance requirements. Through the application, users can get information about the operating status of the sterilization container, how long it has been running and which components need maintenance. This allows users to perform maintenance on time and increases sterilization safety. For example, alerts can be notified via the mobile app when seals or filters need to be replaced after reaching a certain number of cycles. Thanks to this wireless communication via Bluetooth, sterilization processes are more efficient and traceable. The system allows users to easily monitor operations via their mobile devices and intervene when necessary. This is an important advantage, especially considering the high security requirements of sterilization in the health sector. Data transmission via

Bluetooth also simplifies the use of the system, providing a user-friendly experience and making maintenance processes more efficient. This reduces the risk of sterilization container leakage and minimizes the risk of infection in healthcare environments.



Figure 4. Mobile application communication flow

Assembly-Disassembly Feature and Modular Design

In order to maintain the ergonomic structure of the sterilization container, all components are designed as a modular system with disassembly and assembly. As shown in Figure 5, the counter module is compactly integrated into the lid of the sterilization container. This design saves the internal volume of the container while offering ease of use and flexibility in maintenance processes. The counter system is manufactured in a dismountable way so that it can be used in any sterilization device. The module is adaptable to different sterilization systems and designed to be easily assembled or disassembled by users. This system is activated by entering critical data such as serial number, gasket status and filter information via the mobile application. This adaptable structure of the system allows it to be used reliably in various types of sterilization devices. This modular system increases operational efficiency by providing digital traceability in sterilization processes. In addition, the flexible design of the system facilitates timely periodic maintenance, maximizing the sterilization safety of both the device and the users.

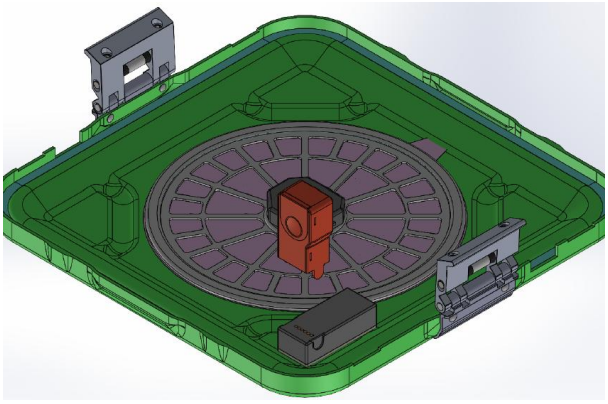

Figure 5. Counter module integrated into the sterilization container lid

3. RESULTS

The findings of this study show that modern sterilization container designs have evolved to meet both traditional sterilization needs and the requirements of modern healthcare environments. These containers have features that increase the effectiveness, efficiency and traceability of the sterilization process. Sterilization packaging systems are crucial in maintaining the integrity of medical instruments. It is not possible to verify the sterile status of surgical sets before use, so it is important that every step of the sterilization process is perfectly controlled and that the sealing status of the sterile product is checked immediately before use (Daoudi vd., 2023).

The effectiveness of sterilization devices depends on regular inspection and maintenance of key components. Especially sealing gaskets play a critical role in sealing the device during the sterilization process. Cracks, wear or deformations that may occur on the gasket surface can lead to loss of tightness and adversely affect sterilization efficiency. Therefore, the seal surface should be visually inspected after each sterilization cycle and renewed at the times recommended by the manufacturer. Special attention 7 should be paid to both static and dynamic seals to ensure that they are truly impermeable to microorganisms (H. L. M. Lelieveld & Holah, 2016).

Water leakage testing is useful for detecting and correcting leakage problems during container maintenance. However, it is difficult to perform this test as a routine practice outside of maintenance due to the time-consuming and logistical challenges of managing non-sealed containers (Daoudi vd., 2023). Regular maintenance and parts replacement improves the performance and safety of sterilization equipment and ensures the efficiency of sterilization processes.

This study highlights the role of the developed counter module and mobile integration features in monitoring and managing sterilization cycles. The counter module in the container provides important data for maintenance and quality control by tracking each sterilization cycle. This feature ensures the correct operation of sterilization containers in healthcare throughout their lifecycle and reduces the risk of equipment failure or contamination. Critical parts of container systems that require maintenance are sealing gaskets, filter elements, locking mechanisms/hinges, lid lock springs, gasket or seal seats, plastic or silicone components, inner tray and accessories.

The sealing gasket plays a critical role in sealing the device during the sterilization process. Cracks, wear or deformations on the gasket surface can lead to loss of tightness and adversely affect sterilization efficiency. Therefore, the seal surface should be visually inspected after each sterilization cycle and renewed at the times recommended by the manufacturer. The water leakage test is very useful during maintenance to detect and remedy sealing problems of containers. However, performing this test routinely outside of maintenance is time-consuming and the management of containers with leakage problems can pose logistical challenges.

Other components of sterilization devices also need regular maintenance and inspection. For example, filter elements should be checked and replaced if necessary after approximately 100-150 sterilization cycles or every 3-6 months. Conditions such as particle accumulation or deformation of the filter can directly affect the efficiency of the sterilization process. Evidence suggests that filters should be replaced after approximately 100-150 sterilization cycles. In addition, regular checks every 3-6 months are recommended.

Moving parts such as the locking mechanism and hinges facilitate the correct closing and sealing of the container lid. If deformation or loosening of these components occurs, the function of the mechanical systems may be impaired and the sterilization process may be compromised. Likewise, the lid lock springs can suffer from metal fatigue over time and lose tension, resulting in a failure of the seal.

The gasket or seal seat ensures that the gasket remains in the correct position and the seal is maintained. It should be checked simultaneously with the gasket or at the latest once a year. Signs such as rusting, deformation of the seat, slipping or loosening of the seal seat indicate that the seat is deformed. In this case, the part or seat must be replaced to maintain the effectiveness of the seal.

Plastic or silicone components, such as handles and grips, are subjected to intense mechanical stress during transportation and use and can wear out quickly. Depending on the intensity of use, they should be checked every 1-2 years. If signs such as breaks, cracks, discoloration, deformation or loosening are detected, these components should be replaced to maintain user safety and sterility integrity.

The inner tray and accessories allow the tools to be placed neatly. They should be checked between 6 months and 1 year, depending on the intensity of regular use. Signs such as scratches, abrasion, corrosion, rust formation on the tray surface or loss of function of the accessories may adversely affect sterilization. It is therefore recommended to replace these parts in case of wear.

4. DISCUSSION AND CONCLUSIONS

In this study, periodic replacement and control requirements of different components and parts of sterilization equipment were examined and the effects of possible problems on device performance were discussed. The data obtained are summarized in Table 1.

The counter module developed within the scope of this study alerts the user in a timely manner about gaskets, filters and other container components that require periodic maintenance and ensures that the necessary maintenance and replacements are made. By analyzing the data sent by the user to the factory via the mobile application, the status of the parts requiring periodic maintenance is evaluated and improvements are made in the light of this data.

This system increases operational efficiency by providing remote access to data related to sterilization cycles, data storage, analysis and traceability in digital environment. Especially in busy healthcare environments, this feature allows for more efficient management of processes. Users can monitor sterilization cycles in real time and intervene when necessary. This feature saves time and makes quality control processes more efficient. In addition, the digital storage of data allows easy access to historical records, enabling long-term analysis and continuous improvement of sterilization processes.

Table 1. Periodic replacement and inspection requirements of critical parts of container systems that require maintenance

Component/Part Name	Recommended Periodic Change/Check Frequency	Signs Indicating the Need for Replacement/Maintenance	Description
Sealing Gasket	- Usually 6 months - 1 year (according to manufacturer's recommendation) - Visual inspection after each sterilization cycle	- Cracks, wear on the gasket surface - Excessive stretching or deformation - Loss of tightness in the sterilization process	This part, which plays a critical role in maintaining the sealing, may deform in a shorter time depending on the intensity of use and the type of sterilization. When deformation is detected, it is strongly recommended to replace it.
Filter Elements	- Usually 6 months to 1 year (according to manufacturer's recommendation) - Visual inspection after each sterilization cycle	- Particle accumulation on the filter surface - Difficulty in the passage of air or sterilizing agent - Visible deformation	Filters act as a bacterial barrier by allowing steam or other sterilization gases to pass through. Clogging or damage adversely affects sterilization efficiency.
Lock Mechanism / Hinge	- After approximately 100-150 sterilization cycles - Check every 3-6 months and change if necessary	- Forced on-off - Deformation or loosening - Incomplete fit during closing	The locking mechanism and hinges facilitate closure and sealing of the lid. If damage or loosening is detected, maintenance or replacement should be carried out to maintain the integrity of the mechanism.
Cover Lock Springs	- Check once a year or after 100-150 cycles	- Incomplete closure of the lid or locking system - Decrease in spring tension (loosening, breakage)	Springs help the lids to close tightly and stably. Over time, metal fatigue or breakage can occur. In this case the tightness is compromised.
Gasket / Seal Seat	- Check simultaneously with the gasket or at the latest once a year	- Rust or deformation of the housing - Slipping or loosening of gasket seating	It ensures that the seal remains in the correct position and sealing is maintained. Deformation of the seat causes the seal to lose its effectiveness. In this case, the part or seat must be replaced.
Plastic / Silicone Components (e.g. handles, handles)	- Check every 1-2 years according to the intensity of use	- Rupture, crack or discoloration - Deformation or loosening	They can wear out quickly as they are subjected to intense mechanical stress during transportation and handling. If damage is detected, they must be replaced to maintain user safety and sterility integrity.

Inner Tray and Accessories	- Control between 6 months - 1 year depending on the intensity of regular use	- Scratches, abrasion on the tray surface - Corrosion or rust formation - Loss of function in accessories	The inner tray and similar accessories, which ensure the orderly placement of instruments, may impair sterilization if scratched or corroded. Replacement is recommended in case of wear.

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REFERENCES

AORN. (2019). Guidelines for Perioperative Practice 2019 (1st edition). AORN, Inc.

Arslanoğlu, A., & Urk, M. (2015). Merkezi sterilizasyon ünitesinde çalışan güvenliği. Sağlık Akademisyenleri Dergisi, 2(4), Article 4. https://doi.org/10.5455/sad.2015131452246847

Daoudi, H., Arbai, S., Marnissi, S. E., Harti, J. E., Derraji, S., & Cadi, M. A. E. (2023). The utility of water leak test in evaluating the functionality of sterilization containers. Jour Med Resh and Health Sci, 6(5), Article 5. https://doi.org/10.52845/JMRHS/2023-6-5-5

Evans, R. P. (2009). Surgical Site Infection Prevention and Control: An Emerging Paradigm. JBJS, 91(Supplement_6), 2. https://doi.org/10.2106/JBJS.I.00549

Frieden, T. R. (2017). A Safer, Healthier U.S.: The Centers for Disease Control and Prevention, 2009–2016. American Journal of Preventive Medicine, 52(3), 263-275. https://doi.org/10.1016/j.amepre.2016.12.024

Hussain, A., Hamad, M., Hafeez, K., & Zainab, T. (2016). Programming a Microcontroller. International Journal of Computer Applications, 155(5), 21-26.

Joslyn, L. (1991). Sterilization by heat. In Disinfection Sterilization, and Preservation, 495-526.

Lelieveld, H. L. M., & Holah, J. (2016). Chapter 29—Specific Requirements for Equipment for Aseptic Processing. İçinde H. Lelieveld, J. Holah, & D. Gabrić (Ed.), Handbook of Hygiene Control in the Food Industry (Second Edition) (ss. 389-394). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100155-4.00029-7

Louis Pasteur | Biography, Inventions, Achievements, Germ Theory, & Facts | Britannica. (2025, Ocak 15). https://www.britannica.com/biography/Louis-Pasteur

Medical Device Sterilization Methods and Information | Analog Devices. (2025, Ocak 15). https://www.analog.com/en/resources/technical-articles/medical-device-sterilization-methods-and-information.html

Peña, E., & Legaspi, M. G. (2020). Uart: A hardware communication protocol understanding universal asynchronous receiver/transmitter. Visit Analog, 54(4), 1-5.

PERÇİN, D. (t.y.). Sterilizasyon Uygulamalari ve Hastane Infeksiyonlari.

The History of Sterilisation Part 2. (2025, Ocak 15). STERIS IMS EMEA. https://www.steris-ims.co.uk/blog/the-history-of-sterilisation-part-2/

Recycling of Zinc Sacrificial Anodes in the Blue Economy

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Abstract: Corrosion is one of the main results of seawater environment exposure, threatening key assets of the blue economy, like ships, shore, and offshore-based infrastructure. Zinc sacrificial anodes are one of the main ways of preventing corrosion and prolonging the operational life of ships and all other metal constructions. This study investigates the recyclability and chemical integrity of spent zinc anodes. The analysis is based on three spent zinc anodes (25COM 2.1, 25COM 2.2, 25COM 2.3), retrieved from local yacht service. Visual and chemical analysis were conducted on six spectra of each zinc anode using Scanning Electron Microscopy(SEM). With visual inspection, we estimated the percentage of residual zinc anode mass in order to test viability and potential scale of their recycling. While SEM analysis gave us an in-depth analysis and composition of zinc anode samples, it additionally provided us with microscopic pictures of their surfaces. Showing us the change in chemical integrity of spent zinc anodes that occurred as a result of their usage on small to medium vessels. The results revealed vastly diversified chemical integrity of each sample and a high percentage of remaining zinc mass. Showing us the average chemical compositions of the spent zinc anodes surface and the percentage of remaining zinc anodes mass as potential for recycling.

Keywords: Corrosion, Zinc, Spent zinc anodes, Recycling.

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1. INTRODUCTION

The Blue Economy represents one of the fundamental pillars of contemporary global development, facilitating worldwide connectivity through various forms of maritime activity. The transport of goods, the movement of people, and the continuous increase in the number of vessels and marine infrastructure including coastal facilities, pipelines, and terminals serving industrial, agricultural, and logistical purposes provide substantial economic and societal benefits (Silver et al., 2015).

However, a common challenge across all these systems is the need for continuous maintenance and monitoring, particularly in marine environments. Due to the unique chemical and mechanical properties of seawater, metallic structures are especially susceptible to intense and ongoing corrosion (Kožuh et al., 2016; Barokah et al., 2018). One of the most effective methods for mitigating such corrosion is cathodic protection, with particular emphasis on the use of sacrificial anodes. This approach involves the application of metals with a lower electrochemical potential such as alloys of zinc (Zn), magnesium (Mg), and aluminum (Al) which are intentionally attached to ship hulls or submerged infrastructure (Krolo et al., 2020; Ivanov, 2016). These sacrificial anodes corrode preferentially, thereby protecting the underlying structural metal and providing an efficient galvanic defense, ultimately extending the operational lifespan of critical systems in marine conditions (Morral, 2004).

Ships, due to their constant exposure to seawater characterized by high salinity and continuous flow along the steel hull and their service life extending up to around 25 years or more, provide ideal conditions for the development of marine corrosion (Kovač et al., 2024; Bulatović et al., 2021). Corrosion can progress persistently in the absence of adequate corrosion protection measures applied to metallic structures (Barokah et al., 2018). It is estimated that corrosion accounts for approximately 5 to 10 percent of a vessel's total operating costs, and in some cases, this value may reach up to 20 percent (Sundar et al., 2022). Therefore, implementing an effective cathodic protection system is essential for ensuring the structural integrity of the ship. In addition to its technical relevance, such protection significantly extends the operational lifespan of ships, enhancing their economic value. It also contributes to safer vessel operation by reducing the risk of hull penetration and seawater ingress due to corrosion (Ivošević et al, 2024;Tampubolon et al., 2021).

Zinc sacrificial anodes operate based on the principle of electrochemical potential differences between dissimilar metals in an electrolyte. When two different metals are electrically connected in a conductive environment, such as seawater, the more active metal, in this case zinc, acts as the anode by releasing electrons, thereby protecting the less active metal, typically steel, from corrosion (Hafizh et al., 2015). The electrode potential of low-alloy steel in seawater is approximately –0.6 V versus a saturated calomel electrode (SEC), while that of zinc is around –1.0 V. Consequently, when zinc is coupled with steel, it functions as the anode and steel as the cathode, effectively reducing the corrosion rate by up to 60% (Tampubolon et al., 2021). However, this protection comes at the expense of the gradual deterioration of the sacrificial anode itself. Factors such as dissolved oxygen, seawater flow, temperature variations, marine biofouling, and salinity contribute to the progressive consumption of the anode material, which typically degrades to between 50% and 60% of

its original mass before being replaced during mandatory inspections, usually carried out while the vessel is dry-docked in accordance with classification society rules and IMO guidelines (DNV RP-B401, 2021; IMO A.798(19), 1995).

Considering that merchant vessels typically consume several tens of tons of zinc sacrificial anodes every three to five years. Often requiring the installation of a practically new set of zinc sacrificial anodes, and up to 60% of partially depleted anodes are discarded during replacement. It becomes evident that a significant quantity of zinc is systematically set aside. When this is further extended to include smaller vessels and extensive shore-based and offshore infrastructure such as pipelines and oil platforms, the cumulative volume of used zinc becomes substantial (Aldous and Rees, 2019; Kharshan et al., 2007). Zinc is currently the fourth most utilised industrial metal, following iron, aluminium, and copper (Zhang, 2005). This underscores the critical importance of implementing effective recycling strategies for spent zinc sacrificial anodes. By recovering and repurposing this material, we support more rational and circular resource use, contribute to sustainable development goals, and reduce dependency on the extraction and processing of primary zinc ore, which is both more expensive and environmentally damaging (Pehlivan et al., 2023).

With the inspection of local shipyards and yacht services in Montenegro, we got our feedback on local potential for the recycling of spent zinc anodes. The biggest flaw in the local system and potential for recycling is the lack of proper and precise evidence of existing stashes of spent zinc anodes. Leaving us only with a visual assessment of local potential. Evidence of local stashes of spent zinc sacrificial anodes was taken from the local yacht service Marković. Three of their samples were taken for analysis for this paper.

Grounded in prior research on sacrificial anodes and zinc recycling, this study explores the recovery potential of spent zinc anodes employed in cathodic protection systems on marine vessels. A laboratory-based analytical methodology was applied to determine the chemical composition and purity levels of zinc extracted from end-of-life anodes following operational deployment. The principal objective of this work is to establish a scientific foundation for assessing the feasibility of reintroducing recovered zinc from used sacrificial anodes into industrial supply chains, thereby supporting sustainable resource utilisation within the maritime sector. The main limitation of the present research is the constrained sample size and its confinement to a specific subset of anodes.

The structure of the paper is organized into four main sections. The second section outlines the research methodology, detailing the data sources and analytical techniques employed. The third section presents the key findings and their interpretation. Finally, the fourth section offers concluding remarks and proposes potential directions for future research.

2. Methodology

Analysis of local yacht service Marković gave us access to all three samples of spent zinc anodes used in this paper's research. Samples were taken as a whole for visual inspection to assess the percentage of leftover mass. After conducting a visual inspection, they were all cut into smaller pieces and sent to the laboratory for Scanning Electron Microscopy SEM analysis.

According to relevant classification societies recommendations and technical standards for cathodic protection, sacrificial anodes should be monitored and replaced in accordance with their consumption rates and remaining protective capacity. This study follows a structured methodology for assessing physical and chemical compositions and characteristics of depleted zinc sacrificial anodes removed from vessels after service and chemical reactions, like on Figure 1. Each was taken from local yacht services and taken as a cut sample for further laboratory analysis.

With standardised visual inspection and laboratory procedures, we got the estimated percentage of remaining zinc mass, chemical composition and purity of zinc sacrificial protectors, true analysis of several material spectrums. Giving us a clear picture of the viability of recycling the spent zinc anodes. From lower spent levels of 50 to 60 percent, as low-end usage recommended by classification societies, especially since they usually weigh from 2-50 kilograms (WRS Cathodic Protection, n.d., ABS, 2017). More often than not even at 90 percent, as sometimes anodes are replaced by time requirements and not their remaining thickness do to their expiration dates, which are not real in practice, as shown in Figure 2. The final stage of analysis compared laboratory results with standard industry values for primary zinc purity to evaluate the feasibility of its recycling. The purpose of the analysis was to determine residual zinc mass, true visual inspection, and its chemical content, and the presence of other elements such as aluminium, biofouling, chlorine, iron, and other impurities to estimate purity levels using laboratory analysis.

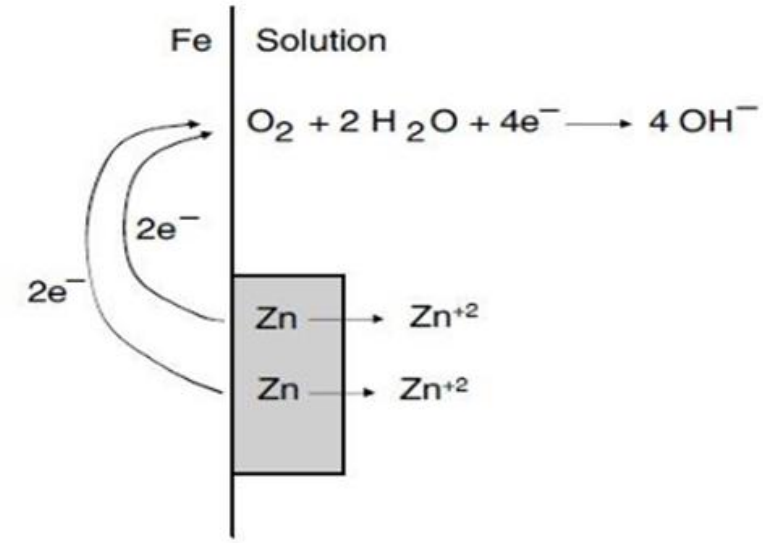

Figure 1. The working principle of zinc sacrificial anodes (Susilo et al., 2018)



Figure 2. Stash of ~90% unused zinc anodes

2.1. Database

In this paper, as the subject of the research, we used a few samples of zinc sacrificial anodes collected from local yacht service and technical data from WRS Cathodic Protection. As the entry database for this study, a set of depleted zinc sacrificial anode samples was collected from local yacht maintenance services following their operational service on small to medium-sized vessels. Each sample was labelled as 25COM 2.1, 2.2, 2.3, shown in Figure 3 and subjected to visual and laboratory-based chemical composition analysis.



Figure 3. Zinc sacrificial anode samples

2.2 Methods

A visual inspection method was conducted on three zinc samples. Analysing the condition of their surface, the presence of dents, and the level of unsmoothed surface. Giving us the ability to determine the residual mass based on the surface condition of spent zinc anode and its comparison to fine and unused ones.

Scanning Electron Microscopy (SEM) was used for assessing the chemical integrity and surface degradation of spent zinc sacrificial anodes, as shown in Figure 4. The analysis assumes that, after extended service life, corrosion and electrochemical activity alter the form, structure, and elemental distribution of the anode surface. SEM imaging enables detailed visualization of surface topography, pore formation, and oxide layer development.

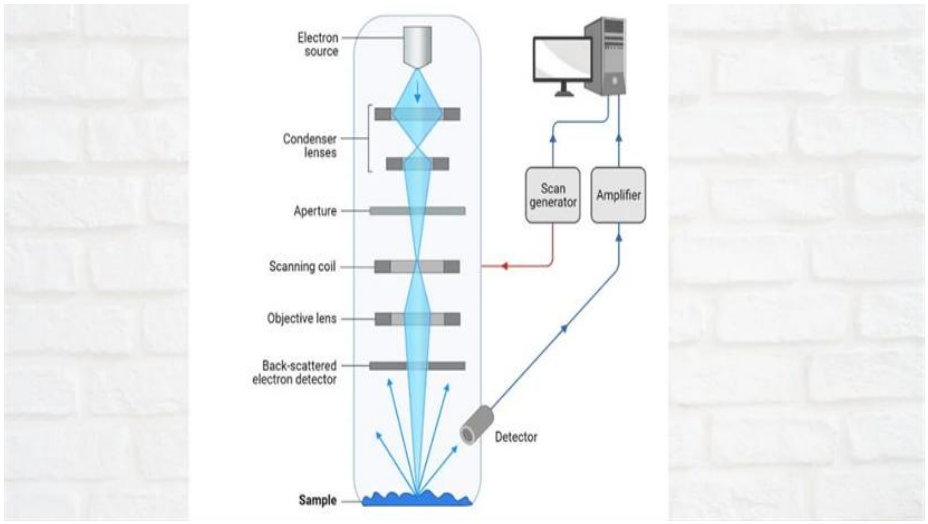

Figure 4. Scanning Electron Microscopy (ScienceInfo.com, 2022)

3. RESULTS

In accordance with the suggested methodology and chosen samples in the following chapters 3.1 and 3.2, we have results of visual inspection and scanning electron microscopy analysis.

3.1. Visual inspection

Following the visual inspection of cut-outs of zinc anodes and the condition of the anode surfaces, we have determined that all three of the zinc anodes have a high percentage of residual mass. With about 10 percent of the spent mass, there is still 90 percent of the mass that was just left aside to decay. Further confirmed by the rest of the potent samples in stashes we found, like in Figure 2. Taking this into account and the weight of zinc sacrificial anodes that go from ~1 to over 100 kilograms per anode, there is a lot of zinc mass left. Showing us there is more than enough mass to be collected and retrieved for recycling and production of secondary zinc through the usage of spent zinc anodes.

3.2. Scanning Electron Microscopy analysis

SEM analysis, as shown in Figure 5, revealed that two of the three separate samples of sacrificial zinc anodes yielded data results on chemical integrity, as presented in Figures 6, 7, and 8, and their following Tables 1, 2 and 3. They contain a detailed chemical composition and surface condition on a microscopic level. All results from Figures 6 and 7, and 8 were summed up and compared in Table 4. Samples themselves were analyzed in 6 separate spectrums and zoomed for visual inspection at a scale of 200qm.

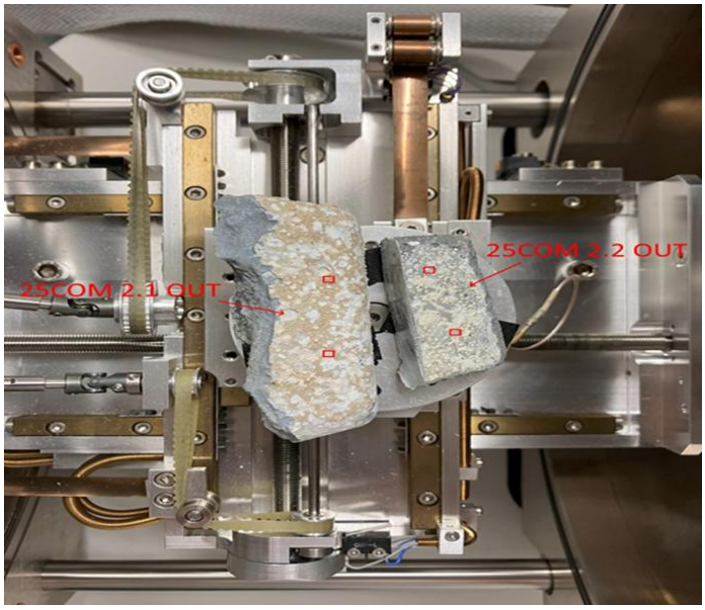

Figure 5. SEM analysis of zinc anode samples 25COM 2.1 and 2.2

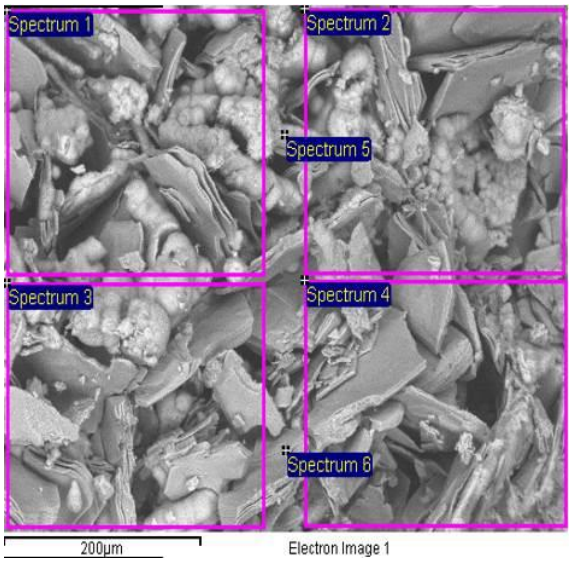

Figure 6. Spectra of zinc anode sample 25COM 2.1

Spectrum	In stats.	O	S	Cl	Zn	Total
Spectrum 1	Yes	24.38	0.91	4.41	70.30	100.00
Spectrum 2	Yes	28.88	2.01	4.28	64.83	100.00
Spectrum 3	Yes	26.60	2.58	4.98	65.84	100.00
Spectrum 4	Yes	28.53	4.19	5.06	62.40	100.00
Spectrum 5	Yes	41.80	5.35	6.00	46.85	100.00
Spectrum 6	Yes	37.11	6.55	5.97	50.37	100.00
Mean		31.18	3.60	5.12	60.10	100.00
Std. deviation		6.67	2.14	0.74	9.33	
Max.		41.80	6.55	6.00	70.30	

Table 1. Chemical analysis of sample 25COM 2.1

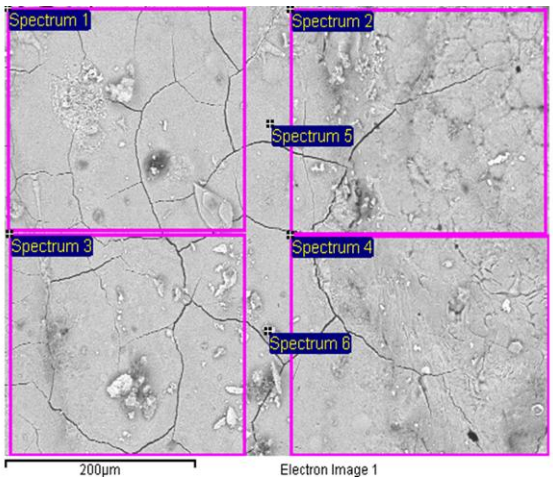

Figure 7: Spectra of zinc anode sample 25COM 2.2

Spectrum	In stats.	O	S	Al	Zn	Total
Spectrum 1	Yes	39.96	0.88	1.00	58.16	100.00
Spectrum 2	Yes	34.73	0.72	0.81	63.75	100.00
Spectrum 3	Yes	42.28	0.60	0.87	56.25	100.00
Spectrum 4	Yes	34.79	0.33	1.06	62.40	100.00
Spectrum 5	Yes	33.92	0.44	0.34	46.85	100.00
Spectrum 6	Yes	24.92	0.12	0.98	50.37	100.00
Mean		35.10	0.52	0.84	60.10	100.00
Std. deviation		6.01	0.27	0.26	9.33	
Max.		42.28	0.88	1.06	73.98	

Table 2. Chemical analysis of sample 25COM 2.2

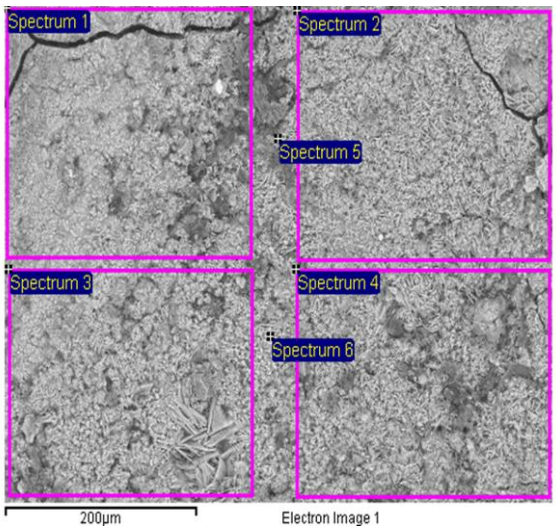

Figure 8. Spectra of zinc anode sample 25COM 2.3

Spectrum	In stats.	O	S	Si	Cl	Zn	Total
Spectrum 1	Yes	35.31	2.32	0.91	1.19	70.30	100.00
Spectrum 2	Yes	35.76	5.59	0.00	5.80	64.83	100.00
Spectrum 3	Yes	39.32	5.39	0.16	5.08	65.84	100.00
Spectrum 4	Yes	36.25	6.78	1.70	6.89	62.40	100.00
Spectrum 5	Yes	33.01	6.87	0.48	6.30	46.85	100.00
Spectrum 6	Yes	39.16	7.31	0.11	6.72	50.37	100.00
Mean		36.47	5.71	0.56	5.33	60.10	100.00
Std. deviation		2.42	1.83	0.65	2.13	9.33	

Max.		39.32	7.31	1.70	6.89	7.30	

Table 3. Chemical analysis of sample 25COM 2.3

The results demonstrate notable variability in the chemical composition of zinc sacrificial anodes, particularly across different surface regions of the same sample. This variability was observed through Scanning Electron Microscopy (SEM) analysis, which revealed differences depending on the precise location of the measurement. The predominant elements identified were zinc (Zn), oxygen (O), chlorine (Cl), and sulphur (S). As expected, zinc exhibited the highest average concentration across all six measurements that are summed up in Table 4 from the three different samples, with a mean value of 57.05%, followed by oxygen at 34.1%, chlorine at 4.28%, and sulphur at 2.65%. All results of exposure to oxygen and seawater, both in static and dynamic circumstances.

Sample	Oxygen (O)%	Aluminum (Al)%	Silicon (Si)%	Sulphur (S)%	Chlorine (Cl)%	Calcium (Ca)%	Zinc (Zn)%
25COM 2.1	30	1.2	1	2	6.1	/	59.4
25COM 2.1’	31.1	/	/	3.6	5.1	/	60.1
25COM 2.2	35.6	0.8	/	0.6	1.3	0.5	60.9
25COM 2.2’	35.1	0.8	/	0.5	/	/	63.5
25COM 2.3	36.4	1.9	4.25	3.49	3.6	1.88	46.5
25COM 2.3’	36.4	/	0.56	5.7	5.3	/	51.9
Avg %	34.1	1.175	1.94	2.65	4.28	1.19	57.05

Table 4. EMS analyses results summary

Assuming that the detected variations in elemental composition are primarily limited to surface layers resulting from prolonged exposure to marine environments, it is reasonable to infer that the inner core of the anode retains a high degree of zinc purity. This suggests that, with appropriate mechanical or chemical separation of the contaminated surface layer, the remaining material is suitable for recycling and reuse, either in the production of new sacrificial anodes or for alternative industrial applications.

4. CONCLUSIONS

This paper highlights the importance of effective resource management in the blue economy, in the case of zinc sacrificial anodes, emphasizing the potential for recycling and reuse, especially in instances where protectors are replaced as a preventive measure despite retaining up to 90% of their original mass. In such cases, only surface treatment, such as mechanical cleaning or polishing, is required to remove accumulated impurities, since contamination is generally limited to the outer layer and does not significantly compromise the underlying zinc purity. With proper systems for collection, sorting, and processing, the recycling of sacrificial zinc anodes can be scaled to a respectable level. This could lead to the recovery of tens of tons of zinc, delivering both environmental and economic benefits. Including reduced waste generation, job creation, support for local industries, and decreased dependence on primary zinc extraction from natural reserves, thereby contributing to sustainable development.

The findings in this study are based on visual and laboratory analysis of three cut-out spent anode samples. While indicative, these results underscore the need for more comprehensive investigations. Future research should incorporate comparative analysis of zinc anodes before and after service, allowing for a more accurate understanding of degradation patterns over time. Additionally, SEM analysis should include both surface and core (drilled) samples, to confirm the internal structural and chemical integrity of the material, even practical testing of their recyclability in the form of their polishing and remelting into secondary zinc.

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Author Contributions / Yazar Katkıları
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REFERENCES

Aldous, B., & Rees, B. (2019). An evaluation of the dissolution of sacrificial zinc anodes in the Hamble estuary. Master's Thesis, Solent University, Southampton.

American Bureau of Shipping (ABS). (2017). Guidance notes on cathodic protection of ships. Houston, TX: ABS. Retrieved from https://ww2.eagle.org/
... [Accessed 25 July 2025]

Barokah, B., Semin, S., Kaligis, D. D., Huwae, J., Fanani, M. Z., & Rompas, P. T. D. (2018). Characteristics from recycled of zinc anode used as a corrosion-preventing material on board ship. IOP Conference Series: Materials Science and Engineering, 306, 012021.

Bulatović, S., Aleksić, V., & Zečević, B. (2021). Corrosion protection of ship structures – zaštita od korozije brodskih konstrukcija. Proc. Knjiga Radova, 177–182.

DNV. (2021). DNV-RP-B401 – Cathodic protection design. Det Norske Veritas, Høvik, Norway.

Hafizh, M. M., Sunhaji, A., Norhayati, S., & Noriyati, S. (2015). Performance analysis of 99.5% aluminium alloy as a sacrificial anode.

IMO. (1995). Guidelines for the selection, application and maintenance of corrosion prevention systems of dedicated seawater ballast tanks (Resolution A.798(19)). International Maritime Organization, London.

Ivanov, H. (2016). Corrosion protection system in offshore structure. University of Akron, Ohio.

Ivošević, Š., & Soszyńska-Budny, J. (2024). The reliability of inner bottom plating of fuel tanks on aging bulk carriers. International Conferences on Science and Technology, Engineering Sciences and Technology (ICONST-EST 2024).

Kharshan, M., Knapp, J. M., Shouse, P. J., & Trujillo, J. R. (2007). Evaluation of environmental effects of sacrificial anodes. Scientific Report No. 279285, Naval Surface Warfare Center, Carderock Division, U.S. Department of the Navy.

Kožuh, S., Vrsalović, L., Gojić, M., Gudić, S., & Kosec, B. (2016). Comparison of the corrosion behavior and surface morphology of NiTi alloy and stainless steels in sodium chloride solution. Journal of Mining and Metallurgy, Section B: Metallurgy, 52(1), 53–61. https://doi.org/10.2298/JMMB150129003K

Kovač, N., Ivošević, Š., & Momčilović, N. (2024). Corrosion-induced thickness diminution of an ageing bulk carrier. Brodogradnja, 75(4), 75404. http://dx.doi.org/10.21278/brod75404

Krolo, J., Kožuh, S., Gojić, M., & Vrsalović, L. (2020). Fatigue and corrosion behavior of steel for the production of rock bolts. Journal of Mining and Metallurgy, Section B: Metallurgy, 56(1), 53–61. https://doi.org/10.2298/JMMB190612002K

Morral, F. J. (2004). Corrosion of zinc and zinc alloys. In S. D. Cramer & B. S. Covino (Eds.), ASM Handbook, Volume 13B: Corrosion: Materials (pp. 474–492). ASM International, Materials Park, Ohio.

Pehlivan, H., Karahan, İ. H., Fındık, F., Küçükömeroğlu, T., & Candan, S. (2023). The effects of corrosion on mechanical properties of reinforcing steel bars and modeling with artificial neural networks. Materials, 16(9), 3930. https://doi.org/10.3390/ma16093930

ScienceInfo.com. (2022). Scanning electron microscopy (SEM): Principle and applications. Retrieved from https://www.scienceinfo.com

Silver, J. J., Gray, N. J., Campbell, L. M., Fairbanks, L. W., & Gruby, R. L. (2015). Blue economy and competing discourses in international oceans governance. Journal of Environment and Development, 24(2), 135–160.

Sundar, S., Sivaraj, R., & Jayanthi, S. (2022). Sacrificial anode materials to protect marine grade steel structures: A review. International Journal of Engineering Research & Technology (IJERT), 11(7), 77–81.

Susilo, A. K., Effendi, M., Pratisna, P., & Suharyo, O. S. (2018). Maintenance strategy for hull structure based on the analysis of the remaining plate thickness on bulk carrier vessels. IPTEK Journal of Proceedings Series, 1(7), 92–102.

Tampubolon, C. M., Aritonang, S., & Arto, R. S. (2021). Optimization of hull protective materials using sacrificial anodes: Review. International Journal of Education and Social Science Research, 4(6), 295–311.

WRS Cathodic Protection. (n.d.). Sacrificial anodes product catalogue. ShipServ. Retrieved from https://www.shipserv.com/ShipServ/pages/profiles/259239/documents/Sacrificial-anodes.pdf
[Accessed 30 July 2025]

Zhang, X. G. (2005). Corrosion of zinc and zinc alloys. In S. D. Cramer & B. S. Covino (Eds.), ASM Handbook, Volume 13B: Corrosion: Materials (pp. 402–417). ASM International.

Some indicators of the risk management importance in a seaport

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Abstract: Risk management in a seaport plays an important role in preventing possible negative effects on people, assets and environment. It can resolve challenges, reduce risk exposure, save time, reduce costs and establish bases for optimization of resources allocation. Necessity of having an adequate risk management in a port is determined by the possibility of hazardous situations, incidents and accidents caused by port operations. There is no specific risk management method or framework to cope with all existing and potential threats and hazards in a seaport. In the available literature are presented results of research related to different aspects of the risk management in a seaport, but, there is an evident lack of researches focused on identifying, analyzing and quantifying impact of elements directly generated by the risk management system to the seaports` characteristics, primarily their efficiency. After a theoretical considerations on risk management in the ports, in this paper are investigated some bases for quantifying influence of risk related parameters on the level of berths` efficiency in a seaport, defined using DEA CCR input oriented method. Based on the considerations on parameters from the established data series, some indicators of risk management importance in a seaport are defined and analyzed. Concrete results presented in this paper are related to the Port of Bar (Montenegro).

Keywords: port, risk management, importance, indicators

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1. INTRODUCTION

In the process of fulfilling their roles, ports are facing numerous challenges of different nature and intensity of influence. The internal and external risks faced by the ports are becoming day by day more complicated. According to ISO 31000 (2018) (https://www.iso.org-a), risk is the effect of uncertainty on achieving the objectives, often quantified as the Likelihood of the occurrence (L) of an event multiplied by its Impact (I), (L x I). This means risk can be managed by reducing the likelihood or the impact of the related uncertainty (harmful events: the loss, injury or other adverse consequences) (John, et.al, 2014). Risk is an unavoidable part of doing business, and identifying and mitigating risks is an important task/challenge for any company (https://www.iso.org-b), including a port.

Based on the previously mentioned principal definition, in different literature sources, authors have proposed some additional definitions: a risk is defined as the likelihood of loss (Vaughan and Elliot, 1978); a risk is an important issue as it often deals with safety, efficiency and transportation reliability (Kristiansen, 2005); a risk as the probability of an adverse event (Siehama and Noumen, 2020); a risk itself as a combination of the likelihood of an occurrence of a hazardous event within a specified period or under specified circumstances and the severity of injury or damage to the health of people, property, environment or any combination of these caused by the event (Kadir et.al., 2020a); a risk is the possibility of an event occurring that may adversely affect the achievement of the subject's set goals. Missed opportunities to achieve goals are also considered a risk (Ministry of Finance, 2015); a risk is the chance that someone or something that is valuated will be adversely affected by the hazard (Woodruff , 2005). The main risk factor groups: man, machines, management, environment, traffic (Kadir et.al., 2020a; Kadir et.al, 2020b).

Risk management is a decision-making process undertaken by identifying, analyzing and mitigating risk measurement results (Yang and Hung, 2007). Risk management can: resolve challenges, reduce risk exposure, engage stakeholders, save time, reduce costs and establish bases for optimization of resources allocation (Janowicz and Pauling, 2016). Risk management in ports plays an important role in mitigating and preventing possible accidents and disruptions (Nagi et.al, 2017).

The maritime supply chain risk management is defined as a process of making and carrying out decisions that will minimize the adverse effects of accidental losses (Yang, 2011). In the industrial environment, port activity is one of the more complex components of the supply chain where risk management is present on financial, technological, organizational and operational aspects (Mabrouki et.al., 2013; Dias et.al., 2019).

Guidance for definition of risk management process and risk tolerability criteria are referred to (Eni Montenegro, 2020): People – the health protection and safety of people; Social context – damage to health and safety of external stakeholders; Environment – damage to the environment deriving from operational activities or from incidents; Assets and Operations – damage to assets and/or impacts on working process; Reputation. Necessity of having the adequate risk management in a port is determined by the possibility of hazardous situations, incidents and accidents caused by handling and other

operations (Bayaras and Palšaitis, 2020). There is no specific risk management method or framework to cope with all existing and potential threats and hazards in a port (Pallis, 2017).

The risk management process consists of six steps: System identification (Port); Risk identification (what go wrong?) Risk assessment (investigation of important risks); Risk control options (measures to mitigate risks); Cost/benefit assessment (cost/benefit of measures); Decision-making (recommendation) (Pallis, 2017).

The risk identification considers: how *likely* is an event to happen and what are the potential *consequences* and their magnitude (https://www.wcoomd.org). It is the first and, from a lot of aspects, the most important step in risk management process (Pallis, 2017). The objective is to identify the critical risk factors of cargo handling and other activities in ports, mostly through a combination of literature reviews and brainstorming with port experts (Trbojevic and Carr, 2000; IEC, 2009).

The risk analysis considers conducting the following processes (John, et.al, 2014): 1) Identification of the „Critical Activities" and the associated „Hazards"; 2) Assessment of the potential „Consequence" of the hazard; 3) Assessment the „Likelihood" of the occurrence of the hazard; etc. Risk analysis in ports plays an increasingly important role in ensuring port operation reliability, maritime transportation safety and supply chain distribution resilience (Alyani et.al., 2014).

Risk estimation can be quantitative or qualitative, or a combination of the these two methods (Pallis, 2017; https://www.wcoomd.org). The likelihood of occurrence is defined by a scale from 1 (very unlikely) to 5 (certain). The likelihood is assessed without considering the presence of control measures (Kadir et.al., 2020a). Risk estimation uses the understanding of risk obtained during risk analysis to make decisions about future actions (IEC, 2009).

Risk measurement is a systematic process in assessing the effects of human actions and activities involving products and systems on risk characteristics (Juliza and Anggiat, 2019). Risk measurement refers to many different methods, approaches and techniques (Mabrouki et.al., 2013).

Risks can be mapped using a risk **severity and probability matrix.** It helps ensure that risks receive differentiated management attention, and allocated resources (UNCTAD; https://www.abpmer). Risk matrix is a tool, which can be used as a background for setting risk tolerability criteria, defined by different standards, depending on the related risks domain, e.g. workplace safety – ISO 45001 (https://www.hsetudyguide.com), Petroleum and natural gas industries — Offshore production installations (https://www.iso.org-c), etc..

Usually, the risk matrices are separated in four regions that identify the limit of risk tolerability, as structured in the following example (Eni Montenegro, 2020): **Continuous improvement (Low Risk Region):** The level of risk that requires continuous monitoring and improvement to prevent negative effects. **Risk reduction measure (Medium Risk Region**): The level of risks that requires control if implementation of such measures is not disproportionate to the benefits (ALARP). **Risk reduction measure (Medium–High Risk Region):** The level of risk has to be reduced applying suitable corrective measures, if the implementation of such measures is not disproportionate to the benefits (ALARP). **High Risk (Intolerable Risk Region):** The level of risk is not acceptable and risk control measures are required to move the risk intensity to the previous regions.

After this introduction, where a summary of available literature overview on risk managements in the ports is shown, in the section 2 is presented a short description of the port where the analysis is performed. In the section 3 is introduced used methodology and in the section 4 results are systematized. Discussion of results and conclusions are given in the section 5.

2. A DESCRIPTION OF THE PORT WHERE THE ANALYSIS IS PERFORMED

The Port of Bar (Port of Bar, 2024) is a multipurpose port, situated at the south of the Adriatic sea, established at the beginning of the last century (1906). The Port is managed according to the landlord port management model. Within the Port area are functioning two terminal operators: Port of Bar JSC (major shareholder is The State of Montenegro, owning 78.15% of shares), and the Port of Adria JSC (majority of shares – 62% are owned by the Turkish Company

Global Ports Holding). There are several specialized terminals in the Port of Bar: Terminal for dry bulk and liquid bulk cargo, Container terminal, General cargo terminal, Ro-Ro terminal and Passenger terminal.

3. METHODOLOGY

Port efficiency is the capability of a port (terminal) to fit the optimum number of inputs to a given output level (Weerawat, 2020). A group of crucially important tasks in the port management process is related to achieving a greater degree of efficiency. Port efficiency is depending on different influential factors: the various technological advancements, including, digitalization, advanced analytics and sustainable technologies (https://www. **visiwise)**.

In general, there are three required elements for measuring efficiency in ports: decision making unit (DMU), output variables, and input variables (Weerawat, 2020). It the available literature related to measuring port efficiency are used different methods (techniques): original least squares (OLS), corrected original least squares (COLS), data envelopment analysis (DEA), stochastic frontier analysis (SFA), etc. (Boakye et.al., 2021).

Efficiency in a port can be measured in different manners, using various metrics: efficiency of whole port (in comparison with other ports), efficiency of terminals in the same port or among different ports, efficiency of berths within a terminal, etc.

Data Envelopment Analysis (DEA), developed by Charnes et al. in 1978, is a linear programming based method for evaluating performance of organizational units called decision-making units (DMUs) (Wang et.al., 2021).

There are two basic DEA models, DEA-CCR (Charnes–Cooper–Rhodes) and DEA-BCC (Banker–Charnes–Cooper) [33]. The DEA-CCR basic model can be defined with following relations (Jablonský, 2008; Ewertowska, 2017):

$$(LP)\ max\theta = \sum_{r=1}^{p} u_r\, y_{r0} \quad (1)$$

Subject to:

$$\sum_{i=1}^{m} v_i\, x_{i0} = 1 \quad (2)$$

$$\sum_{r=1}^{p} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0, (\forall j = 1, 2, \dots, n) \quad (3)$$

$$u_r \geq 0, r = 1, 2, \dots, p \quad (4)$$

$$v_i \geq 0, i = 1, 2, \dots, m \quad (5)$$

3.1 Selection of input and output variables

The assessment of port efficiency using DEA method begins with the adequate selection of input and output variables (Dewarlo, 2019). The most frequently used inputs are resources such as land, human resources, and equipment as well as the total quay length (m); net berth productivity (t/h); operation costs; maximal allowed ship draft (m); etc. (Kammoun, 2018; Tabaoda et.al., 2020; Pjevcevic et.al., 2012). The measurement of the output is done by: throughput (t); terminal capacity (t); number of ships; number of passengers; number of containers; berth occupancy; vessel turnaround time (Dewarlo, 2019; Kammoun, 2018; Pjevcevic et.al., 2012), etc. For the purpose of conducting research whose results are presented in this paper are selected following input variables and output.

Input variables: input - number of workers directly engaged in the cargo handling process, N_w, berth length, B_l (m), water depth (by the berth), D_w (m), operation costs, C_o (€);

Output: annual cargo throughput by berths (DMU_s), Q_{bi} (t);

Decision Making Units (DMUs): berths (seven berths) at the Terminal for dry bulk and liquid bulk cargo in the Port of Bar JSC (Table 1).

Table 1. Decision Making Units (DMUs)

DMU_i	Purpose/Main activities carried out
DMU_1 – berth 01	loading/unloading operations with dry bulk cargo
DMU_2 – berth 02	loading/unloading operations with dry bulk cargo
DMU_3 – berth 03	loading/unloading operations with dry bulk cargo
DMU_4 – berth 04	unloading operations with dry bulk cargo
DMU_5 – berth 05	loading operations with liquid bulk cargo
DMU_6 – berth 06	loading/unloading operations with liquid bulks
DMU_7 – berth 07	loading/unloading operations with liquid bulks

(source: author)

Period taken into consideration: 2021 – 2024.

In the Table 2. are presented data series for defined DMUs (berths at the Terminal for dry bulk and liquid bulk cargo in the Port of Bar JSC) and selected input and output variables, for the period from the year 2021 to the year 2024. Sources of data were official reports from the Port of Bar JSC Information System (Port of Bar, 2024).

Table 2. Data series

DMU_i	Year	Output	Inputs							
		Annual throughput (t)	Number of directly engaged workers		Quay length (m)		Water depth (m)		Direct operation costs (€)	
			Total	Risk related	Total	Risk related	Total	Risk related	Total	Risk related
Berth 01	2021	156,745.43	494	371	185	185	14	14	34,307	29,002
	2022	182,676.68	576	432	185	185	14	14	39,983	33,800
	2023	343,069.54	1,081	811	185	185	14	14	75,089	63,476
	2024	306,095.91	965	724	185	185	14	14	66,996	56,635
Berth 02	2021	662,581.47	1,077	718	185	185	14	14	175,681	160,892
	2022	1,084,764.78	1,763	1,175	185	145	14	14	287,621	263,410
	2023	323,597.26	526	351	185	145	14	14	85,801	78,578
	2024	204,585.48	333	222	185	185	14	14	54,245	49,679
	2024	188,439.24	102	51	93.3	93.3	9.9	9.9	10,723	1,824
...										
Berth 07	2021	50,471.23	27	14	198	198	12.8	12.8	2,872	489
	2022	83,110.87	45	22	198	198	12.8	12.8	4,729	805
	2023	30,315.94	16	8	198	198	12.8	12.8	1,725	293
	2024	20,140.00	11	5	198	198	12.8	12.8	1,146	195

(source: author, based on (Port of Bar, 2024))

Description of the input parameters is given in the Table 3.

Table 3. Description of the input paramters

Input parameters - Total	Input parameters – Risk related component
Total number of workers, directly engaged in the cargo handling process – N_{w1}: a group of workers engaged for realization a loading/unloading operation;	**Number of workers – risk related, N_{w2} -** engaged in the cargo handling process, after deduction (isolation) of risk related workers (whose engagement is determined by the requirements of the risk management process);
Berth lenght, B_{l1} (m)	**Berth lenght – risk related, B_{l2} (m) -** available berth lenght after deduction (isolation) of the lenght of a part which was under maintence (risk related activities);
Water depth (by the berth), D_{W1} (m)	**Water depth (by the berth) – risk related, D_{W2} (m) –** there were no differences in values of this parameter in both variants;
Direct operation costs, C_{o1} (€): *-daily wages, $C_{01\text{-}1}$(€)* - related to the workers engaged for realization a loading/unloading operation; *-port machinery costs, $C_{01\text{-}2}$(€)* – related to used port machinery, depending on the type of the cargo handling operation and type of the cargo; costs are a sum of following components: fuel costs, electric power costs, depreciation costs and cost of periodical inspection by authorized external body (fulfillment of safety requirements); *-costs of personal safety equipment, $C_{01\text{-}3}$(€)*, calculated based on costs of personal safety equipment per year, total number of working hour of a employee per year, ...; *-costs of fire truck, $C_{01\text{-}4}$(€)*, caclulated based on fuel consumptions per effective working hour, average price of the fuel, number of effective working hours per year, ...; *-costs of insurance of engaged workers, $C_{01\text{-}5}$(€)*, calculated based on annual insurance costs per employee, total annual fund of working hour per employee, ...; *-costs of using protective dam, $C_{01\text{-}6}$(€)*, against spilages of oil derivates during handling operation with that cargo type, calculated based on costs of usage protective dam per hour and number of effective working hours used for loading/unloading total annual quantity of cargo per berth. --- Direct operation costs - total: $C_{o1} = C_{01\text{-}1} + C_{01\text{-}2} + C_{01\text{-}3} + C_{01\text{-}4} + C_{01\text{-}5} + C_{01\text{-}6}$	**Direct operation costs – risk related, C_{o2} (€) –** after deduction (isolation) of risk related components: *-daily wages-risk related, $C_{02\text{-}1}$(€)* – is caclulated based on the value of the component $C_{01\text{-}1}$ reduced for costs of the risk related workers (signal man, fireman), depending on the type of cargo and type of operation. *-port machinery costs, $C_{02\text{-}2}$(€)* – is calculated based on the value of the component $C_{01\text{-}2}$ reduced for the cost of periodical inspection by authorized external body (fulfillment of safety requirements). --- Direct operation costs – risk related: $C_{o2} = C_{02\text{-}1} + C_{02\text{-}2}$

(source: author)

4. RESULTS

Based on values of input (column "total") and output variables given in the Table 2, efficiency scores for defined DMUs (berths at the Terminal for dry bulk and liquid bulk cargo in the Port of Bar JSC), per years of the analyzed period from 2021 to 2024, are calculated using appropriate software (based on DEA CCR model) – Table 4.

Table 4. Eficiency scores related to selected DMU_i

DMU_i, Berths	2021		2022		2023		2024	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
01	0.4632	6	0.5019	7	0.8291	7	0.8806	5
02	1	1	1	1	0.8309	6	0.6405	6
03	0.4597	7	0.6119	6	1	1	1	1
04	1	1	1	1	1	1	1	1
05	1	1	1	1	1	1	0	7
06	1	1	1	1	1	1	1	1
07	0.9638	5	0.9882	5	1	1	0.9828	4

(source: author)

5. DISCUSSION AND CONCLUSIONS

Ranges and intensity of variations of berths` efficiency scores are analyzed in the Table 5.

Table 5. Ranges and intensity of variations of berths` efficiency scores

DMU_i	Purpose/Main activities carried out	Range of the efficiencyscores in the period 2021 – 2024	Intensity of variations of the efficiency scores
(1)	(2)	(3)	(4)
DMU_1 – berth 01	loading/unloading operations with dry bulk cargo	0.4632 – 0.8806	High (max/min = 1.90)
DMU_2 – berth 02	loading/unloading operations with dry bulk cargo	0.6405 - 1	High (max/min = 1.56)
DMU_3 – berth 03	loading/unloading operations with dry bulk cargo	0.4597 – 1	High (max/min = 2.17)
DMU_4 – berth 04	unloading operations with dry bulk cargo	1	const.
DMU_5 – berth 05	loading operations with liquid bulk cargo	0 – 1	Extremely high
DMU_6 – berth 06	loading/unloading operations with liquid bulks	1	const.
DMU_7 – berth 07	unloading operations with liquid bulks	0.9638 - 1	Low (max/min = 1.03)

(source: author)

Intensity of variations (relation between the maximum and minimum) of efficiency scores is categorized based on following (adopted) criteria:
- low: < 50%; - high: >50%; - const.: no changes over the period; - extremely high: variation from 0 to 1;

Changes in correlations between the output (throughput) and inputs determine intensity of variations of the berths` efficiency scores. Each input parameter has its own risk related component (as described in the Table 3.) what indicate influence of the risk related parameters on efficiency scores. At the same time, character and values of those risk related parameters can be, among other, used as indicators for identifying general importance of the risk management process and a base for increasing its adequacy level all in order to eliminate risks or to reduce risks up to the acceptable level.

As shown with the Table 2. and described in the Table 3. input "workers - directly - engaged in the in the cargo handling process" has a risk related component, according to results of analyzes presented in the Table 6.

Table 6. Average number of risk related workers

Berth	Average annual throughput per berths (tons/year)	Average total number of engaged workers per year	Average number of risk related workers in a group of engaged workers (%)	Workers who have tasks from the domain of risk management (100% of effective works)	Average efficiency score per year	Type of cargo loaded/unloaded (type of operation, used handling system) – basic related risk category prevented by engaged risk related workers
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Berth 01	247,147	779	25%	signal man: assisting the crane operater	0.6687	Dry bulk, non hazardous cargo (lo-lo operations, cranes) – operational risks, safety and health risks, technical risks, ...; estimated level of risk requires direct engagement of risk related workers;
Berth 02	568,882	925	33%	signal man: assisting the crane operater	0.8679	Dry bulk, non hazardous cargo (lo-lo operations, cranes) – operational risks, safety and health risks, technical risks, ...; estimated level of risk requires direct engagement of risk related workers;

Berth 03	521,401	1,689	14%	signal man: assisting the crane operater	0.7679	Dry bulk, non hazardous cargo (lo-lo operations, cranes)– operational risks, safety and health risks, technical risks, ...; estimated level of risk requires direct engagement of risk related workers (with 100% of tasks related to risk mitigation);
Berth 04	123,493	94	0%	-	1.0000	Dry bulk, non hazardous cargo (unloading, pneumatic system) - estimated level of risk does not require direct engagement of risk related workers (with 100% of tasks related to risk mitigation);
Berth 05	8,344	6	0%	-	0.7500	Liquid bulk, non hazardous cargo (loading, pumps/pipelines system) - estimated level of risk does not require direct engagement of risk related workers (with 100% of tasks related to risk mitigation);
Berth 06	187,199	101	50%	fireman: prevention of accidents	1.0000	Liquid bulk, hazardous cargo (loading/unloading, pumps/pipeline system) – safety and health risks, environmental risks
Berth 07	46,010	25	50%	fireman: prevention of accidents	0.9837	Liquid bulk, hazardous cargo (unloading, pumps/pipeline system) – safety and health risks, environmental risks, ...; estimated level of risk requires direct engagement of risk related workers (with 100% of tasks related to risk mitigation);

(source: author)

Based on the data and results of their analysis presented in the previous table, following correlations can be established:

- Non hazardous cargo (dry bulks), lo/lo operations (loading/unloading), cranes (berths: 01, 02 and 03):
  - range of average efficiency scores: 0.6687 – 0.8679;
  - average percentage of risk related workers engaged in the working process: 14% - 33%;
- Non hazardous cargo (dry bulk), unloading, pneumatic system (berth 04):
  - average efficiency score: 1.0000;
  - average percentage of risk related workers engaged in the working process: 0%;
- Non hazardous cargo (liquid), loading, pumps-pipeline system (berth 05):
  - average efficiency score: 0.7500;
  - average percentage of risk related workers engaged in the working process: 0%;
- Hazardous cargo (liquid), loading/unloading, pumps-pipeline system (berths: 06, 07);
  - range of average efficiency scores: 0.9837 – 1.0000;
  - average percentage of risk related workers engaged in the working process: 50%;

Previous results of analysis enable some conclusions on engaged risk related workers:

- average number of engaged risk related workers depends on the type of cargo (non hazardous or hazardous) and the type of the used cargo handling technology (lo-lo operations, cranes; pneumatic system; pump-pipeline system);

- average number of engaged risk related workers is significantly bigger in handling operations with hazardous cargo;
- engagement of risk related workers in cargo handling operations (lo-lo operations, cranes and pump-pipeline system) is a key prerequisite for achieving maximal level of berth`s efficiency;
- when the pneumatic system is used for unloading operations, than no risk related workers were engaged (directly engaged in the handling operations);

Essentially important prerequisites for the concretization of duties of workers from the domain of risk management are: existence and application of adequate working procedures, the optimal level of training of workers for the implementation of tasks from the scope of duties of the workplace and an adequate level of awareness regarding the importance of the risk management system.

In order to additionally illustrate importance of the risk management system for the complete port, with the Table 7. are given results of an analysis of the structure of employees by organizational units in the Port of Bar JSC. The participation of the number of employees with duties of 100% of working time (at the annual level) in the field of risk management in the total number of employees by organizational units (sectors) is identified.

Table 7. Structure of employees

Organizational unit	"Risk related employees", with 100% of working time in the domain of the risk management (%) of total number of employees	Risk related activities performed	Related risk category
(1)	(2)	(3)	(4)
Board of directors` office	40%	Internal audit	Financial risks, Legal risks, Reputational risks
CEO	-	-	-
CEO`s office	6.3%	Safety on work	Safety risks
Operations Department	-	-	-
Maintenance Department	34%	Preventive and corrective maintenance of technical systems	Technical risks, Safety risks
Development Department	16.7%	Environmental protection	Environmental risks
Financial and Accounting Department	5.9%	Costs analyses	Financial risks
Marketing and Sales Department	12.5%	Collection of receivables	Financial risks
Administration Department	15.4%	Legal affairs	Legal risks
IT Department	35.7%	Maintenance of the hardware and cyber security	Technical risks, Cyber risks
Security Department	84.7%	Physical and technical security, rescue	Safety risks, Security risks, Natural risks
Total	19%		

(source: author based on [93])

It is important to analyze share of the risk related cost components in the calculated total direct operation costs of handling operations per analyzed berths at the Terminal for dry bulk and liquid bulk cargo. Results are presented with the Table 8.

Table 8. Share of the risk related cost components in the direct operation costs

Berth	Average annual throughput per berths (tons/year)	Average operation costs per year (eur)	Average share of risk related components in the calculated direct operation costs (%)	Average efficiency score per year	determining factors: type of cargo, hazardous/non hazardous cargo, loading/unloading system, number of engaged workers
(1)	(2)	(3)	(4)	(5)	(6)
Berth 01	247,147	54,094	15%	0.6687	Dry bulks, non hazardous cargo, usage of cranes in the loading/unloading operations (lo-lo operations).
Berth 02	568,882	150,837	8%	0.8679	Dry bulks, non hazardous cargo, usage of cranes in the loading/unloading operations (lo-lo operations).
Berth 03	521,401	230,531	13%	0.7679	Dry bulks, non hazardous cargo, usage of cranes in the loading/unloading operations (lo-lo operations).
Berth 04	123,493	3,520	5%	1.0000	Dry bulks, non hazardous cargo, pneumatic system of ships` unloading.
Berth 05	8,344	214	5%	0.7500	Liquid bulks, non hazardous goods, pump-pipeline system for loading ships.
Berth 06	187,199	10,652	83%	1.0000	Liquid bulks, hazardous cargo, pump-pipeline system for loading/unloading ships.
Berth 07	46,010	2,618	83%	0.9837	Liquid bulks, hazardous cargo, pump-pipeline system for loading/unloading ships.

(source: author)

Taking into account results of analysis from the Table 8., some relevant correlations between the paramters can be identified:

- Non hazardous cargo (dry bulks), lo/lo operations (loading/unloading), cranes (berths: 01, 02 and 03):
  - range of average efficiency scores: 0.6687 – 0.8679;
  - average share of risk related costs components in the direct operation costs: 8% - 15%;
- Non hazardous cargo (dry bulk), unloading, pneumatic system (berth 04):
  - average efficiency score: 1.0000;
  - average share of risk related costs components in the direct operation costs: 5%;
- Non hazardous cargo (liquid), loading, pumps-pipeline system (berth 05):
  - average efficiency score: 0.7500;
  - average share of risk related costs components in the direct operation costs: 5%;
- Hazardous cargo (liquid), loading/unloading, pumps-pipeline system (berths: 06, 07);

- range of average efficiency scores: 0.9837 – 1.0000;
- average share of risk related costs components in the direct operation costs: 83%;

Previously made considerations enable following basic conclusions on correlations between the average share of risk related costs in direct operation costs and efficiency scores by berths:

- average share of risk related costs in direct operation costs depends on the type of cargo (non hazardous or hazardous) and the type of the used cargo handling technology (lo-lo operations, cranes or pneumatic system or pump-pipeline system);
- average share of risk related costs in direct operation costs is significantly bigger in handling operations with hazardous cargo, what is in line with unavoidable necessity to eliminate or reduce to the acceptable level numerous risk appeared there (and usage of additional port resources in the process);
- usage of port resources for eliminating or reducing risks to the acceptable level and related components of costs enable achieving maximal level of berth`s efficiency;

In the context of an analysis of the risk related operations costs, it is important to point out that in the structure of total costs characteristic for functioning of a port appear a lot of components of costs which are risk related – completely purposed for mitigation of different risk categories. With the next table are systematized some concrete risk related components of costs in the Port of Bar JSC, which are in total purposed for mitigation of mentioned risks categories.

Table 9. Correlation: components of costs – risk categories

Component of costs	Related risk category
(1)	(2)
Costs of occupational health and safety (medical examinations, training, personal protective equipment, periodic inspections of facilities, installations and port machinery, .., ...)	Health and safety risks
Costs of physical and technical security	Security risks
Costs of protection and rescue (from fire, technical-technological accidents, ...)	Security risk, Health and safety risks, Natural risks
Costs related to debt collection	Financial risks
Maintenance costs (preventive maintenance of facilities, installations, port machinery, ...; corrective maintenance of facilities, installations, port machinery, ...) in order to reduce the negative consequences of interruption of work processes caused by failures of mentioned systems	Technical risks, Operational risks
Insurance costs for employees, facilities, machinery	Health and safety risks, Technical risks, Natural risks
Costs of internal and external financial audits	Financial risks
Maintenance of the Port Information System and the Port Community System	Operational risks, Contractual risks, Cyber risks
...	

(source: author)

Based on the previous discussion of results, following indicators of risk management process importance in a seaport, from the aspects closely connected with the berths` efficiency, can be directly defined:

- **Indicator 1**: Number of risk related workers directly engaged in the cargo handling process, by berths;

- **Indicator 2**: Share of risk related components of costs in the direct operation costs (characteristic for cargo handling operations by berths);

By the considerations done in this paper are highlighted some aspects of correlation between berths` efficiency (as one of the frequently used port efficiency metrics) and risk related parameters.

Author plans to continue research of the correlation between berths` efficiency and risk related parameters giving priority to quantification of influence of risk related parameters to efficiency scores.

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REFERENCES

Alyami, H., et.al. (2014). An advanced risk analysis approach for container port safety evaluation. Maritime Policy & Management, 41, 634-650. https://doi.org/10.1080/03088839.2014.960498.

Bazaras, D., Palšaitis, R. (2020). Risk Management in Sea Ports – Insights and Trends. Lecture Notes in Networks and Systems, pages 268-274. DOI: 10.1007/978-3-030-44610-9_27.

Boakye, G., Li, Y, Asare, E. (2021). Determination of the Efficiency of Port Performance and Productivity Based on Data Envelopment Analysis in the West Africa Sub-region. Indian Journal of Science and Technology, 14(46), 3396-3406. https://doi.org/ 10.17485/IJST/v14i46.1755.

Dewarlo, O. (2019). DEA Window Analysis for Measuring Port Performances Efficiency of Four Islands Countries Located in West Indian Ocean Countries. American Journal of Industrial and Business Management, 12(9). DOI: 10.4236/ajibm.2019.912139.

Dias, G.C., Leal, I.C., Rébula de Oliveira, U. (2019). Supply chain risk management at seaport container terminals. Gestao & Producao, 26(3),1-14. https://doi.org/10.1590/0104-530X4900-19/.

Ewertowska, A. (2017). Systematic Tools Based on Data Envelopment Analysis for the Life Cycle Sustainbility Evaluation of Technologies, doctoral thesis, Universitat Rovira i Virgili, Taragona. http://hdl.handle.net/10803/457128, accessed 22 November 2024.

https://www.iso.org/standard/65694.html. accessed 1October 2024.

https://www.hsestudyguide.com/iso-45001-risk-assessment-matrix/. accessed 24 October 2024.

https://www.iso.org/standard/63062.html. accessed 27 November 2024.

IEC (2009). INTERNATIONAL STANDARD IEC/FDIS 31010, Risk management — Risk assessment techniques. https://bambangkesit.wordpress.com/wp-content/uploads/2015/12/iso-31010_risk-management-risk-assessment-techniques.pdf. accessed 1 December 2024.

John, P., Christie, J.S., Ircha, M.C. (2014). Port risk management strategy. https://ctrf.ca/wp-content/uploads/2014/07/13JohnChristieIrchaPortRiskManagement.pdf. accessed 23 November 2024.

Janowicz, K., Pauling, J. (2016). Risk Assessment, Management, and Mitigation for Port and Marine Terminals Projects. AAPA Cargo Optimization. https://www.aapa-ports.org/files/SeminarPresentations/2016Seminars/2016CargoOptimization/Kat%20J.pdf. accessed 2 October 2024.

Jablonský, J. (2008). A Spreadsheet Based System for DEA models. https://mcdm.ue.katowice.pl. accessed 22 July 2024.

Juliza, H., Anggiat, H,O.S. (2019). Identify The Operational Risk Of The Port By The Risk Breakdown Structure (RBS) Method. IOP Conference Series: Materials Science and Engineering, volume 505. Medan City, North Sumatera, Indonesia. **DOI:** 10.1088/1757-899X/505/1/012012.

Kadir, Z.A., Mohammad, R., Othman, N., Amrin, A., Muhtazaruddin, M.N., Abu-Bakkar, S.H., Muhammad-Sukki, F. (2020). Risk management framework for handling and storage of cargo at major ports in Malaysia towards port sustainability. Sustainability, 12(2), 516. https://doi.org/10.3390/su12020516.

Kadir, Z.A., Mohammad, R., Othman, N. (2020). An Advanced Risk Matrix Analysis Approach for Safety Evaluation at Major Ports in Malaysia. Journal of Advanced Research in Business and Management Studies, 18(1), 31-41. https://www.akademiabaru.com/doc/ARBMSV18_N1_P31_41.pdf. accessed 15 November 2024.

Kammoun, R. (2018). The Technical Efficiency of Tunisian Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis Scores. Logistics & sustainable transport, 9(2), 73-84. DOI:10.2478/jlst-2018-0011.

Kristiansen, S. (2005). Maritime Transportation: Safety Management and Risk Analysis, Elsevier Butterworth-Heinemann, 2005. https://books.google.me/books/about/Maritime_Transportation.html?id=-O57NcHhkLMC&redir_esc=y. accessed 4 November 2024.

Mabrouki, C., Bellabdaoui, A., Mousrij, A. (2013).
Risk Analysis and Assessment by Multicriteria Approach Based in RO-RO Port Terminal. Case Study. International Journal of Computer Science Issues, 10(3), 37-45. https://ijcsi.org/papers/IJCSI-10-3-1-37-45.pdf. accessed 4 October 2024.

Marine risk management: best practice. https://www.abpmer.co.uk/blog/marine-risk-management-best-practice/. accessed 18 November 2024.

Ministarstvo finansija (Ministry of Finance) (2015). Smjernice za uspostavljanje i sprovodjenje procesa upravljanja rizicima u subjektima javnog sektora (Guidelines for establishing and performing risk management process in the public sector). https://wapi.gov.me. accessed 3 December 2024.

Nagi, A., Indorf, M., Kersten, W. (2017). Bibliometric analysis of risk management in seaports.
Proceedings of the Hamburg International Conference of Logistics (HICL), 23, 491-521. https://doi.org/10.15480/882.1463.

Pallis, P.L. (2017). Port risk management in container terminals. Transportation research
procedia, 4411–4421. https://doi.org/10.1016/j.trpro.2017.05.337.

Pjevčević, D., Radonjić, A., Hrle, Z., Čolić, V. (2012). DEA Window Analysis for Measuring Port Efficiencies in Serbia. Promet – Traffic&Transportation, 24(1), 63-72. DOI: https://doi.org/10.7307/ptt.v24i1.269.

Port of Bar (2024). Documentation of the Development Department.
Procedure "opi sg hse 001 ups r03" (2020). HSE Risk Management and Reporting, Professional Operating Instruction. Eni Montenegro.

Risk management ISO 31000. https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100426.pdf. accessed 17 August 2024.

Risk management in the customs context. https://www.wcoomd.org/-/media/wco/public/global/pdf/topics/enforcement-and-compliance/activities-and-programmes/risk-management-and-intelligence/risk-management-compendium-volume-1.pdf?la=en. accessed 21 December 2024.

Role of Technology in Enhancing Port Efficiency. https://www.visiwise.co/blog/enhancing-port-efficiency/. accessed 9 October 2024.

Sihem, S., Noumen, R. (2020). Port risk assessment in container terminals: the case of Tunisia. International Journal of Transport Development and Integration, 4(1), 42-50. DOI: 10.2495/TDI-V4-N1-42-50.

Taboada, G.L, Seruca, I, Sousa, C, Pereira, Á. (2020). Exploratory Data Analysis and Data Envelopment Analysis of Construction and Demolition Waste Management in the European Economic Area. *Sustainability,* 12(12), 4995. https://doi.org/10.3390/su12124995.

Trbojevic, V.M., Carr, B.J. (2000). Risk based methodology for safety improvements in
ports. Journal of Hazardous Materials, 71(1–3), 467–480. https://doi.org/10.1016/S0304-3894(99)00094-1

UNCTAD, Port risk management and resilience-building toolbox. https://resilientmaritimelogistics.unctad.org/guidebook/5-port-risk-management-and-resilience-building-toolbox. accessed 12 November 2024.

Vaughan, E.,J., Elliott, C.,M. (1978). Fundamentals of Risk and Insurance, Wiley. https://books.google.me/books/about/Fundamentals_of_Risk_and_Insurance.html?id=RdbuAAAAMAAJ&redir_esc=y. accessed 2 October 2024.

Wang, C. N., et.al. (2021). Efficiency Assessment of Seaport Terminal Operators Using DEA Malmquist and Epsilon-Based Measure Models. *Axioms*, *10*(2), 48. https://doi.org/10.3390/axioms10020048

Weerawat, W. (2020). Evaluation Efficiency of Indonesian Seaports: Data Envelopment Analysis, https://www.eg.mahidol.ac.th. accessed 11 June 2024.

Woodruff, J.,M. (2005). Consequence and likelihood in risk estimation: a matter of balance in UK health and safety risk assessment practice, Safety Science, 43(5–6), 345–353. DOI:10.1016/j.ssci.2005.07.003.

Yang, T., Hung, C.-C. (2007). Multi-Attribute Decision Making Methods for Plant Layout Design Problem. Robotics and Computer Integrated Manufacturing, 23(1), 126-137. http://dx.doi.org/10.1016/j.rcim.2005.12.002.

Yang, Y.-C. (2011). Risk management of Taiwan's maritime supply chain security. Safety Science, 382–393. https://doi.org/10.1016/j.ssci.2010.09.019.

A Novel Hybrid Solar System for Combined Power, Heating, Cooling, and Hydrogen Production: A Thermodynamic Investigation

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Abstract: The growing global demand for energy, coupled with the environmental impacts of fossil fuel use, has accelerated interest in renewable-based multigeneration systems. This study presents a comprehensive thermodynamic analysis of a solar-powered polygeneration system designed to simultaneously produce electricity, heating, cooling, and hydrogen. The proposed configuration integrates a solar power plant (SPP), Rankine power plant (RPP), organic Rankine cycle (ORC), hydrogen production and storage plant (HPSP), proton exchange membrane fuel cell plant (PEMFCP), and an absorption-based cooling production plant (CPP). Energy and exergy analyses were conducted under steady-state conditions, with parametric investigations performed for variations in ambient temperature (25–50 °C) and solar irradiance (400–1000 W/m²). At base conditions (25 °C, 750 W/m²), the system achieved an overall energy efficiency of 53.9% and an exergy efficiency of 49.6%, with total production capacities of 6068 kW electricity, 2216 kW heating, 1050 kW cooling, and 0.0605 kg/s hydrogen. Exergy destruction analysis revealed the solar field and hydrogen production unit as the dominant sources of irreversibilities, highlighting opportunities for performance enhancement. Parametric results showed that higher solar irradiance significantly improved all useful outputs, whereas rising ambient temperature reduced efficiencies due to increased irreversibilities. The findings demonstrate that integrated solar-based multigeneration systems can provide diversified, efficient, and sustainable energy services while addressing energy transition challenges. This study contributes to the design basis for future renewable-driven polygeneration plants, offering insights for performance optimization and practical implementation.

Keywords: Solar energy, Multigeneration system, Exergy analysis, Hydrogen production, Energy efficiency

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1. INTRODUCTION

Industrialization, population growth, urbanization, and rising living standards are driving a steady increase in energy consumption (Kautish et al., 2025). However, current energy needs continue to be met through fossil fuels (Kalair et al., 2021). Fossil fuels are not only limited and highly sensitive to price fluctuations but also contribute significantly to environmental degradation and climate change through greenhouse gas emissions (Mohamad Taghvaee et al., 2023). Such problems threaten the long-term sustainability of current energy systems (Kabeyi and Olanrewaju, 2022). Therefore, the transition from high-carbon energy production methods to low-emission, renewable alternatives has become a priority and necessitates the diversification of energy sources (Jaroń and Borucka, 2024).

Among renewable energy sources, solar energy is emerging as a particularly promising option due to its abundance, environmental benefits, and rapidly decreasing technological costs (Ukoba et al., 2024). Solar energy can be used to generate electricity and thermal energy through both direct and indirect means (Sun et

al., 2022). It can also be used in advanced processes such as electrolysis, thermochemical cycles, and photocatalytic reactions to produce hydrogen (Hassan et al., 2024) and other chemical energy carriers (Kong et al., 2025). This versatility allows solar energy to serve not only as a standalone source but also as a key component in integrated, multifunctional energy systems.

In recent years, research has focused on hybrid and integrated systems that convert solar energy into multiple forms of energy (Cardemil et al., 2021). These systems aim to increase overall efficiency by combining electricity generation, heating, and cooling applications, and hydrogen production within a single, unified platform. A key advantage of integrated systems is their scalability and adaptability for use in a variety of environments, including residential buildings, commercial complexes, agricultural operations, and industrial facilities (Ahmad et al., 2025).

In this context, this study aims to analyze the interactions between various system components and evaluate the overall performance of the system using key engineering parameters.

2. SYSTEM DESIGN

Figure 1 shows the schematic diagram of a solar energy-based power generation plant. The integrated plant consists of five subsystems: the solar power plant, the Rankine power plant, the ORC plant, the cooling production plant, and the hydrogen production and storage plant. The system, created by combining various components, focuses on electricity, heating-cooling, and hydrogen production. As shown in Figure 1, solar radiation is transferred to the solar tower using a heliostat. The fluid whose temperature increases in the solar tower is sent to the thermal energy storage facility. The aim here is to store energy by heating or cooling the fluids. As shown in Figure 1, the fluid first passes through a heat exchanger using a pump. In HEX-1, heat transfer occurs and is transferred to the Rankine power plant, where electricity is generated. In the HEX-1, the fluid that reaches a certain thermal level is transferred to the steam turbine. Power is generated by expanding the working fluid in two different steam turbines: high-pressure and low-pressure. Another subsystem involved in electricity generation is the ORC plant. In the HEX-2, the fluid that reaches a certain thermal level is transferred to the steam turbine. The steam generates electricity in the generator. Then, the fluid is sent to the condenser. The heat is used for domestic heating. The fluid, whose pressure and temperature have decreased in the condenser, is sent back to HEX-2 via a pump, completing the cycle. On the other hand, the water leaving the HEX-1 is sent to the heater to reach the appropriate temperature. Water at approximately 80°C is pumped into the PEM electrolyzer to produce H2 and O2. The separate H_2 is pressurized and cooled by a booster and heat exchanger. This process is repeated several times, then sent to the H_2 storage tank. The stored H_2 is sent to the Proton Exchange Membrane (PEM) fuel cell to generate electrical energy. The electrical energy is then made available for vehicle use at the charging station by an inverter. Finally, the proposed system incorporates the cooling production plant. The water leaving the heater enters the generator. Heat transfer occurs in the fluid in the generator and is transferred to the condenser-2 and the HEX-7. The fluid leaving the condenser-2 first enters the HEX-8 and from there, via a valve, into the evaporator, completing the cooling process.

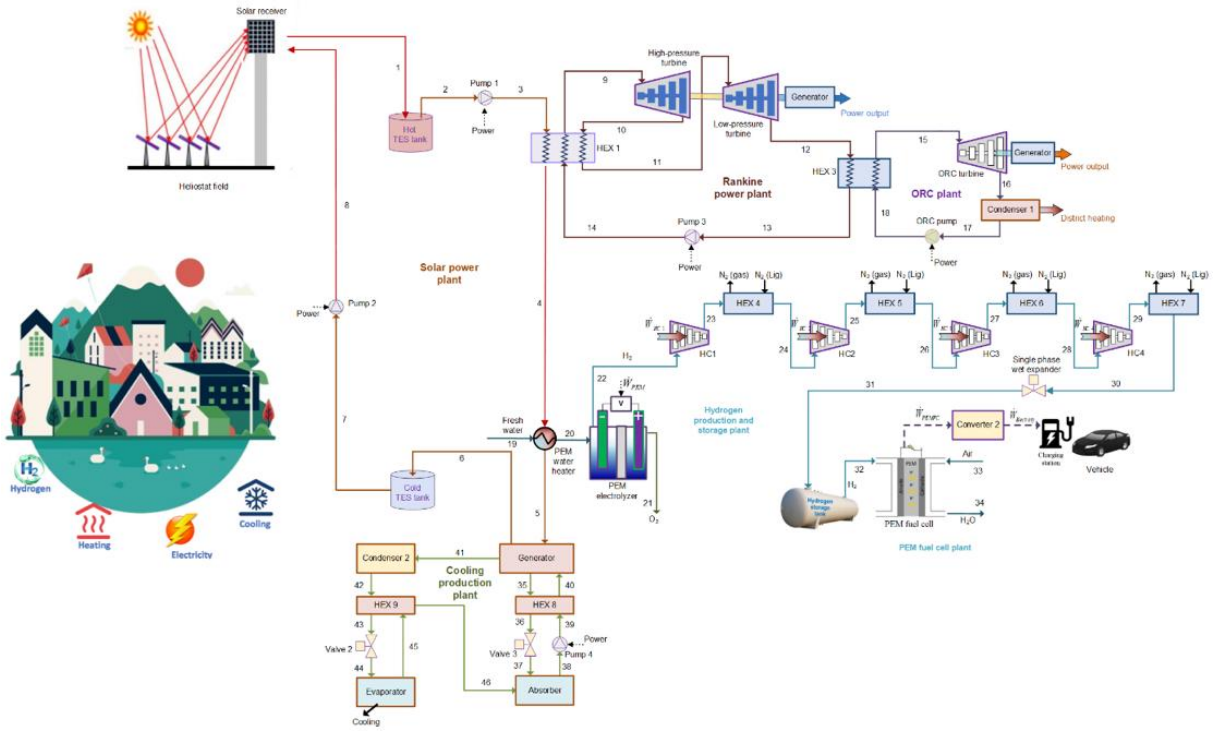

Figure 1. A schematic illustration of the solar-powered combined system

3. MODELING AND ANALYSIS

3.1. Global assumptions and reference states

Steady-state, steady-flow is assumed for all components; kinetic and potential energy changes are neglected. Ambient (dead-state) conditions are $T_0 = 25$ °C and $P_0 = 101.3$ kPa**;** reference solar irradiance in the base case is $G = 750$ W/m²**.** Heat exchanger effectiveness is $\varepsilon = 0.99$**;** isentropic efficiencies are $\eta_{i,pump} = 0.85$**,** $\eta_{i,steam\text{-}turb} = 0.85$**,** $\eta_{i,ORC\text{-}turb} = 0.80$**,** $\eta_{i,ORC\text{-}pump} = 0.80$**;** hydrogen compressor $\eta_{i,comp} = 0.85$ with overall compression ratio $r_c = 8$**.** LHV(H_2) = 120 MJ/kg and standard specific chemical exergy of H_2 = 117.12 MJ/kg**.** Working fluids: SPP molten salt 59.5% LiCl–40.5% KCl**,** ORC fluid R290, absorption pair NH_3–H_2O. Design parameters and modeling assumptions of the solar-powered combined system are given in Table 1. In addition, Table 2 presents the thermophysical properties of each state numbered in Figure 1 of the designed system.

Table 1. Input parameters and working conditions for system modeling

Reference temperature	25 °C
Reference pressure	101.3 kPa
Solar radiation	750 W
Energy efficiency of HEXs	0.99
LHV of hydrogen	120 MJ/kg
Exergy of hydrogen	117.12 MJ/kg
Isentropic efficiency of pumps	0.85
Isentropic efficiency of hydrogen compressors	0.85
Isentropic efficiency of steam turbines	0.85
Isentropic efficiency of ORC turbine	0.80
Isentropic efficiency of ORC pump	0.80
Compression ratio of the compressor	8
Working fluid of solar power plant	59.5%LiCl-40.5%KCl
Working fluid of ORC plant	R290
Working fluid of cooling plant	NH_3-H_2O

Table 2. Thermophysical properties of each state of the solar-powered combined system

State	Mass flow rate (kg/s)	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)	Mass fraction of NH_3	Specific exergy (kJ/kg)	Exergy (kW)
1	12	670	101.3	1178	0.5186	-	1168	14010
2	12	628	101.3	1163	0.5086	-	1156	13871
3	12	631	110	1164	0.5093	-	1157	13881
4	12	320	110	325.4	0.4229	-	343.6	4123
5	12	310	110	314.5	0.419	-	333.8	4006
6	12	200	110	197.2	0.3715	-	230.7	2769
7	12	188	101.3	184.7	0.3658	-	219.9	2639
8	12	191	110	187.8	0.3672	-	222.6	2672
9	1.933	300	3500	2978	6.448	-	1060	2050
10	1.933	170	800	719.1	2.042	-	114.9	222.2
11	1.933	300	800	3057	7.234	-	904.5	1748
12	1.933	100	101.3	2676	7.355	-	487.3	942
13	1.933	25	101.3	104.9	0.3672	-	0	0
14	1.933	25	3500	108.1	0.3663	-	3.406	6.584
15	9.925	57	800	669.6	2.598	-	112.7	1118
16	9.925	-11	101.3	572.5	2.638	-	3.771	37.42
17	9.925	-13	101.3	569.4	2.626	-	4.209	41.77
18	9.925	-12.7	800	169	0.8814	-	124	1230
19	0.537	25	101.3	104.9	0.3672	-	0	0
20	0.537	80	101.3	335.1	1.076	-	18.94	10.17
21	0.4765	80	101.3	50.8	0.1564	-	128.2	61.08
22	0.0605	80	101.3	4723	55.81	-	117690	7120
23	0.0605	87.9	150	4837	54.51	-	118192	7151
24	0.0605	47.9	150	4260	52.82	-	118120	7146
25	0.0605	99.5	225	5005	53.29	-	118723	7183
26	0.0605	59.5	225	4428	51.66	-	118634	7177
27	0.0605	113	337.5	5201	52.14	-	119264	7215
28	0.0605	73	337.5	4623	50.56	-	119157	7209
29	0.0605	128.6	506.3	5428	51.04	-	119819	7249
30	0.0605	88.6	506.3	4849	49.52	-	119692	7241
31	0.0605	-252.7	100	450	22.14	-	123456	7469
32	0.05143	35	500	4077	47.26	-	119593	6150
33	0.3025	25	200	298.1	6.663	-	58.19	17.6
34	0.2541	25	200	105	0.3672	-	0.09899	0.02515
35	0.2843	95	925.5	293.2	1.435	0.36	50	14.22
36	0.2843	50	925.5	4.24	0.6138	0.36	5.76	1.638
37	0.2843	45.3	260	4.24	0.6164	4.98	0.36	0.1023
38	1.131	22	260	-138.1	0.1705	0.55	36.23	40.96
39	1.131	22.16	925.5	-136.8	0.1723	0.55	36.99	41.82
40	1.131	39.48	925.5	-64.56	0.4303	0.55	32.35	36.58
41	0.8463	95	925.5	1478	4.939	0.9996	326.3	276.1
42	0.8463	21	925.5	98.13	0.3565	0.9996	312	264
43	0.8463	-10	925.5	-45.57	-0.1595	0.9996	322	272.5
44	0.8463	-12.71	260	-45.57	-0.1555	0.9996	320.9	271.5
45	0.8463	-12.51	260	1195	4.587	0.9996	148.2	125.4
46	0.8463	23.53	260	1339	5.114	0.9996	134.8	114.1

3.2. Property evaluation

Thermophysical properties are obtained from Engineering Equation Solver (EES) software. Specific exergy at state i is,

$$ex_i = (h_i - h_0) - T_0(s_i - s_0) + ex_{chem,i} \quad (1)$$

where ex_{chem} is included only for streams with chemical availability (e.g., H_2). Component exergy rates:

$$\dot{E}x = \dot{m}ex \quad (2)$$

Solar field and receiver

Useful thermal input to the receiver can be written as:

$$\dot{Q}_{rec} = A_{sf} G \eta_{opt} \eta_{th} \quad (3)$$

with η_{opt} capturing cosine, reflectivity, intercept, and shading losses; η_{th} accounts for convective/radiative receiver losses.

Rankine power plant

$$\eta_{i,turb} = \frac{h_{in} - h_{out,actual}}{h_{in} - h_{out,is}} \quad (4)$$

$$\dot{W}_{turb} = \dot{m}(h_{in} - h_{out,act}) \quad (5)$$

Organic Rankine cycle

$$\dot{W}_{ORC} = \dot{W}_{turb,ORC} - \dot{W}_{pump,ORC} \quad (6)$$

Hydrogen production, compression, storage, and PEMFC

$$\dot{m}_{H_2} = \frac{\dot{W}_{el} + \dot{Q}_{el}}{SPE} \quad (7)$$

where SPE is the specific energy requirement (kJ/kg H_2) at the chosen operating T and P (include ohmic/activation/thermal needs). In the current model, $\dot{m}_{H_2}$ aligns with Table 4 values (e.g., **0.0605 kg s⁻¹** at the base case).

Compression train: staged, intercooling optional. For each stage:

$$\dot{W}_{comp} = \frac{\dot{m}RT_1}{\eta_{i,comp}(k-1)} \left[\left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} - 1 \right] \quad (8)$$

with overall ratio $r_c = 8$.

PEM fuel cell**:**

$$\dot{W}_{FC} = \eta_{el} FC \dot{m}_{H_2} LHV_{H_2} \quad (9)$$

Energy efficiency metrics

Subsystem energy efficiency:

$$\eta = \frac{\sum useful\ outputs}{\sum energy\ inputs} \quad (10)$$

Overall plant energy efficiency:

$$\eta_{OP} = \frac{\dot{W}_{net} + \dot{Q}_{heat} + \dot{Q}_{cool} + \dot{m}_{H_2} LHV_{H_2}}{\dot{Q}_{rec}} \quad (11)$$

Exergy analysis

For each component, exergy balance:

$$\sum \dot{E}x_{in} - \sum \dot{E}x_{out} = \dot{E}x_D = T_0 \dot{S}_{gen} \quad (12)$$

4. DISCUSSION AND CONCLUSIONS

The thermodynamic performance metrics presented in Table 3 provide a critical evaluation of the integrated solar-powered polygeneration system, quantifying both its efficacy and its inherent irreversibilities.

The overall plant (OP) demonstrates robust energy efficiency (η = 53.91%) and exergy efficiency (ψ = 49.57%), indicating that the system successfully converts a significant portion of incident solar energy into a diversified mix of useful outputs (power, heating, cooling, and hydrogen). This high level of integration efficiency underscores the technical viability of such polygeneration systems for sustainable energy services.
A central tenet of exergy analysis is the identification of inefficiencies to guide system optimization. The exergy destruction data reveals that the solar power plant (SPP) is the predominant source of irreversibility ($\dot{E}x_D$ = 4112 kW), attributable to the high-entropy nature of solar radiation conversion and significant thermal losses in the receiver. This is followed by the hydrogen production and storage plant (HPSP) ($\dot{E}x_D$ = 2894 kW), where the electrochemical processes of electrolysis and the mechanical work of compression incur substantial thermodynamic losses.
Furthermore, the analysis on a subsystem level reveals a significant performance gradient. The SPP operates at the highest energy efficiency (η = 72.58%), functioning as the effective primary energy harvester. In contrast, the cooling production plant (CPP) exhibits the lowest efficiencies (η = 16.45%, ψ = 12.58%), highlighting the thermodynamic challenges associated with absorption refrigeration cycles.

Table 3. Energy efficiency, exergy efficiency and exergy destruction rates of solar-powered combined system and its sub-systems.

Sub-plants and the overall plant	**Energy efficiency (η)**	**Exergy efficiency (ψ)**	**Exergy destruction rate, kW ($\dot{E}x_D$)**
Solar power plant (SPP)	0.7258	0.6526	4112
Rankine power plant (RPP)	0.3723	0.3297	2391
ORC plant (ORCP)	0.1914	0.1645	951
Hydrogen production and storage plant (HPSP)	0.6347	0.5843	2894
PEM fuel cell plant (PEMFCP)	0.5144	0.4537	2207
Cooling production plant (CPP)	0.1645	0.1258	1297
Overall plant (OP)	0.5391	0.4957	13852

Table 4 quantifies the net production outputs of the polygeneration system at base operating conditions (25°C, 750 W/m²), demonstrating its capacity to simultaneously deliver multiple energy vectors from a single solar source, with a total electrical power output of 6068 kW, thermal energy for heating at 2216 kW, cooling capacity of 1050 kW, and hydrogen production at a rate of 0.0605 kg/s, thereby effectively validating the system's core objective of achieving diversified and scalable utility generation through integrated design.

Table 4. The production capacities of the solar-powered combined system.

Productions	**Quantity**	**Unit**
Power	6068	kW
Heating	2216	kW
Cooling	1050	kW
Hydrogen	0.0605	kg/s

4.1. Parametric analyses

The reference temperature
Figure 2a demonstrates that the energy efficiency of the entire system and all its subsystems increases consistently as the ambient temperature rises from 0 to 50 °C. This improvement is primarily due to reduced heat rejection losses to the environment, as a smaller temperature differential makes the dissipation of waste heat more efficient. Consequently, the system performs more effectively in hotter climatic conditions. Figure 2b shows the effect of increasing ambient temperature (T_0) on the exergy efficiency (ψ) of the system and its subsystems. Like energy efficiency, the exergy efficiency also increases consistently with rising ambient temperature. This occurs because the exergy of waste heat rejected to the environment decreases as the temperature difference between the system and the environment narrows, reducing irreversibility and improving second-law performance. Figure 2c illustrates that as the ambient temperature (T_0) increases, the exergy destruction ($\dot{E}x_D$) decreases across all subsystems and the overall system. This reduction occurs

because a higher ambient temperature lowers the temperature gradient for heat rejection, thereby diminishing thermodynamic irreversibilities during the dissipation of waste heat. Consequently, the system operates more efficiently from an exergy perspective in hotter environments. Figure 2d demonstrates the effect of increasing ambient temperature on the useful output products of the system. As T_0 rises from 0 to 50 °C, the electrical power, heating capacity, and hydrogen production rate all show a significant increasing trend, while the cooling output decreases. This inverse relationship for cooling occurs because the absorption chiller's performance is degraded by the reduced temperature differential for heat rejection, whereas the power cycles benefit from lower condenser pressures, leading to higher net power and, consequently, greater hydrogen production.

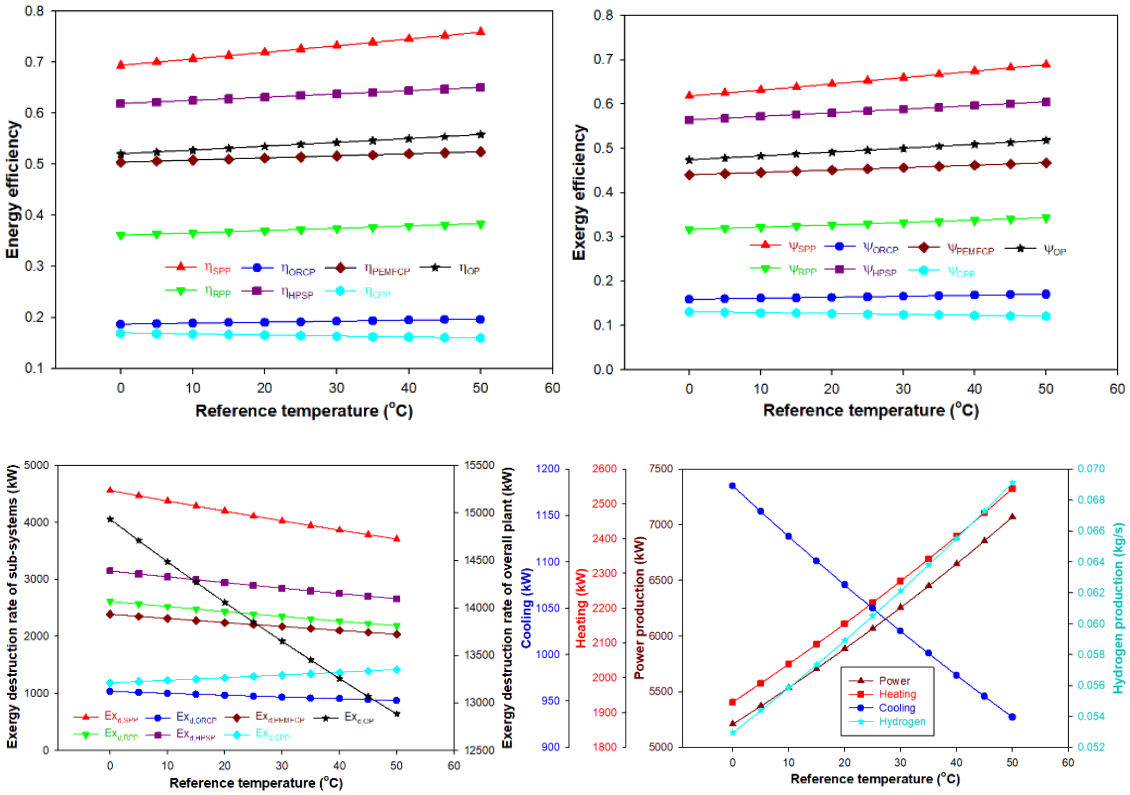

Figure 2. The effect of T_o on (a) η, (b) ψ, (c) $\dot{E}x_d$ and (d) useful products.

The solar radiation

Figure 3a shows that as solar irradiance increases from 400 to 1000 W/m², the energy efficiency (η) of the overall system and all subsystems improves significantly. This is because higher irradiance provides more usable thermal energy to the receiver ($\dot{Q}_{rec}$), enhancing the output of electricity, heating, cooling, and hydrogen without a proportional increase in parasitic losses. The solar field (SPP) benefits most directly, but downstream components also operate closer to their design capacity. Similar to energy efficiency, the exergy efficiency (ψ) of all system components increases with rising solar irradiance, as shown in Figure 3b. The exergy of solar radiation is better harnessed at higher irradiance levels, reducing relative losses in energy quality. This trend confirms that the system not only captures more energy but does so more effectively from a second-law perspective when solar input is intensified. Despite the rise in efficiency, Figure 3c reveals that exergy destruction rate ($\dot{E}x_D$) decreases across all components as irradiance increases. Although absolute energy flows are larger, the relative irreversibilities—especially in the solar receiver and heat exchangers—are reduced due to improved temperature matching and more stable operational conditions. This indicates better thermodynamic performance at higher solar intensities. Figure 3d demonstrates that all useful outputs—power, heating, cooling, and hydrogen production—increase nearly linearly with solar irradiance. This is expected since solar energy is the primary input. The hydrogen production rate, in particular, benefits from increased electrical output from the power cycles, which supplies more energy to the electrolysis unit. This underscores the system's scalability and reliance on consistent solar availability. While Figure 2 highlighted the role of ambient temperature (affecting heat rejection), Figure 3 emphasizes the central importance of solar irradiance as the driving energy input. Higher irradiance improves both energy and exergy efficiency, reduces specific

exergy destruction, and linearly scales all useful outputs, confirming the system's design dependency on solar resource quality.

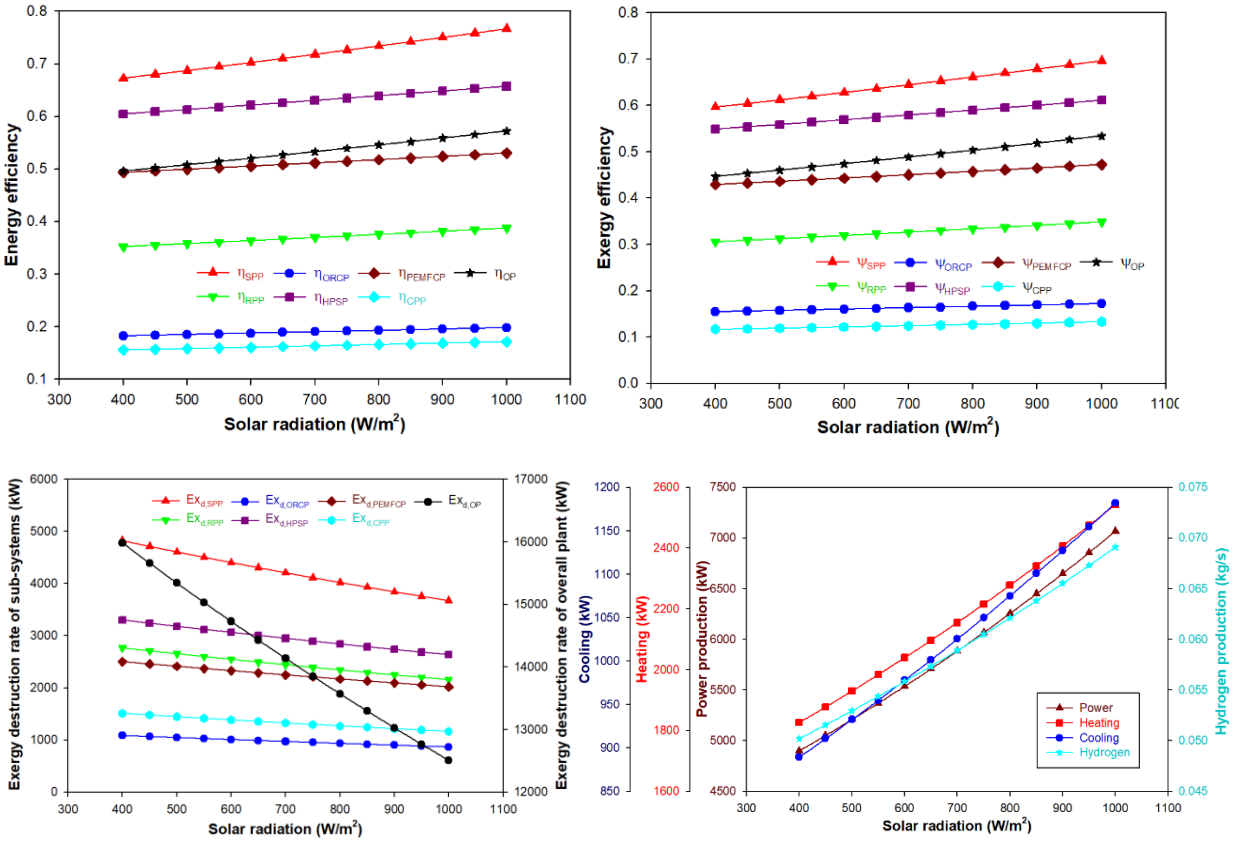

Figure 3. The effect of I_s on (a) η, (b) ψ, (c) $\dot{E}x_d$ and (d) useful products.

4.2. Conclusion

This study presented a comprehensive thermodynamic analysis of a novel solar-powered polygeneration system designed to produce electricity, heating, cooling, and hydrogen simultaneously. Through detailed energy and exergy modeling under steady-state conditions, the system performance was evaluated parametrically against variations in ambient temperature and solar irradiance.

The results demonstrated that the integrated system is capable of achieving high overall energy and exergy efficiencies of 53.9% and 49.6%, respectively, under base conditions (25°C, 750 W/m²), with substantial output capacities of 6068 kW of power, 2216 kW of heating, 1050 kW of cooling, and 0.0605 kg/s of hydrogen. Exergy analysis identified the solar field and the hydrogen production unit as the primary sources of irreversibility, suggesting that future design improvements should focus on these components to enhance overall performance. Parametric studies revealed that increasing solar irradiance significantly boosts both efficiencies and all useful outputs, while elevated ambient temperatures improve efficiencies but reduce cooling capacity due to degraded heat rejection performance.

In conclusion, this work confirms the technical feasibility and thermodynamic benefits of using concentrated solar energy to drive multigeneration systems. Such configurations not only improve resource utilization but also offer a sustainable pathway to decarbonize energy sectors by providing multiple utilities without reliance on fossil fuels. This study provides a foundational basis for the optimization and practical implementation of solar polygeneration systems, contributing to the transition toward resilient and renewable-based energy infrastructure.

Future work may involve economic analysis, dynamic modeling under real weather conditions, and experimental validation of the proposed system.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Kautish, P., Siddiqui, A., Marak, Z. R., Raman, R., & Siddiqui, M. (2025). Countering carbon emissions: FDI, industrialization, mineral rents, and population rise impacting sustainable economic growth. Discover Sustainability, 6(1), 387. https://doi.org/10.1007/s43621-025-01244-3.

Kalair, A., Abas, N., Saleem, M. S., Kalair, A. R., & Khan, N. (2021). Role of energy storage systems in energy transition from fossil fuels to renewables. Energy Storage, 3(1), e135. https://doi.org/10.1002/est2.135.

Mohamad Taghvaee, V., Nodehi, M., Assari Arani, A., Rishehri, M., Nodehi, S. E., & Khodaparast Shirazi, J. (2023). Fossil fuel price policy and sustainability: energy, environment, health and economy. International Journal of Energy Sector Management, 17(2), 371-409. https://doi.org/10.1108/IJESM-09-2021-0012.

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable energy transition for renewable and low carbon grid electricity generation and supply. Frontiers in Energy research, 9, 743114. https://doi.org/10.3389/fenrg.2021.743114.

Jaroń, A., & Borucka, A. (2024). Analysis of Energy System Transformations in the European Union. Energies, 17(23), 6181. https://doi.org/10.3390/en17236181.

Ukoba, K., Yoro, K. O., Eterigho-Ikelegbe, O., Ibegbulam, C., & Jen, T. C. (2024). Adaptation of solar energy in the Global South: Prospects, challenges and opportunities. Heliyon, 10(7). https://doi.org/10.1016/j.heliyon.2024.e28009.

Sun, X., Jiang, S., Huang, H., Li, H., Jia, B., & Ma, T. (2022). Solar energy catalysis. Angewandte Chemie, 134(29), e202204880. https://doi.org/10.1002/ange.202204880.

Hassan, Q., Tabar, V. S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2024). A review of green hydrogen production based on solar energy; techniques and methods. Energy Harvesting and Systems, 11(1), 20220134. https://doi.org/10.1515/ehs-2022-0134.

Kong, H., Zhang, J., & Tong, L. (2025). Thermodynamic analysis of solar thermochemical hydrogen production using coal-based reductants. Applied Thermal Engineering, 127565. https://doi.org/10.1016/j.applthermaleng.2025.127565.

Cardemil, J. M., Starke, A. R., Zurita, A., Mata-Torres, C., & Escobar, R. (2021). Integration schemes for hybrid and polygeneration concentrated solar power plants. Wiley Interdisciplinary Reviews: Energy and Environment, 10(6), e412. https://doi.org/10.1002/wene.412.

Ahmad, R., Liu, G., Rehman, S. A. U., Gao, Y., Meng, F., Zhou, X., ... & Cristiano, S. (2025). Integrated Systems Modeling for Assessing the Water–Energy Nexus in Pakistan: Lessons Learned From Coupling LEAP–WEAP Planning Approaches. Engineering. https://doi.org/10.1016/j.eng.2025.02.013.

Design and thermodynamic analysis of an integrated geothermal energy-based liquid hydrogen generation facility

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Abstract: The transition to a sustainable energy economy necessitates the integration of renewable sources with advanced energy carriers like hydrogen. This study proposes the design and thermodynamic analysis of a novel integrated facility that utilizes geothermal energy for the multi-generation of electricity, fresh water, heating, and liquid hydrogen (LH_2). The system synergistically combines a double-flash geothermal power plant, an Organic Rankine Cycle (ORC) for waste heat recovery, a reverse osmosis (RO) desalination unit, a proton exchange membrane (PEM) electrolyzer, and a cryogenic hydrogen liquefaction cycle. A comprehensive model of the entire system is developed, and its performance is rigorously evaluated through energy and exergy analyses using the Engineering Equation Solver (EES) software. The results indicate that the overall system achieves energy and exergy efficiencies of 59.71% and 57.66%, respectively, and can simultaneously produce 10,360 kW of power, 13,357 kW of heating, 10.77 kg/s of fresh water, and 0.019 kg/s of liquid hydrogen. A parametric study demonstrates that the geothermal source temperature is a critical performance driver, with all useful outputs and efficiencies increasing significantly alongside it. This study conclusively establishes the technical viability of using geothermal energy as a robust and sustainable primary source for efficient liquid hydrogen production within a multi-generation framework, offering a promising pathway for decarbonized energy systems.

Keywords: Geothermal Energy, Liquid Hydrogen, Multi-generation, Exergy Analysis, Hydrogen Liquefaction, Thermodynamic Modeling.

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1. INTRODUCTION

The transition to a sustainable and decarbonized energy economy necessitates the integration of extractable energy processes with advanced energy carriers. Hydrogen, in particular, is attracting increasing interest due to its liquid state (LH_2), high gravimetric energy density, compatibility with long-distance transportation, and usability in various sectors, from utilities to grid-capable storage (Liu et al., 2023). However, the traditional hydrogen liquefaction process consumes more energy than traditional storage (Zang et al., 2023). Therefore, combining liquefaction with replacement sources offers a promising path toward more efficient and lower-carbon production.

Geothermal energy stands out among other energy sources due to its continuous availability and high heat generation capacity (Lund and Toth, 2021). Due to this feature, when geothermal energy is combined with hydrogen production and liquefaction systems, the consumption of external electricity sources can be reduced.

Additionally, various studies report increased efficiency in systems integrated with geothermal energy. It has been reported that hybrid systems can achieve more efficient multiplexing by integrating geothermal heat with systems such as organic Rankine cycles (ORC), reverse osmosis, and proton exchange membrane (PEM) electrolyzers (Bahrami and Rosen, 2024; Geng et al., 2024).

Li et al. (2022) have demonstrated that power, cooling, fresh water, and hydrogen can be produced simultaneously by combining double-flash geothermal cycles, Kalina and ejector cooling cycles, and desalination units.

It has been emphasized that fresh water and hydrogen production rates can be more efficient in a double-flash geothermal power plant integrated with a transcritical CO_2 Rankine cycle, reverse osmosis, and PEM electrolysis (Çelik Toker et al., 2024).

Another study reported that costs for green hydrogen production could be reduced in a geothermal power plant integrated with a PEM electrolyzer (Putra et al., 2025).

This study proposes the conceptual design and comprehensive thermodynamic evaluation of an integrated facility utilizing geothermal energy for liquid hydrogen production.

2. SYSTEM DESIGN

Figure 1 presents the detailed structure of an integrated energy system that simultaneously enables the production of electricity, fresh water, heating, and liquid hydrogen by utilizing geothermal energy. In the first stage of the system, geothermal fluid extracted from underground is separated into phases using high-pressure and low-pressure separators. The high-pressure steam is then expanded in steam turbines to generate electricity. The low-temperature fluid from the turbine outlet is directed to an ORC system, where working fluid R123 is used to generate additional electricity and recover heat for district heating. The same geothermal source also provides the thermal energy required for seawater desalination. Seawater undergoes low-pressure and high-pressure pumping, chemical pretreatment, and reverse osmosis filtration to produce fresh water, while the brine waste is passed through a Pelton turbine to recover mechanical energy before being reinjected into the ground via an injection well. The produced freshwater is fed into a PEM electrolyzer, where hydrogen and oxygen are generated through water electrolysis. The electricity required for electrolysis is supplied by the geothermal-driven steam and ORC systems. The generated hydrogen is compressed using a compressor powered by the internal electricity of the system and is then cooled through a series of multi-stage heat exchangers to cryogenic temperatures, achieving liquefaction with the help of a nitrogen-based cooling loop. This refrigeration system operates in a closed cycle, where nitrogen gas is liquefied and then returned to its gaseous state. In the final stage, the liquefied hydrogen is separated and transferred to insulated storage tanks.

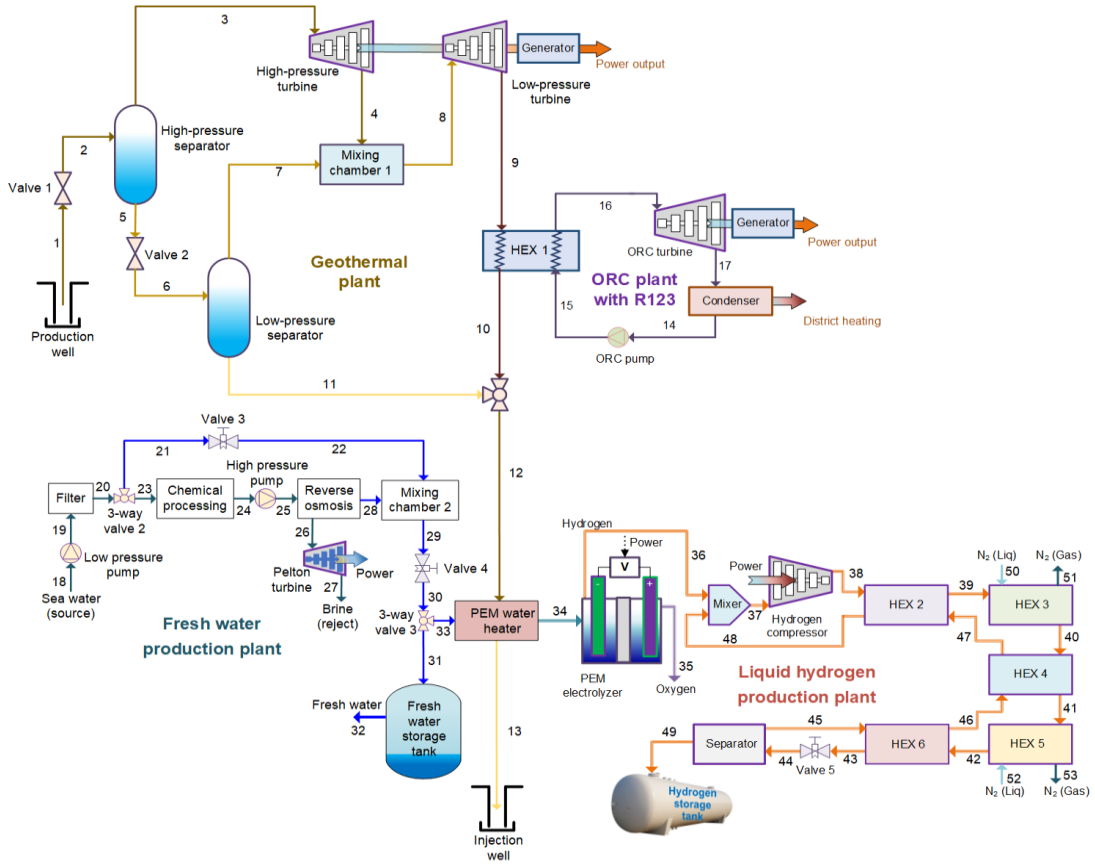

Figure 1. A schematic view of the integrated geothermal energy-based liquid hydrogen generation facility

3. MODELING AND ANALYSIS

The integrated system, schematically shown in Figure 1, was modeled and analyzed using the Engineering Equation Solver (EES) software package to solve the mass, energy, entropy, and exergy balance equations for each component and the overall system. The following general balance equations were applied for a control volume at steady-state conditions:

Mass balance:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

Energy balance:

$$\dot{Q} - \dot{W} = \sum \dot{m}_{out}\, h_{out} - \sum \dot{m}_{in}\, h_{in} \quad (2)$$

Entropy balance:

$$\sum \dot{m}_{in} s_{in} + \frac{\dot{Q}}{T} + \dot{S}_{gen} = \sum \dot{m}_{out} s_{out} \quad (3)$$

Exergy balance:

$$\sum \dot{E}x_{in} - \sum \dot{E}x_{out} = \sum \dot{E}x_{dest} \quad (4)$$

$$\dot{E}x = \dot{m}[(h - h_0) - T_0(s - s_0)] \quad (5)$$

where the subscript '0' represents the properties at the dead state (reference environment: T_0 = 25 °C, P_0 = 101.3 kPa).

The performance of the system and its sub-plants was evaluated using energy efficiency (η) and exergy efficiency (ψ), defined as:

$$\eta = \frac{useful\ energy\ output}{energy\ input} \quad (6)$$

$$\psi = \frac{useful\ exergy\ output}{exergy\ input} = 1 - \frac{\dot{E}x_{dest}}{exergy\ input} \quad (7)$$

The analysis was conducted under the assumptions given in Table 1. The thermodynamic properties for each state point in the integrated cycle, as calculated by the model, are presented in Table 2. These data form the basis for all subsequent efficiency and production calculations.

Table 1. The design indicators and working conditions for modeling the solar-powered combined system

Data	**Value**
Reference temperature	25 °C
Reference pressure	101.3 kPa
Energy efficiency of HEXs	0.86
LHV of hydrogen	120 MJ/kg
Exergy of hydrogen	117.12 MJ/kg
Isentropic efficiency of pumps	0.85
Isentropic efficiency of hydrogen compressors	0.85
Isentropic efficiency of steam turbines	0.85
Isentropic efficiency of ORC turbine	0.80
Isentropic efficiency of ORC pump	0.80
Isentropic efficiency of Pelton turbine	0.80
Working fluid of ORC plant	R123
The ratio of salt rejection	0.9
Recovery ratio	0.6
Seawater salinity	35000 ppm
Desalinated outlet freshwater salinity	450 ppm
Molecular masses	Salt (NaCl): 58.44 g/ molWater (H_2O): 18.02 g/mol

Table 2. State points table of the integrated geothermal energy plant obtained through the balance equations and the EES software package

State	Mass flow rate (kg/s)	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kg.K)	Specific exergy (kJ/kg)	Exergy (kW)
1	179.2	197.3	1500	840.1	2.305	157.5	28219
2	179.2	154	532.1	840.1	1.882	283.5	50799
3	16.55	154	530	2751	6.801	727.4	130346
4	16.55	98.4	96	2673	7.373	479.2	7931
5	162.6	154	530	649.5	1.882	92.81	15096
6	162.6	98.4	96	649.5	1.289	269.7	43863
7	17.64	98.4	96	2673	7.373	479.2	8452
8	34.19	98.4	96	2673	7.373	479.2	16384
9	34.19	95.1	85	2668	7.414	461.9	15792
10	34.19	72.3	85	302.7	0.9831	14.2	485.4
11	145	96.4	85	2670	7.421	462.5	67074
12	179.2	89.3	85	374.1	1.185	25.44	4558
13	179.2	87.6	85	367	1.165	24.18	4334
14	405.6	40	154.7	241.9	1.142	0.4732	191.9
15	405.6	40.31	764.2	242.4	1.143	0.9057	367.3
16	405.6	98.72	764.2	441.8	1.693	36.18	14675
17	405.6	57.11	154.7	419.9	1.71	9.393	3810
18	19.88	25	101.3	101.9	0.384	-8.024	-159.5
19	19.88	25.2	650	103.2	0.3866	-7.523	-149.5
20	19.86	25.2	617.5	103.2	0.3866	-7.523	-149.4
21	0.1344	25.2	617.5	106.2	0.3699	0.5179	0.06959
22	0.1344	25.2	110	105.8	0.37	0.009006	0.00121
23	19.74	25.2	617.5	103.2	0.3866	-7.523	-148.5
24	19.74	25.2	586.6	103.2	0.3866	-7.553	-149.1
25	19.74	26.7	6000	114	0.4055	-2.3	-45.4
26	8.94	26.7	5100	109.2	0.417	-10.64	-95.12
27	8.94	26.7	101.3	105	0.4183	-15.15	-135.4
28	10.8	26.7	110	112	0.391	0.02891	0.3122
29	10.94	26.7	110	112	0.391	0.02891	0.3161
30	10.94	26.7	101.3	112	0.391	0.02019	0.2208
31	10.77	26.7	101.3	112	0.391	0.02019	0.2173
32	10.77	26.7	101.3	112	0.391	0.02019	0.2173
33	0.1698	26.7	101.3	112	0.391	0.02019	0.003427
34	0.1698	80	101.3	335.1	1.076	18.94	3.215
35	0.1508	80	101.3	50.8	0.1564	7.836	1.181
36	0.019	80	101.3	4723	55.81	129100	2453
37	0.027	52.54	101.3	4327	54.64	128692	3475
38	0.027	52.74	8080	4372	36.54	129113	3486
39	0.027	-127	8080	1825	25.24	126793	3423
40	0.027	-195.7	8080	903.3	16.69	126020	3403
41	0.027	-201.3	8080	820.7	15.58	125950	3401
42	0.027	-208.2	8080	713.3	14.01	125879	3399
43	0.027	-227.8	8080	381.3	7.921	125668	3393
44	0.027	-252.8	101.3	-0.08484	-0.004531	125457	3387
45	0.007999	-252.8	101.3	-0.08484	-0.004531	125457	1003
46	0.007999	-216.3	101.3	840.6	33.15	125819	1006
47	0.007999	-206.9	101.3	939.2	34.76	125891	1007
48	0.007999	14.85	101.3	3787	52.88	128385	1027

49	0.019	-252.8	101.3	-0.008484	-0.004531	125500	2385
50	0.1069	-208.2	101.3	-147.1	2.481	841.8	90.02
51	0.1069	-188.2	101.3	85.59	5.513	170.6	18.24
52	0.01246	-208.2	101.3	-147.1	2.481	841.8	10.49
53	0.01246	-188.2	101.3	85.59	5.513	170.6	2.125

The energy and exergy efficiencies, along with the exergy destruction rates for the overall plant and its sub-systems, are given in Table 3. The Geothermal Plant (GP) has the highest exergy efficiency (59.81%), while the ORC Plant (ORCP) has the lowest (22.57%), indicating a significant potential for improvement in the secondary power generation cycle. The overall plant (OP) has an energy efficiency of 59.71% and an exergy efficiency of 57.66%, with a total exergy destruction of 21,685 kW.

Table 3. Energy and exergy efficiencies, exergy destruction rates of integrated plant and its sub-plants

Sub-plants and overall plant	**Energy efficiency (η)**	**Exergy efficiency (ψ)**	**Exergy destruction rate, kW ($\dot{E}x_D$)**
Geothermal plant (GP)	0.5673	0.5981	9646
ORC plant (ORCP)	0.2534	0.2257	2764
Fresh water production plant (FWPP)	0.6548	0.6103	2082
Liquid hydrogen production plant (LHPP)	0.6306	0.5984	7193
Overall plant (OP)	0.5971	0.5766	21685

The production capacities of the integrated system are summarized in Table 4. The facility can simultaneously generate 10,360 kW of power, 13,357 kW of heating, 10.77 kg/s of fresh water, and 0.019 kg/s of liquid hydrogen, demonstrating its effective multi-generation capability.

Table 4. The production capacities of the solar-powered combined system

Productions	**Quantity**	**Unit**
Power	10360	kW
Heating	13357	kW
Liquid hydrogen	0.019	kg/s
Fresh water	10.77	kg/s

Parametric studies

The effects of varying reference environment temperature (T_0) and geothermal source temperature (T_{geo}) on system performance were investigated.

Figure 2a presents the effect of the reference temperature on energy efficiencies of sub-systems and the overall plant. The positive correlation between reference temperature (T_0) and the energy efficiency (η) of all subsystems is a direct consequence of the changing definition of "waste" heat. As T_0 increases, the temperature of the heat rejected from the system (e.g., in condensers or coolers) moves closer to this elevated reference temperature. Thermodynamically, this rejected heat is deemed lower in quality and is therefore considered less valuable. Since energy efficiency is the ratio of useful output to total input, this devaluation of waste heat at higher T_0 effectively increases the calculated efficiency, even if the actual useful energy outputs remain constant or only change slightly due to minor property variations.
The increase in exergy efficiency (ψ) with rising reference temperature (T_0) is fundamentally tied to the definition of exergy itself. Exergy is a measure of useful work potential relative to a defined environment. As T_0 increases, the temperature difference between the system's heat rejection units (e.g., condensers) and the environment decreases. This smaller temperature gap means the waste heat is rejected with a lower exergy content, as its potential to produce work is diminished. Consequently, the numerator (useful exergy output)

remains largely unchanged while the denominator (exergy input, which is fixed by the geothermal source) is constant, leading to a higher calculated exergy efficiency. Essentially, the same useful output is achieved with a lower penalty for "waste," as that waste is now thermodynamically closer to the dead state.

The decrease in the exergy destruction rate ($\dot{E}x_{dest}$) with increasing T_o is a result of the changing baseline for calculating exergy. Exergy destruction, which represents irreversibilities, is calculated as the difference between input and output exergy streams. A key component of these streams is the physical exergy of flows, which is highly sensitive to T_o. As T_o rises, the specific exergy of all material streams entering and exiting the system decreases because their temperature and pressure differences relative to the environment are smaller. Since the actual irreversibilities (entropy generation from friction, heat transfer across finite temperature differences, etc.) remain physically unchanged, the calculated exergy destruction, which is the difference between these now-smaller exergy values, also decreases. The system isn't more reversible; the metric's frame of reference has shifted.

The apparent increase in the production rates of power, heating, fresh water, and hydrogen with rising T_o is a direct result of the parametric definition of the system's useful outputs. For the same physical mass flow rates and operating conditions, the energy content of the "heating" and "hydrogen" products is fixed. However, their exergy content (used in the efficiency calculations that govern the model's reported outputs) decreases as T_o increases. To maintain or even slightly increase the reported energy and exergy efficiencies shown in Figures 2a and 2b, the model's solving algorithm must correspondingly increase the calculated mass flow rates of these useful products. Therefore, the rising curves do not indicate a physical increase in production but rather a thermodynamic accounting effect driven by the changing reference state.

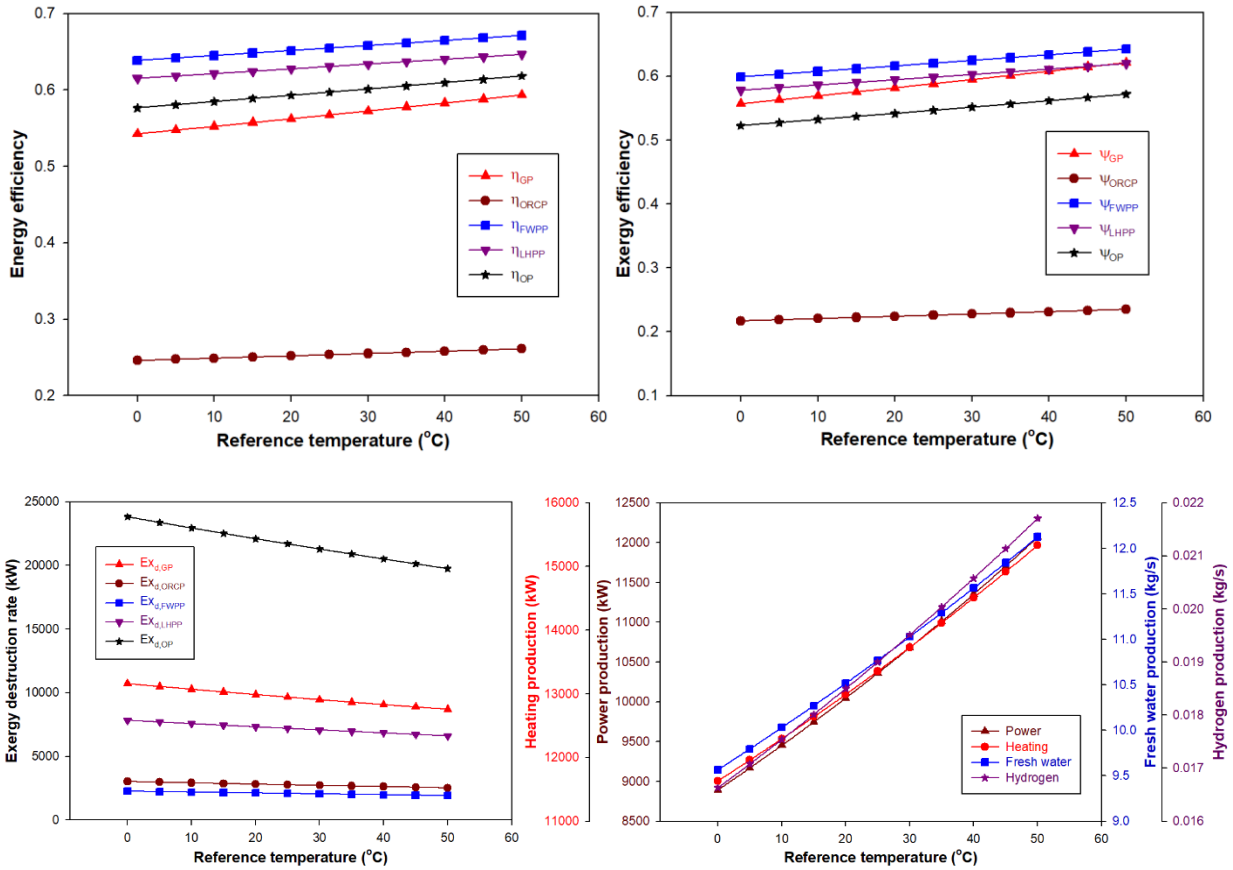

Figure 2. The effect of T_o on (a) η, (b) ψ, (c) $\dot{E}x_d$ and (d) useful products.

The significant increase in energy efficiency (η) with rising geothermal temperature (T_{geo}) is a direct consequence of the higher quality energy input. A higher T_{geo} provides a larger available temperature difference (ΔT) for heat addition in power cycles like the steam and ORC systems. This enables more effective work extraction according to the Carnot principle ($\eta_{Carnot} = 1 - {}^{T_{cold}}/_{T_{hot}}$), as the hotter source drives a greater portion of the heat transfer across a larger thermal potential. Consequently, for a given mass flow rate

of geothermal brine, the system generates more useful outputs (power, hydrogen, etc.) from the same initial resource, thereby increasing the ratio of useful energy output to energy input, as presented in Figure 3a. The improvement in exergy efficiency (ψ) with higher T_{geo} is even more pronounced than the energy efficiency trend. This is because exergy analysis directly quantifies the quality of the energy. Figure 3b reveals that, the exergy content of the geothermal brine is not linear with temperature; it increases significantly as T_{geo} rises due to its greater potential to perform work relative to the environment. While the system's irreversibilities (exergy destruction) also increase with higher temperatures, the useful exergy output (power, high-exergy hydrogen, etc.) increases at a faster rate. This leads to a more favorable ratio of useful exergy output to the much larger exergy input, resulting in a higher exergy efficiency. The increase in exergy destruction ($\dot{E}x_{dest}$) with T_{geo} is a classic trade-off in high-temperature energy systems (Figure 3c). While a hotter source enables greater work output, it also amplifies the inherent irreversibilities. The larger temperature differences between the geothermal brine and the working fluids in heat exchangers, though necessary for efficient heat transfer, generate more entropy. Furthermore, components like turbines and compressors handle larger enthalpy drops and higher pressures, processes inherently associated with greater irreversibilities. Thus, the total system exergy destruction rises as the driving potential (T_{geo}) and the intensity of all processes increase. The substantial increase in all useful product outputs with T_{geo} represents the core benefit of a higher-temperature resource, as shown in Figure 3d. A hotter geothermal brine contains more enthalpy (thermal energy) and significantly more exergy (work potential). This enhanced input energy is converted more effectively through the system's cascading design. It results in more power generated by the turbines, which in turn produces more hydrogen in the electrolyzer and powers more pumps for greater freshwater production. The district heating output also rises due to the higher heat content available for recovery. Unlike the parametric effect of T_0, this increase is a real, physical enhancement of the system's production capacity driven by a more potent energy source.

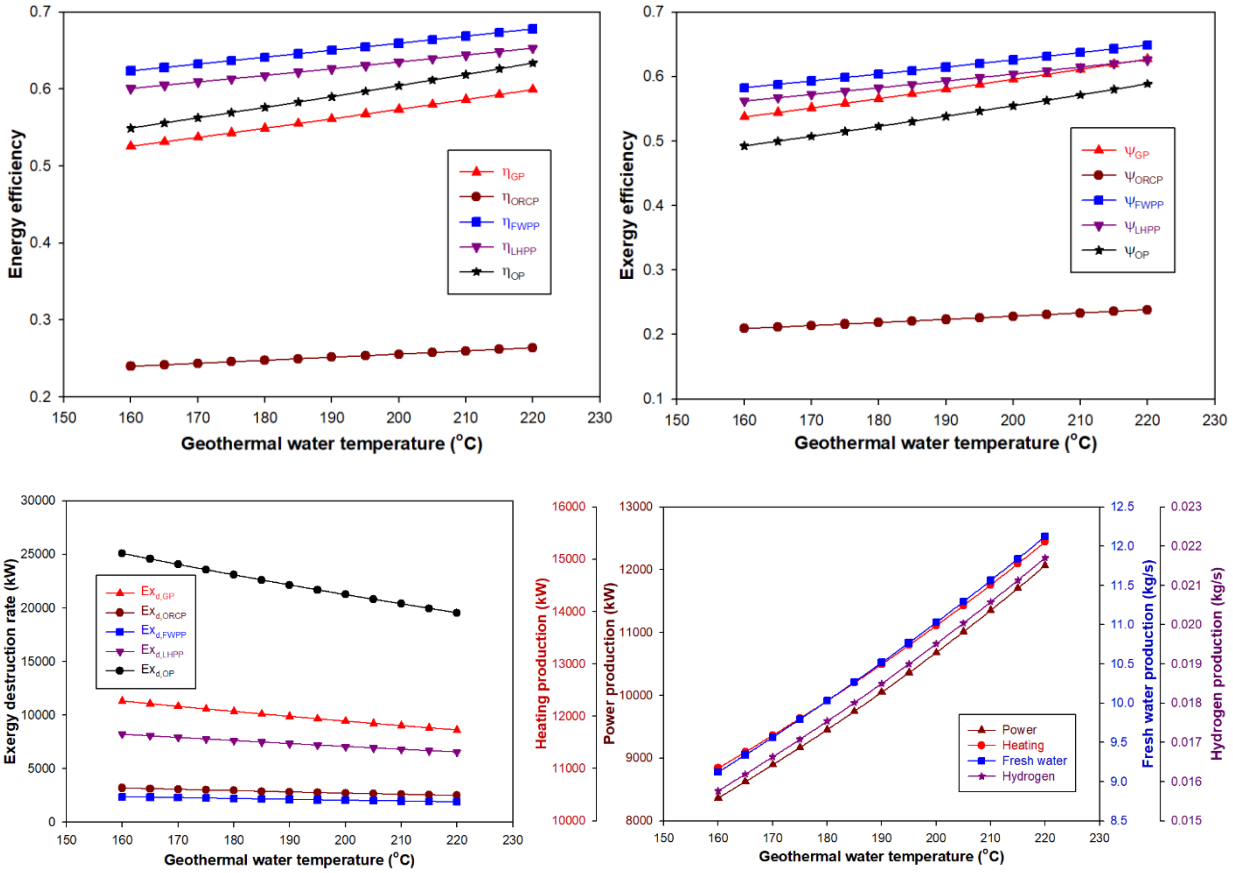

Figure 3. The effect of T_{GW} on (a) η, (b) ψ, (c) $\dot{E}x_d$ and (d) useful products.

4. DISCUSSION AND CONCLUSIONS

This study presented the conceptual design and a detailed thermodynamic analysis of a novel integrated system for multi-generation of power, heating, fresh water, and liquid hydrogen from a geothermal source. The modeling and performance evaluation, conducted through energy and exergy analyses, lead to the following key conclusions:

- The proposed system successfully demonstrates the technical feasibility of integrating liquid hydrogen production with a geothermal-powered multi-generation plant. The overall plant energy and exergy efficiencies were calculated to be 59.71% and 57.66%, respectively, which are notably high for a system performing such energy-intensive processes as hydrogen liquefaction and desalination. This underscores the advantage of cascading and synergizing multiple subsystems to maximize resource utilization.
- The parametric study revealed that the temperature of the geothermal resource (T_{geo}) is the most critical factor determining the system's performance and output. Increasing T_{geo} from 160°C to 220°C led to a substantial increase in all useful products (power, heating, fresh water, and liquid hydrogen) and significantly improved both energy and exergy efficiencies. This highlights the paramount importance of sourcing high-temperature geothermal fields to maximize the economic and technical viability of such integrated facilities.
- The analysis of the reference environment temperature (T_0) provided crucial insights into thermodynamic accounting. The results showed that standard performance metrics like efficiency and exergy destruction are highly sensitive to the defined dead state. This underscores the necessity for clear and consistent definition of reference conditions when comparing different systems and emphasizes that performance improvements driven by T_0 are accounting-based, whereas those driven by T_{geo} represent genuine physical gains.

- The exergy analysis identified the Geothermal Plant (GP) and the Liquid Hydrogen Production Plant (LHPP) as the largest contributors to total exergy destruction, highlighting them as primary targets for future optimization efforts. Focusing on enhancing heat exchanger design, optimizing turbine performance, and improving the efficiency of the cryogenic liquefaction cycle could yield significant overall efficiency gains.

In conclusion, this study confirms that geothermal energy is a highly viable and sustainable primary source for decarbonized energy systems that include liquid hydrogen production. The integrated design not only improves overall efficiency but also contributes to energy security and sustainability by providing multiple critical commodities from a single, renewable resource. Future work will focus on a detailed exergoeconomic analysis to assess the economic feasibility and cost-competitiveness of the proposed system.

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REFERENCES

Liu, W., Gottschall, T., Scheibel, F., Bykov, E., Fortunato, N., Aubert, A., Zhang, H., Skokov, K., & Gutfleisch, O. (2023). Designing magnetocaloric materials for hydrogen liquefaction with light rare-earth Laves phases. Journal of Physics: Energy, 5(3), 034001. https://doi.org/10.1088/2515-7655/accb0b.

Zhang, T., Uratani, J., Huang, Y., Xu, L., Griffiths, S., & Ding, Y. (2023). Hydrogen liquefaction and storage: Recent progress and perspectives. Renewable and Sustainable Energy Reviews, 176, 113204. https://doi.org/10.1016/j.rser.2023.113204.

Lund, J. W., & Toth, A. N. (2021). Direct utilization of geothermal energy 2020 worldwide review. Geothermics, 90, 101915. https://doi.org/10.1016/j.geothermics.2020.101915.

Bahrami, H. R., & Rosen, M. A. (2024). Exergoeconomic evaluation and multi-objective optimization of a novel geothermal-driven zero-emission system for cooling, electricity, and hydrogen production: capable of working with low-temperature resources. Geothermal Energy, 12(1), 12. https://doi.org/10.1186/s40517-024-00293-7.

Geng, Q., Li, J., Zhu, W., Yang, M., Qian, S., & Sardari, F. (2024). Thermodynamic and exergo-economic analyses and multi-objective optimization of an innovative and efficient geothermal-assisted power and hydrogen cogeneration system. Applied Thermal Engineering, 242, 122416. https://doi.org/10.1016/j.applthermaleng.2024.122416.

Li, K., Ding, Y. Z., Ai, C., Sun, H., Xu, Y. P., & Nedaei, N. (2022). Multi-objective optimization and multi-aspect analysis of an innovative geothermal-based multi-generation energy system for power, cooling, hydrogen, and freshwater production. Energy, 245, 123198. https://doi.org/10.1016/j.energy.2022.123198.

Toker, S. C., Kizilkan, O., & Nižetić, S. (2024). Development and modeling of power, hydrogen, and freshwater production based on a novel double-flash geothermal power plant. Energy, 309, 133082. https://doi.org/10.1016/j.energy.2024.133082.

Putra, T. A., Sulistyo, & Harmoko, U. (2025). Feasibility study of green hydrogen production from geothermal power plant. International Research Journal of Innovations in Engineering and Technology, 9(3), 198–204. https://doi.org/10.47001/IRJIET/2025.903026.

Implementation of a Campus Safety Chatbot: An AI-Powered Digital System for Real-Time Incident Reporting and Emergency Support

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Abstract: The issue of campus safety within universities is gaining more attention due to increased campus population. Traditional safety approaches are time-consuming because responses are usually inefficient due to delayed communication and manual reporting. To better handle these challenges, this project aims to design and implement a system that will be built as a scalable digital resource to enhance access to the information on safety and streamline reporting incidents. The system incorporates a knowledgebase that enables administrators to pre-populate the potential questions and answers. It functions as a real-time safety system that integrates existing emergency protocols, providing quick access to safety procedures through an AI-powered interface. Moreover, the system was developed using modern web and natural language processing (NLP) technologies, featuring an AI-powered chatbot that enables users to report incidents in real time, receive alerts and access answers to frequently asked safety questions while an admin dashboard allows university staff to analyze and manage reports, incidents and responses efficiently. Testing proved to have great reliability in classification of user queries and greater ease of integration between the chatbot and the reporting dashboard. These outcomes demonstrate that such a system has the potential to drastically improve the level of campus safety due to decreasing the time lag and other communication issues, raising student safety-consciousness, and assisting in making proactive decisions. The project adds value to sustainable technology through the ability to make the campus digital-first idea in terms of safety that is convenient, affordable, and applicable to other universities. The end user testing revealed the chatbot to be usable and reliable, showing promising response accuracy and addressing key gaps in traditional safety approaches.

Keywords: Campus safety, AI Chatbot, emergency Response System, Incident Reporting, Natural Language Processing, Real-Time Communication

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1. INTRODUCTION

Educational facilities such as universities should continuously strive to ensure a safe and secure environment for their students, employees and visitors. Student safety refers to a state in school where students feel protected from possible harmful situations which are fundamental in providing necessary conditions for unimpaired teaching and learning process (Jackline et al., 2020). It is a persisting issue that should not be neglected, and facility managers are responsible for developing and implementing policies that guarantee the safety of everyone within the facility. Besides, adhering to legal requirements, it is an ongoing challenge to create a culture of safety that is integrated in every aspect through training and other initiatives (Astutis, 2024).

However, traditional methods of spreading information during emergency situations, such as manuals, papers, posters, and boards, are inefficient and aren't up to date with the latest safety guidelines. These static forms of emergency communication remain inaccessible for immediate actions since such methods do not provide real-time access. Emails can often remain unread, printed materials can easily get misplaced and bulletin board posts can be inefficient in handling emergencies because of low visibility. Such an emergency system can result in unfortunate outcomes, while more advanced methods could furthermore save lives (Layered Solutions, 2017). Hence, individuals encounter difficulties with safety procedures and protocols which lead to confusion that is the source of delayed responses and hazardous situations on the campus.

It has been recorded that in 2007, a student at Virginia Tech opened fire on classmates, killing 32 and injuring 17 in just 11 minutes. Officials failed to send out campus-wide alerts by issuing only four emails during the incident. It was marked as the worst mass-shooting in U.S. history, and it forever changed their emergency management and response system across schools (Layered Solutions, 2017).

At University of Pittsburgh, in 2012, an accident occurred in a training session which triggered an unintentional mass campus-wide alert about shots fired followed by shelter instructions. The wrong emergency alert which spread through digital channels triggered widespread panic among people at the college (Wikipedia, 2012). Hence, a responsive emergency system should exist within the universities to retrieve safety guidelines but also let individuals report incidents such as fire hazards and medical emergencies.

Existing solutions used are mass notification systems, mobile safety applications, emergency websites and social media updates, campus patrols, emergency phones, surveillance systems, and sirens. Besides, regular drills and crisis training, with addition of Virtual Reality simulations are conducted globally across public facilities (Buzzpeak, 2024). Despite various advantages, many solutions rely on user action which can be hard to achieve in high-stress situations. Additionally, accessibility and insufficient integration between external emergency services and campus security can raise concerns in safety measures.

The aim of the proposed solution “Campus Safety Chatbot” as an interactive web-based system is to enhance campus security through providing real-time safety assistance and guidance for emergencies and enabling adequate reporting mechanisms. With the use of modern web technologies and their advantages the chatbot pursues to address the drawbacks of traditional safety communication methods that are often „unable to keep up with the speed and scale required for effective security“(Campus ID News, 2024). Reporting functions would enable users to submit reports that include severity categories. Artificial Intelligence would allow this chatbot to deliver automated customized answers that would improve security measures. This accessibility is especially valuable in the time of emergencies, where a chatbot automatically provides clear and instantaneous instructions (Campus ID News, 2024). By using natural language processing through AI and security alert notifications, the response system would be more efficient without having to navigate between old documents or large manuals provided by the chatbot help in active threat notification to students and staff which enhances the overall readiness of the campus environment.

2. LITERATURE REVIEW

2.1. Overview of campus safety and emergency communication research

The steps a college or university takes to guarantee the protection of its employees, students, and guests are referred to as campus safety and security. These actions are meant to lower campus crime, safeguard individuals from injury, and promote welfare in general. The intention is to eliminate dangers so that students may concentrate on their studies and feel at ease (Lenel.S2, 2025).

In recent years, advanced technologies that focus on this topic have been adopted, like Real-Time Emergency Alert Systems (The Dig at Howard University, 2020), Emergency Notification Systems (ENS) (University of Evansville, 2025), mobile applications (Carnegie Mellon University, 2019). Traditionally, universities have relied on existing communication channels to communicate.

Digital technologies have changed emergency communication tactics and one of those is the use of social media platforms. The growth of mobile devices has allowed social networking sites to quickly share information. “Research suggests that students are more likely to comply with emergency notifications received through social networking channels” (School of Management - University at Buffalo, 2015). The popularity of these platforms allows for timely and accurate distribution of information which enhances the safety of the campus community (School of Management - University at Buffalo, 2015).

Despite the benefits, there are drawbacks. One such drawback is the “exposure to rumors and conflicting information that arise out of the ambiguity of a crisis” (Jones et al., 2017).

To sum up, campus safety relies on effective emergency communication to protect students and staff. Despite technological innovations, limitations like misinformation show the need for a balanced system.

2.2. Existing digital solutions for campus safety

To be in step with the rapidly changing environment of campus safety, universities are increasingly utilizing modern digital solutions (Appinventiv, 2025). While emergency notification systems have been founded on traditional methods, fast adoption of AI-chatbots, mobile apps, and real-time alert systems are changing how universities manage security (Airmeez, 2024).

A variety of mobile apps are designed and created for the safety and security of higher education. While some universities opt to pay subscription or license fees, others have developed their own apps for campus safety guidelines. Rave Guardian or LiveSafe are examples of third-party solutions that improve campus security by providing real-time connection with law enforcement, GPS-based location sharing, emergency notification and anonymous tip reporting (National Center for Campus Public Safety, 2016).

On the other side there are examples of apps some universities developed tailoring to their specific campus needs. WalkSafe, an app developed by Pennsylvania State University, provides location-based, real-time emergency alerts and allows reporting of incidents (Vaghela and Shih, 2018). SDSU Safe app at San Diego State University offers emergency news and Friend Walk (San Diego State University, 2025). SafeZone at UTSA offers direct access to campus police (UT San Antonio, 2025). Similarly, UGA Safe at the University of Georgia integrates emergency response features like Mobile Bluelight (UGA Student Affairs, 2022). One more example is Safe at UT app, developed by the University of Tennessee, which includes a 911 speed dial and live police chat (The Daily Beacon, 2024).

As for chatbot utilization, one such example is the RIPEC project, where a chatbot was created to assist Erasmus mobility students and university staff in emergency situations. Developed with Google Dialogflow, the RIPEC chatbot provides real-time safety tips and university-specific information and is deployed on the RIPEC website and Telegram (Balderas et al., 2023).

Overall adopting these and similar solutions provides students and staff with quick access to critical information, real-time alerts and essential support, ensuring a safer campus environment.

2.3. Gaps in existing solutions

Despite substantial improvements regarding campus safety and technologies for emergency communication, there exist limitations and gaps. AI-driven chatbots, mobile applications and notification systems have advanced crisis management, however challenges related to misinformation, accessibility and privacy persist.

Even though social media platforms increase the speed of communication, they also carry the risk of misinformation (School of Management - University at Buffalo, 2015). The research states that inaccurate information may be posted by users, which may cause widespread panic and distrust in official alerts (Shahbazi and Dunker, 2024).

One of the challenges of emergency communication systems is accessibility and inclusivity. The systems should be created so that they are used by all students and staff, including those with disabilities. Many mobile apps and AI chatbots rely mostly on text and graphic interactions which are not convenient for users with visual impairments (Clifford Chance, 2024).

Another challenge is related to technical limits of AI systems. Despite AI's effectiveness at analyzing data, it might not be capable of handling the complexities of real-world emergencies (Arena, 2023). For example, during the floods in Southeast Queensland in 2022, the Emergency Alert system had major delays due to overload (ABC News, 2022). Similarly, chatbots can face scalability challenges during peak crisis periods if no proper infrastructure was implemented (Business Admin Tools, 2025).

Safety solutions for campuses usually require location, personal details, and emergency contacts of users which raises concerns about security and data privacy (Securiti,2024). Robust security measures and precise policies must be developed (Arena, 2023).
Despite modern emergency communication technologies, there still persist gaps regarding accessibility, misinformation, real-time responsiveness and data security.

The chatbot being developed through this project aims to focus on crucial gaps present in other systems. It copes with real-time responsiveness by leveraging prompt communication infrastructure, addresses accessibility by providing inclusive design principles, and integrates robust data protection. The IUS Safety Chatbot also incorporates university-specific safety protocols, contact information and multilingual capabilities, and provides AI-powered interactive guidance that gives real-time assistance as a superior approach to FAQ-based systems.

3. Overview

Campus safety is a fundamental component of college life that has a direct impact on students' experience and well-being. Students should be safe and secure on the university campus and higher education institutions should provide this to contribute to a better educational environment (LinkedIn, 2025). Campus safety measures include initiatives and programs designed to create a safe environment, while campus security involves protocols such as "security cameras, unmanned aerial systems, emergency blue light phones, patrolling security guards, and mass notification systems" (BestColleges, 2022). By implementing comprehensive safety measures and protocols, universities can significantly lower safety risks

and improve awareness among students and staff. Next to being a legal necessity (International University of Sarajevo, 2021), it is also important that safety information is accessible and regularly used. The proposed solution was chosen to improve existing solutions and develop a system that ensures campus safety is more accessible and manageable, addressing the need for accurate information with emphasis on emergency guidance and reporting mechanisms. In order to fulfill that goal, the following objectives need to be accomplished

- **Real-Time Response and Assistance**

The first objective is to make sure that the chatbot provides accurate information related to safety regulations which help users with emergencies and safety procedures right away.

- **Effective System for Reporting Incidents**

The second objective is to create a simple user-friendly incident reporting system that enables users to report safety concerns in real time.

- **Integration of Emergency Protocols**

This objective means that the chatbot is linked with current emergency protocols, giving users precise guidance on how to handle various scenarios regarding security.

- **Natural Language Processing for Queries**

Furthermore, using NLP capabilities, this solution ensures that the chatbot has the ability to understand user queries and guarantee clear communication.

- **Data Security and Privacy**

Standard encryption techniques and role-based access control are used to secure all user data, including incident reports, personal details and any other sensitive information.

4. DATA COLLECTION AND ANALYSIS

The data collection and analysis process were initiated by researching the official IUS website which contains documents regarding policies and regulations including safety and security on campus. There are Occupational Safety Rule Book, QA Rule Book, Code of Ethics and Rule Book on Disciplinary and Material Liability of Students where legal rules and responsibilities of the University are stated. Additionally, Policy on Drugs and Alcohol Abuse and Sexual Harassments Policy are available on the website, as well as necessary contacts and office location information of IUS directors, educators, maintenance managers, personnel, infirmary and security office. After determining the usable documentation, files have been analyzed and with the help of AI tools a set of questions and answers has been extracted. Obtained data were used for training the Chatbot, providing a foundational grasp of university's existing safety protocols and legal duties.

To expand the research, the Student Affair Office was approached. Guidance was provided by the Student Affairs Office Manager, with whom a short interview was conducted. Further details are elaborated under Interview section. Meanwhile, a comprehensive survey was prepared and distributed to university members. All key findings are presented in the Survey section.

4.1. Interview

IUS Student Affairs Office has the major responsibility of implementing and overseeing university's policies and procedures. By visiting their office valuable information was obtained. They provide number of paper forms, including Student Appeal Form and ID Card Replacement form, while digital versions are also available on the official website. The Student Affairs Office Manager participated in an interview about multiple protection and reporting mechanisms at the institution. The Quality Assurance Office receives feedback from students who submit reports through anonymous QR code boxes or suggestion boxes. She also informed us about individual professor/student complaints that should be reported to the Student Affairs Office whereas all other complaints remain anonymous.

She explained how most parts of the campus remain uncovered by surveillance cameras since administrators wish to preserve a natural environment for student life. A special committee handles disciplinary measures when violence or criminal activities occur in the institution. Insights shared by the manager provided guidance for further research and were used in future steps of the proposed solution.

4.2. Survey

The IUS Campus Safety Chatbot Survey was conducted to assist in tailoring and refining chatbot to users' needs. The survey aimed to determine frequently asked questions for training, assess campus safety perceptions and users' familiarity with IUS emergency contacts and protocols, and collect preferences for chatbot features. It was managed online through Google Forms, over the period of a week and disseminated via personal networks and Microsoft Teams channel. In total there were 78 responses, of which 91% were students, while the remaining were academic and non-academic staff.

Regarding safety perception, the average rating was 4.4 out of 5, with most respondents opting 4 or 5. Some rated lower because of harassment or cybersecurity threats. Theft was the most frequently mentioned concern, followed by poor lighting as a physical hazard in the evening. Cyber threats in the form of phishing scams and hacking were also common. Several respondents referred to harassment, while some expressed worries about bomb threats and fire emergencies.

The survey also assessed emergency awareness. About 60% of respondents were unaware or uncertain how to contact campus security. Roughly 70% indicated they had little to no knowledge of fire, medical or active shooter protocols. These findings suggest more frequent training programs such as drills or workshops are needed. Around 50% of respondents demand a list of emergency contacts along with real-time emergency alerts to be included in chatbot. A significant number selected cybersecurity awareness as desired feature. Other top requested features are direct incident reporting, campus map with safety zones, and safety tips and guidelines.

Respondents also identified their most frequently asked safety questions. Based on the frequency, Chatbot should prioritize three key functions: providing emergency contact information, locating first aid stations and explaining violence/harassment protocols.

Concerning trustworthiness in chatbot during an emergency, a large percentage rated the chatbot 4–5, with an average trust rating of 3.8 out of 5. While generally receptive, some uncertainty regarding dependability still exists.

After considering all data collected, the survey identified several insights for chatbot development and broader campus safety. Many respondents confirmed lacking awareness of emergency procedures and contacts, emphasizing a need for better communication through initiatives like drills and workshops. Among the chatbot's top priorities are emergency FAQs, incident reporting, mental health support, real-time alerts, interactive maps and cybersecurity guidelines. The survey also revealed issues beyond the chatbot's scope like poor campus lighting, highlighting the necessity for physical infrastructure enhancements.

5. FEATURE EXTRACTION AND SYSTEM REQUIREMENTS

Having defined the objectives, it can be concluded that the system will have two primary actors: users, mainly students and staff, and the administrator. Users can perform actions such as asking questions regarding safety, logging in, reporting incidents together with attaching evidence, and others. Actors with the role of administrator interact with the system by managing reports, updating their statuses, and receiving notifications.

After defining the user classes, it is possible to extract the necessary features and requirements. The main features of the system include:

- **Safety guidelines chatbot interface -** This user interface provides students immediate access to university security regulations and rules as well as guidelines through interactions with a chatbot. This is the first user interface provided to give real-time responses through a hybrid approach using rule-based as well as NLP-based modelling.

- **Registration -** Security measures were implemented utilizing the university's Microsoft Outlook domain for authentication. Rather than using standard registration with password storage, Microsoft's identity system is integrated to restrict access so that only users with a valid student or staff email granted by university can have access to the application. Since Microsoft manages authentication, password protection and multi-factor authentication (MFA) when enabled, it reduces risk associated with managing credentials manually.

- **Login -** Login enables secure access to the system for both students and authorized personnel (like campus security staff and administration). The system supports the use of RBAC (role-based access control) with appropriate access privileges. This feature ensures that other parts of the system are well protected and secure from unauthorized access.

- **Incident reporting module -** This module allows users to submit incident reports through a structured form and organize their collection within the application interface. Users send detailed reports with the type of incident, date, severity level, location and potential attachments which are then sent to the administrative dashboard for inspection and further action. Because of this feature, staff members can quickly warn managers, and they can manage their concerns openly.

- **Real-time communication -** This characteristic of the system ensures low-latency communication between the chatbot and the user. Its purpose is handling user interactions in emergencies and answering safety questions. This module is responsible for understanding and responding to user inputs using NLP, providing real-time suggestions for unclear queries, and delivering safety guidelines and emergency protocols. Users can interact with the chatbot over web or mobile app interface to request guidelines, report incidents, or seek help. Upon request, the chatbot extracts intent and entities, identifies the relevant regulation query, fetches the data, and delivers clear instructions through the user interface.

- **Admin dashboard for incident reports -** This module ensures a distinct interface for authorized personnel, including security staff and admins, to access submissions from users through a dedicated dashboard. It allows efficient monitoring, reviewing, and managing of incident reports. Users can view, sort, and filter reports and access uploaded evidence. Admins have the ability to update the status of reports and notify users through the notification system. This module contains essential tools for safety management, including real-time chat interactions, streamlined incident reporting, and a comprehensive dashboard.

In addition to these main system features with appropriate functional requirements, the system is also expected to fulfill following non-functional requirements:

- **Performance -** The system must answer users' queries within a specified time of two seconds within an ordinary load.

- **Reliability -** The system should have an uptime equal to or greater than 99.5 %.

- **Security -** All access shall be protected via secure login**.**

- **Availability -** The system should be available 24 hours a day, 7 days a week, except during announced maintenance windows.

- **Portability -** The system should run on both Windows as a web page and as mobile application. Frontend must be responsive on desktop and mobile browsers.

- **Maintainability -** The system shall follow modular architecture providing easy maintenance and updates.

- **Usability -** The chatbot must use clear, intelligible language, along with guidance to users who have unclear or unambiguous requests.

6. SYSTEM IMPLEMENTATION

The aim of this section is to show how system's design is implemented as a fully functioning application, outlining the technical implementation of the overall Campus Safety Chabot system. All tools and technologies used to build user interface, implement backend logic, integrate with chatbot and manage the data storage are specified in detail.

6.1. Tools used

During development, several tools were utilized to simplify implementation and enhance collaboration. Tools were chosen based on compatibility, convenience, and suitability.

- **Dialogflow Console –** Used for building chatbot logic. With built-in NLP, the chatbot can understand and respond to user inquiries without custom implementation, while intents, entities, and training phrases are easily managed (Dialogflow, 2025).

- **Visual Studio Code –** The integrated development environment (IDE) for frontend and backend development was Visual Studio Code. It was preferred option for coding mainly because of its built-in support for .NET framework through extensions and ease of use (Microsoft Visual Studio, 2025).

- **Microsoft SQL Server Management Studio (SSMS)** – To handle and monitor SQL Server database, code-first approach was used to populate database through writing code. Microsoft SQL Server Management Studio was then used to verify that the migrations were successful and to further monitor databases throughout development process (Microsoft Learn., 2025).

- **Docker –** Containerized the application to ensure reproducibility. By packaging the backend, database, and other

dependencies in isolated containers, Docker made the setup process easier and made the whole system more portable as well as scalable (Docker, 2025).

- **Swagger –** For API documentation and testing, Swagger simplified the process by automatically generating interactive documentation in the browser without requiring manual URL processing as in Postman. Its integrated testing tools and self-documenting endpoints make development faster and ensure API reliability (Swagger, 2025).

- **Figma –** Figma, a collaborative design platform, was used to prototype and create the chatbot's user interface for both web and mobile applications (Home – Figma, 2025).

6.2. Technologies Used

Both frontend and backend achieve core capabilities through the following technologies, providing secure data processing, natural language communication, and cross-platform access.

- **C#** - The Web API development and all server-side processing including user authentication and incident management and API endpoint administration use C# as a primary backend language (Microsoft Learn., 2025).
- **TypeScript** – The statically typed extend of JavaScript functions as a frontend tool together with React. Its code reliability and readability along with maintainability gets enhanced through strong typing along with improved tooling capabilities (TypeScript, 2025).
- **React.js** – JavaScript library serves to develop the web-based user interface which functions for students and administrator users. The component modular design features of React enhances interactive and responsive user interfaces in web development (React, 2025).
- **Flutter –** A mobile-version chatbot development framework which creates platform-consistent performance standards using native operating system capabilities (Flutter, 2025).
- **.NET Core –** The platform builds RESTful Web APIs by using this powerful scalable framework. This platform executes all backend activities through its business operation functions and security features and database interactions (Microsoft Learn., 2025).
- **SQL Server –** Relational database management system keeps their structured data in three main sections: user accounts, safety guidelines alongside incident reports. The framework ensures both data consistency and security access together with data integrity (Microsoft Learn., 2025).
- **Entity Framework Core (ORM)** – Entity Framework Core functions as an .NET object-relational mapping framework which lets developers create database definitions through C# classes using a code-first methodology (Microsoft Learn., 2025).

6.3. Database System

The database system of the project was designed and implemented using a Code-First approach with Entity Framework Core, an Object-Relational Mapper (ORM) for .NET applications and APIs. This approach allowed defining database schemas using C# classes, simplifying the process of creating and updating tables.

Microsoft SQL Server was selected due to its compatibility with the .NET environment, reliability, and support for complex queries. The schema was designed and managed through migrations to synchronize the evolving data model with the source code. The database contains components including chatbot conversations, incident reports, and administrative responses.

6.4. Security Implementation

Security measures were implemented using the university's Microsoft Outlook domain for authentication. Instead of standard registration with password storage, Microsoft's identity system restricts access so only users with a valid student or staff email can use the application. Microsoft manages authentication, password protection, and multi-factor authentication (MFA), reducing risks of manual credential management. Using OAuth 2.0 and OpenID Connect, it provides secure and standardized user authentication.

As the application is built on .NET, HTTPS is enabled by default, ensuring encrypted communication between user and server. Role-based access control limits functionality according to roles, allowing only authorized users to access sensitive features. Although passwords are not stored, other data is secured by restricting access and avoiding unnecessary personal data collection. These measures make the chatbot secure, minimize vulnerabilities, and provide reliable experience for users.

7. CONCLUSION

Building the Campus Safety Chatbot has made it possible to overcome the challenges of previous campus safety communication systems. With the help of artificial intelligence, natural language processing and advanced web services, the project produces a useful platform for reviewing safety information and reporting affected areas. The use of dense research, a focus on users and planned construction, makes the system better at preparing for emergencies and also benefits the entire university. Because the chatbot offers immediate help, has an easy-to-use incident reporting tool and controls access according to roles, safety and access on campus have both seen improvements.

The results laid a reliable basis for software developments that enhance safety and communication in schools and universities, showing that technology can help when communication becomes an issue during an emergency. Regardless, the process can be improved even more. Moving forward, it is planned to grow the chatbot's training data to make its responses better and more accurate for various contexts. At this time, chatbot is available in English and multilingual options, including Bosnian and Turkish, are important for serving more of the university community.

Other improvements planned involve adding mapping features to help users identify safety spots or get help close by and working directly with campus security to distribute warnings right away. It would be beneficial for the chatbot to send reminders or learn about safety when users act in certain ways. These upgrades want to turn the chatbot into a constant companion for safety. Ultimately, the IUS Campus Safety Chatbot leads the way in changing university safety systems and gives other institutions a solid design to follow.

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REFERENCES

ABC News, (2022). Emergency alerts were delayed during south-east Queensland's flood disaster, report finds. https://www.abc.net.au/news/2022-10-12/queensland-flood-report-emergencymanagement-brisbane-alerts/101512840 (accessed 01 April 2025).

Airmeez, (2024). Emergency Alert Systems: Improving Safety with AI-Powered Notifications. https://www.airmeez.com/blog/emergency-alert-systems--improving-safety-with-ai-powerednotifications?utm_source=chatgpt.com (accessed 13 April 2025).

Appinventiv, (2025). A Guide on Smart Campus Technology for Higher Education. https://appinventiv.com/blog/smart-campus-technologyfor-higher-education/?utm_source=chatgpt.com (accessed 13 April 2025).

Arena, F. (2023). Artificial Intelligence in Emergency Response Systems. Massachusetts Institute of Technology.

Astutis, (2024).What Are Your Health and Safety Responsibilities in Facilities Management? https://www.astutis.com/astutis-hub/blog/understanding-health-and-safety-in-facilities (accessed 19 March 2025).

Balderas, A., García-Mena, R. F., Huerta, M., Mora, N., & Dodero, J. M. (2023). Chatbot for communicating with university students in emergency situation. *Heliyon*, *9*(9). https://doi.org/10.1016/j.heliyon.2023.e19517.

BestColleges, (2022). Campus Safety Guide. https://www.bestcolleges.com/resources/campus-safety-guide/ (accessed 20 March 2025).

Business Admin Tools, (2025). Solving Chatbot Scalability Issues. https://bizbot.com/blog/solving-chatbot-scalability-issues/ (accessed 01 April 2025).

Buzzpeak, (2024). Campus Safety: Innovations and Strategies Colleges are Using to Ensure Student Safety https://buzzpeakblog.wordpress.com/2024/09/06/campus-safety-innovations-and-strategies-colleges-are-using-to-ensure-student-safety/? (accessed 05 April 2025).

Campus ID News, (2024). How Generative AI is shaping the future of campus security. https://www.campusidnews.com/how-generative-ai-is-shaping-the-future-of-campus-security/ (accessed 20 March 2025).

Carnegie Mellon University, (2019). CMU Releases Mobile App for Safety, Emergency Preparedness. https://www.cmu.edu/piper/news/archives/2019/july/mobile-safety-app.html (accessed 06 April 2025).

Clifford Chance, (2024). Inclusive AI for people with disabilities: Key considerations. https://www.cliffordchance.com/insights/resources/blogs/talking-tech/en/articles/2024/12/inclusive-ai-for-people-with-disabilities--key-considerations.html (accessed 01 April 2025).

Dialogflow.
https://dialogflow.cloud.google.com/#/agent/campussafetychatbot-pom9/intents (accessed 03 May 2025).

Docker. Docker: Accelerated Container Application Development. https://www.docker.com/ (accessed 03 May 2025).

Flutter. Flutter Documentation. https://docs.flutter.dev/ (accessed 05 May 2025).

Home – Figma.
https://www.figma.com/files/team/1072541884147986321/recents-andsharing?fuid=1072541873722263438 (accessed 03 May 2025).

International University of Sarajevo, (2021). General IUS Regulations. https://www.ius.edu.ba/en/regulations. (accessed 01 April 2025).

Jackline, S., Betty J, T., & Frederick BJ A, N. (2020). Relationship between implementation of safety standards and guidelines for physical infrastructure, and student safety in public mixed boarding secondary schools in Nakuru County, Kenya. Journal of Education and Learning. 2(1), 275-285. https://doi.org/10.51317/ecjces.v2i1.167

Jones, N. M., Thompson, R. R., Dunkel Schetter, C., & Silver, R. C. (2017). Distress and rumor exposure on social media during a campus lockdown. Proceedings of the National Academy of Sciences, *114*(44), 11663-11668. https://doi.org/10.1073/pnas.1708518114.

Layered Solutions, (2017). Virginia Tech: Mistakes & Takeaways in Keeping Students Safe. https://layeredsolutionsinc.com/virginia-tech-mistakes-takeaways-keeping-students-safe/ (accessed 23 March 2025).

Lenel.S2. How to Improve Campus Security & Safety. https://www.lenels2.com/en/news/insights/how-to-improve-campus-security---safety.html (accessed 06 April 2025).

LinkedIn, (2023). The Role of Campus Safety in Higher Education: More Than Just Security. https://www.linkedin.com/pulse/role-campus-safety-higher-education-more-than-just-tyrone/ (accessed 20 March 2025).

Microsoft Learn. ASP.NET documentation.
https://learn.microsoft.com/en-us/aspnet/core/?view=aspnetcore-9.0 (accessed 05 May 2025).

Microsoft Learn. C# Guide - .NET managed language. https://learn.microsoft.com/en-us/dotnet/csharp/ (accessed 05 May 2025).

Microsoft Learn. Download SQL Server Management Studio (SSMS). https://learn.microsoft.com/enus/ssms/download-sql-server-management-studio-ssms (accessed 03 May 2025).

Microsoft Learn. Overview of Entity Framework Core.
https://learn.microsoft.com/en-us/ef/core/ (accessed 05 May 2025).

Microsoft Learn. SQL Server technical documentation. https://learn.microsoft.com/en-us/sql/sqlserver/?view=sql-server-ver16 (accessed 05 May 2025).

Microsoft Visual Studio. Visual Studio: IDE and Code Editor for Software Developers and Teams. https://visualstudio.microsoft.com/ (accessed 03 May 2025).

National Center for Campus Public Safety, (2016). Campus Safety Mobile Apps. www.nccpsafety.org (accessed 20 March 2025).

React. The library for web and native user interfaces. https://react.dev/ (accessed 05 May 2025).

San Diego State University. SDSU Alert Notifications and SDSU Safe App. https://urgent.sdsu.edu/sdsu-alert-platform (accessed 20 March 2025).

School of Management - University at Buffalo, (2015). Social media can help alert students during campus emergencies. https://management.buffalo.edu/about/news.host.html/content/shared/mgt/news/socialalerts.detail.html (accessed 20 March 2025).

Securiti, (2024). What is Sensitive Data Exposure & How to Protect Yourself from Data Exposure. https://securiti.ai/blog/sensitive-data-exposure/ (accessed 01 April 2025).

Shahbazi, M., & Bunker, D. (2024). Social media trust: Fighting misinformation in the time of crisis. International Journal of Information Management, *77*, 102780.doi: 10.1016/J.IJINFOMGT.2024.102780.

Swagger. Why Swagger?. https://swagger.io/why-swagger/ (accessed 03 May 2025).

The Daily Beacon, (2024). UT's new campus safety app 'Safe at UT' makes emergency services easily accessible, prioritizes students' well-being. https://www.utdailybeacon.com/campus_news/campus_events/ut-s-new-campus-safety-app-safe-at-ut-makes-emergency-services-easily-accessible-prioritizes/article_30727678-6a22-11ef-96c0-57081417f03a.html (accessed 20 March 2025).

The Dig at Howard University, (2020). Howard University Launches New Emergency Alert System and Mobile App, Bison. https://thedig.howard.edu/all-stories/howard-university-launches-new-emergency-alert-system-and-mobile-app-bison-safe (accessed 06 April 2025).

TypeScript. TypeScript: JavaScript With Syntax For Types. https://www.typescriptlang.org/ (accessed 05 May 2025).

UGA Student Affairs, (2022). New Safety App – UGA. https://studentaffairs.uga.edu/new-safety-app-uga/ (accessed 20 March 2025).

University of Evansville. Emergency Notification System / Rave Guardian Mobile App. https://www.evansville.edu/safety/emergencySystem.cfm (accessed 06 April 2025).

UT San Antonio. Student Union, Support the Pantry. https://www.utsa.edu/studentunion/pantry/support.html (accessed 20 March 2025).

Vaghela, S. J. D. and Shih, P. C., (2018). WalkSafe: College campus safety app. Proceedings of the 15th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2018), Rochester, NY, USA. ISCRAM Association. https://idl.iscram.org/files/salonijdvaghela/2018/2170_SaloniJDVaghela+PatrickC.Shih2018.pdf

Wikipedia, (2012). University of Pittsburgh bomb threats. https://en.wikipedia.org/wiki/2012_University_of_Pittsburgh_bomb_threats?utm_source=chatgpt.com (accessed 24 March 2025).

The effect of covid-19-related anxiety on performance efficiency: an application among basketball players

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Abstract: The aim of this study is to determine the effect of COVID-19 anxiety on the performance efficiency scores of basketball athletes. The study was conducted using a relational survey model, one of the quantitative research designs. The research population consisted of basketball teams actively competing in Turkey, including Nadir Gold İstanbul, Balıkesir Metropolitan Municipality Basketball, Merkezefendi Denizli Basket, and Sigortam.net basketball teams. The sample of the study comprised 62 basketball players, determined using the simple random sampling method, one of the probability-based sampling methods, calculated with a 95% confidence interval and a 5% margin of error. The Coronavirus Anxiety Scale and the State Anxiety Inventory were utilized in the study. While no significant difference was found between athletes' demographic variables (marital status, history of illness, age, and weight) and their levels of COVID-19 anxiety, a significant difference was identified between athletes' average height and their COVID-19 anxiety levels. According to the results, athletes with a height of 180 cm had higher anxiety levels compared to those who were 190 cm tall. No prior studies in the literature were found that reported a significant relationship between average height scores and anxiety levels among athletes. Therefore, it can be stated that this study contributes to the existing literature in this regard.

Keywords: Basketball, Covid-19, Productivity.

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1. GİRİŞ

Yeni tip koronavirüs hastalığı (COVID-19), ilk olarak Aralık 2019'un sonlarında Çin'in Wuhan kentinde, akut solunum yolu semptomları (ateş, öksürük, nefes darlığı) gösteren bir grup hasta üzerinde yapılan incelemeler neticesinde, 13 Ocak 2020 tarihi itibarıyla tanımlanmıştır. (Team, E. (2020).SARS virüsü ile benzerliklerinden dolayı, bu yeni virüs "SARS-CoV-2" olarak adlandırılmıştır (T.C. Sağlık Bakanlığı Halk Sağlığı Genel Müdürlüğü, 2020). Salgının başlangıcı, Wuhan'daki bir deniz ürünleri ve hayvan pazarından kaynaklanmış gibi görünmektedir. Ancak, zamanla virüs insandan insana bulaşarak önce Wuhan ve Hubei eyaletindeki diğer şehirlere, ardından ülke genelinde ve küresel boyutta pek çok ülkeye yayılmıştır. Bu hızlı yayılma nedeniyle, Dünya Sağlık Örgütü (WHO) 30 Ocak 2020'de Uluslararası Halk Sağlığı Acil Durumu ilan etmiştir. Salgın, günümüzde hâlâ ciddi bir halk sağlığı tehdidi oluşturmaktadır. Dünya genelinde, 23 Mayıs 2020 saat 03:00 (GMT+3) itibarıyla toplamda 5.061.476 doğrulanmış vaka ve 331.475 ölüm rapor edilmiştir (World Health Organization, 2020). Türkiye'ye gelindiğinde ise ilk COVID-19 vakası, Sağlık Bakanlığı tarafından 11 Mart 2020 tarihinde açıklanmıştır (T.C. Sağlık Bakanlığı, 2020a). Türkiye'de, 12 Mayıs 2020 itibarıyla toplam test sayısı 1 milyon 440 bin 671 olarak bildirilmektedir. Aynı tarihte toplam vaka sayısı 141 bin 475'e, can kaybı ise 3 bin 894'e ulaşmıştır. Mart ayının ortalarındaki günlük 2-3 bin seviyelerinde seyreden test sayısı, iki aylık süreç içerisinde günlük ortalama 35 bin düzeyine yükselmiştir. Bunun yanı sıra Türkiye'de COVID-19 vakalarının iyileşme oranı dünya genelindeki ortalamanın oldukça üstünde seyretmektedir; dünya genelinde vakaların %35'i iyileşirken Türkiye'de bu oran 12 Mayıs 2020 itibarıyla yaklaşık %70 seviyesine ulaşmıştır. 2019 yılının sonlarında ortaya çıkan ve hızla küresel bir sorun haline gelen COVID-19 salgını, toplumda geniş çaplı bir korku dalgasına yol açmıştır (T.C. Sağlık Bakanlığı, 2020b). Hastalığın bulaşma biçimi, ölüm oranları ve salgının ne ölçüde yayılacağına dair belirsizlikler insanlarda derin endişelere neden olmuştur. Salgın sürecinde insanlar sadece fiziksel sağlıkları açısından değil, aynı zamanda psikolojik ve sosyal açıdan da ciddi olumsuzluklarla karşı karşıya kalmıştır (Reardon et al., 2021). Bu bağlamda, bireylerin yanı sıra toplumun geneli üzerinde derin etkiler bırakan salgın, Ocak 2020'den itibaren dünya çapında halk sağlığını tehdit eden bir kriz haline dönüşmüştür. COVID-19'un kontrol altına alınabilmesi adına pek çok önlem devreye sokulmuştur. (Mehrsafar et al., 2020). Sosyal izolasyon tedbirleri sonucu insanlar zamanlarının büyük kısmını evlerinde geçirmek zorunda kalmış, bu durum bireysel ve toplumsal yaşamın pek çok boyutunda köklü değişimlere neden olmuştur. İş dünyasında birçok sektör uzaktan çalışma modeline geçerken, eğitim alanında çevrimiçi öğrenim süreci başlamış ve pek çok sportif faaliyet neredeyse tamamen durmuştur. Bu durumun sporcular üzerinde gerek fiziksel gerekse psikolojik düzeyde çeşitli etkiler yarattığı gözlemlenmiştir (Doğan, 2022). Pandemi süresince uygulanan kısıtlamalar sporcuların idman yapma şartlarını da önemli ölçüde sınırlamış; bu beklenmedik değişikliklerin sporcuların uzun vadede fiziksel performansı üzerinde olumsuz etkiler yaratma potansiyeline sahip olduğu ifade edilmektedir. Alışkanlıklarının kesintiye uğraması dolayısıyla sporcuların, pandeminin oluşturduğu bu durumun ardından eski formlarına dönmelerinin zaman alacağı açıktır. Ayrıca karantina ve izolasyon sürecinde ortaya çıkan ruhsal sorunlar arasında endişe, kaygı bozukluğu, panik duygu hali, sağlıkla ilgili obsesyonlar, değersizlik ve suçluluk hissi, motivasyon kaybı, isteksizlik, dikkat

dağınıklığı, iştah problemleri (azalma ya da artış), öfke, tükenmişlik hali ve yalnızlık gibi belirtiler dikkat çekmektedir (Tükel, 2020; Durmuş, 2021). Mevcut çalışma araştırmacı tarafından hazırlanan verimlilik puanlarının üzerine etkisini ölçme bakımından literatürdeki benzer çalışmalardan şu yönüyle ayrılmaktadır. Bu açıdan literatüre önemli katkıları olabilmektedir. Bu özden hareketle çalışmanın amacı Basketbol Sporcularının Covid-19 Kaygısının Performans Verimlilik Puan Düzeylerine Etkisini belirlemek amaçlanmıştır.

2. MATERYAL VE METOT

Bu çalışmada Covid-19 kaygısı ile sporcuların performans verim düzeyleri arasındaki ilişkinin belirlenmesi amaçlandığından, çalışma nicel araştırma desenlerinden ilişkisel tarama desenine göre yürütülmüştür. İki ya da daha fazla bağımsız değişken arasında bir ilişki olup olmadığını belirlemeyi arzulayan nicel araştırma yöntemlerinden deneysel olmayan bir desendir (Gürbüz ve Şahin, 2018). Bu araştırmanın evreni Türkiye'de aktif olarak faaliyet gösteren basketbol takımları olan: Nadir Gold İstanbul, Balıkesir Büyükşehir Belediyesi Baketbol, Merkezefendi Denzili Basketbol, Sigortam.net basketbol takımlardan oluşturmaktadır. Çalışmanın örneklemi %95 güven aralığı ve %5 hata payına göre hesaplanan, basit olasılık temelli örnekleme yöntemlerinden basit rastgele örneklem yöntemine göre belirlenmiş 62 basketbol sporcularından oluşmaktadır. Çalışmada (Biçer ve ark. 2020) tarafından geliştirilen Koronavirüs anksiyete ölçeği kısa formu kullanılmıştır. Ölçek toplamda 5 maddeden oluşan likert tipli bir ölçektir. Ayrıca araştırmacı tarafından geliştirilen verimlilik puanı tablosu kullanılmıştır. Covid-19 anksiyete ölçeğinin maddeler arasındaki güvenirlik katsayısı α= 80 olarak belirlenmiştir. Bu sonuç ölçeğin yüksek düzeyde güvenilir olduğunu göstermektedir.

3. BULGULAR

Tablo 1. Katılımcılara İlişkin Tanımlayıcı İstatistikler

Gruplar	Değişkenler	f	%
Takımlar	Akhisar Belediye Spor	12	19,4
	Balıkesir Büyük Şehir Belediye Spor	12	19.4
	Merkez Efendi Denizli Belediye Spor	12	19.4
	Nadir Gold İstanbul Basket	16	25.8
	Sigortam.Net Basketbol	10	16.1
Medeni Durum	Evli	14	22.6
	Bekar	48	77.4
Covid-19 Hastalık Durumu	Hastalığı Taşıyanlar	42	67.7
	Hastalığı Taşımayanlar	20	32.3
Spor Geçmişi	1-5 Yıl	19	30.6
	6-10 Yıl	22	35.5
	11-15 Yıl	21	33.9

Tablo 1'de görüldüğü gibi sporcuların %19.4'ü Akhisar Belediye Spor, Balıkesir Büyükşehir Belediye Spor, Merkez Efendi Denizli Belediye Spor, %25.8'i Nadir Gold İstanbul Basket, %16.1'i Sigortam.net, Sporcuların %22.6'sı evli, %77.4'ü bekarlardan, %67.7'si hastalık bulaşanlardan, %32.3'ü hastalık bulaşmayanlardan oluşurken, 30.6'sının spor geçmişi 1-5 yıl arasında, %38.5'i 6-10 yıl arasında, %33.9'u da 11-15 yıl arasında olan sporculardan oluşmaktadır.

Tablo 2. Verilere İlişkin Betimsel İstatistikler

Değişkenler	n	Minimum	Maximum	Ort.	sd
Verimlilik	62	.14	20.19	7.67	5.81
Covid 19 Anksiyete	62	5.00	24.00	10.12	5.24
Durumluk Kaygı	62	31.00	68.00	50.82	7.28

Tablo 2'de görüldüğü gibi katılımcılardan elde edilen veriler incelendiğinde Covid-19 anksiyete düşük düzeyde ($\bar{x}$=10.12), durumluk kaygı orta düzeyde ($\bar{x}$=50.82) olduğu belirlenmiştir.

Tablo 3. Covid-19 hastalığına yakanlanma kaygısı ile sporcuların medeni durum ve hastalığa yakalanma durumu arasındaki farklılık analizi

Değişkenler	Gruplar	n	Mean Rank	Sum of Ranks	U	p
Medeni Durum	Evli	14	28.75	402.50	297.500	.511
	Bekar	48	32.30	1550.50		
Hastalığa Yakanlanma Durumu	Yakalandım	42	32.00	1344.00	399.000	.749
	Yakalanmadım	20	30.45	609.00		
Yaş	21-25	33	35.23	1162.50	355.500	.79
	26-30	29	27.26	790.50		
Kilo	71-80	20	29.25	585.00	375.000	.403
	81-90	42	32.57	1368.00		

Tablo 2'de görüldüğü gibi covid-19 kaygısı ile sporcuların medeni durumları, hastalığa yakalanıp yakalanmama durumu, kilo ve yaş arasında istatistiksel açıdan bir farklılık belirlenmemiştir ($p>0.05$).

Tablo 4. Sporcuların Boy Ortalama Puanları ile Covid-19 Kaygı Değişkeni ile arasındaki farklılık analizi

Boy	n	Mean Rank	H	df	p	Farklılık Gruplar
181-190	26	40.13				
191-200	24	29.25	14.148	**2**	**.001****	1>2/1>3 2>3
200 ve üst	12	17.29				

Tablo 4'te görüldüğü gibi sporcuların boy ortalamaları ile covid-19 kaygı değişkeni arasında istatistiksel olarak %99 düzeyinde anlamlı bir farklılık belirlenmiştir. Gruplar arasındaki anlamlı farklılığın kaynağını analiz etmek amacıyla yapılan Mann Whitney U testinde boyu 181-190 olanlar ile 191-200 cm ve 200 cm ve üstü arasında, boyu 1.91-2.00 cm olanlar ile 1.81-1.90 cm ve 2.00 ve üstü arasında, 2.00 cm ve üstü boy uzun olan sporcular ile 1.81-1.90 ve 1.91-2.00 cm arasında istatistiksel olarak anlamlı bir farklılık belirlenmiştir.

Tablo 5. Sporcuların Spor Geçmişi Ortalama Puanları ile Covid-19 Kaygı Değişkeni ile arasındaki farklılık analizi

Spor Geçmişi	n		Ss	F	p
1-5 Yıl	19	9.84	6.40		
6-10 Yıl	22	9.81	4.03	.193	.825
11-15 Yıl	2115	10.71	5.41		

Tablo 4'te görüldüğü gibi sporcuların spor geçmişleri ile covid-19 kaygı değişkeni arasında istatistiksel olarak anlamlı bir farklılık belirlenmemiştir ($p>0.05$).

4. TARTIŞMA VE SONUÇLAR

Basketbol Sporcularının Covid-19 Kaygısının Performans Verimlilikleri üzerine Etkisini incelemeyi amaçladığımız mevcut çalışmada, sporcuların covid-19 anksiyeteleri düşük, durumluk kaygı düzeyleri ise orta düzeyde oldukları tespit edilmiştir (Tablo 2). Çalışmaya katılan sporcularda covid-19 anksiyetesi ile hastalığına yakalanma durumu, yaş, kilo, medeni durum arasında istatistiksel açıdan bir fark olmadığı tespit edilmiştir. Çalışmamızdan farklı olarak Kajtna & Vuckovic (2022) çalışmalarında covid-19 kaygısı ile medeni durum değişkeninde bekarların lehine anlamlı bir farklılık belirlemişlerdir. Yaş değişkeni ile ilgili bir başka çalışmada ise (Civan ve ark., 2010; Karabulut, 2019; Elce et al., 2022) fiziksel aktivite ve performans düzeyleri arasında istatistiksel açıdan anlamlı bir farklılık tespit etmişlerdir. Çalışmamızı destekler nitelikteki bir başka çalışmada ise (Kaplan, 2018; Yıldız, 2019) covid-19 katygısı ile sporcuların yaş değişkeni arasında anlamlı bir farklılık belirlememiştir. Covid 19 kaygısının basketbolcuların sportif verimlilik puanları üzerinde anlamlı bir etkisinin olmadığı mevcut çalışmada tespit edilmiştir. Ancak çalışmamızdan farklı olarak (Arslan ve ark., 2016; Kargün ve ark., 2016) çalışmasında yürüme, orta şiddet ve yüksek şiddetli fiziksel aktivite düzeyleri ile covid-19 kaygısı arasında anlamlı bir ilişki belirlemişlerdir. Bu sonuca göre sürekli ve durumluk kaygı da içeren covid-19 kaygısı sporcularda arttıkça sportif performanslarında zamana bağlı olarak belli oranda düşme tespit edilmiştir. Bu farklılığın sebebi farklı kategorilerden örneklemin toplanmış olabileceği düşünülmektedir. Mevcut çalışmada hastalığa yakalanma durumu ile covid-19 kaygısı arasında anlamlı bir farklılık bulunmamıştı. Çalışmamızdan farklı olarak (Yaman, 2022) çalışmasında covid-19 hastalığa yakalanma korkusu ile covid-19 kaygısı alt boyutlarından sosyal kaygı ile arasında anlamlı bir farklılık tespit etmiştir. Çalışmamız da covid-19 kaygısı ile sporcuların boy ortalamaları arasında anlamlı bir farklılık belirlenmiştir. Bu sonuca göre Boyu 1.80-1.90 cm arasında olan sporcuların kaygı düzeylerinin daha düşük olduğu belirlenmiştir. Literatür incelendiğinde çalışmamızı destekleyen ya da desteklemeyen çalışmalara rastlanılmamıştır. Sonuç olarak; Covid-19 kaygısının basketbol sporcuları üzerinde genel olarak etkisinin düşük olduğu dolaysıyla sporcuların bilişsel ya da sosyal kaygılarının sportif performanslarını olumsuz yönde etkileyecek herhangi bir bulguya rastlanılmamıştır. Gelecek çalışmalarda farklı spor dallarından da örneklem toplanarak araştırmalar yapılabilir.

Farklı spor dallarındaki sporcuların kaygı düzeylerinin ölçülmesi ve araştırmanın sonuçlarının literatüre katkı sağlayacağı düşünülmektedir.

Teşekkür
Verilerin toplanmasına yardımcı olan basketbol antrenörüne teşekkür ederim.

Etik Kurul Onayı
Etik kurul onayı alınmamıştır.

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KAYNAKLAR

Arslan, S. A., Daşkapan, A., & Çakır, B. (2016). Üniversite öğrencilerinin beslenme ve fiziksel aktivite alışkanlıklarının belirlenmesi. *TAF Preventive Medicine Bulletin*, *15*(3), 171-180.. https://doi: 10.5455/pmb.1-1436432564

Civan, A., Arı, R., Görücü, A., & Özdemir, M. (2010). Bireysel ve takım sporcularının müsabaka öncesi ve sonrası durumluk ve sürekli kaygı düzeylerinin karşılaştırılması. *Uluslararası İnsan Bilimleri Dergisi*, *7*(1), 193-206.

Doğan, A. (2022) Yetişkinlerde covid-19 kaynaklı psikolojik sıkıntı ile yeme arzusu ve sosyal medya bağımlılığı arasındaki ilişkinin incelenmesi. (Yüksek Lisans Tezi). Beykent Üniversitesi, Lisansüstü Eğitim Enstitüsü, İstanbul.

Durmuş, M., (2021) Covıd-19 pandemisinin psikolojik etkileri ve koruyucu davranışların değerlendirilmesi. (Yayımlanmamış Tıpta Uzmanlık Tezi) Bolu Abant İzzet Baysal Üniversitesi, Tıp Fakültesi Aile Hekimliği Anabilim Dalı, Bolu.

Elce, A., Daniele, A., Loperto, I., De Coppi, L., Sangiorgio, A., Vivona, A., ... & Nigro, E. (2022). COVID19 pandemisi ve fiziksel aktivite: Uyku kalitesi ve kaygı üzerine bir gözlemsel çalışma. *Spor* , *10* (3), 44.

Kajtna, T., & Vučković, V. (2022). Effect of decrease of physical activity on depression and anxiety after the COVID-19 lockdown: a survey study. *Frontiers in psychology*, *13*, 961798. https://doi.org/10.3389/fpsyg.2022.961798

Kargün, M., Togo, O. T., Biner, M., Pala, A. (2016). Üniversite Öğrencilerinin Fiziksel Aktivite Düzeylerinin İncelenmesi. Marmara Üniversitesi Spor Bilimleri Dergisi, 1(1), 61-72. https://doi.org/10.22396/sbd.2016.6

Karabulut, E. O., & Mavi-var, S. (2019). Taekwondocuların durumluk ve sürekli kaygılarının müsabaka performansı ve yaralanma durumu ile ilişkisi. *Türk Spor Bilimleri Dergisi*, *2*(1), 47-54.

Kaplan, H., & Şentürk, A. (2018). Yüzme Türkiye Şampiyonasına Katılan Bedensel Engelli Sporcuların Kaygı Düzeylerinin Araştırılması. *Onur Kurulu, 114*.

Mehrsafar, AH, Gazerani, P., Zadeh, AM ve Sánchez, JCJ (2020). COVID-19 pandemisinin elit sporcuların fiziksel ve ruhsal sağlığı üzerindeki potansiyel etkisinin ele alınması. *Beyin, davranış ve bağışıklık* , *87* , 147.

Reardon, C. L., Bindra, A., Blauwet, C., Budgett, R., Campriani, N., Currie, A., ... & Hainline, B. (2021). Mental health management of elite athletes during COVID-19: a narrative review and recommendations. *British journal of sports medicine*, *55*(11), 608-615. https://doi.org/10.1136/bjsports-2020-102884

Serin Yaman, S. (2022). Üniversite Öğrencilerinin Covid-19'a Yakalanma Kaygıları ve Sportif Aktivitelerde Bulunma Tercihleri Arasındaki İlişkinin İncelenmesi. Uluslararası Spor Bilimleri Öğrenci Çalışmaları, 4(2), 92-111.

Team, E. (2020). The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) — China, 2020. *China CDC Weekly*, *2*(8), 113.

Beyond The Brain: Glutamate Excitotoxicity And Its Systemic Effects

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Abstract: Glutamate, the principal excitatory neurotransmitter in the central nervous system (CNS), is vital for synaptic plasticity, learning, and memory. However, its over-accumulation in the synaptic cleft triggers a pathological cascade known as excitotoxicity, a primary mechanism of neuronal injury. This process, which begins with the excessive activation of glutamate receptors (particularly NMDA and AMPA types) and the subsequent intense calcium influx, has traditionally been approached from a neurocentric perspective and has been extensively studied as a fundamental factor contributing significantly to cell death in stroke, traumatic brain injury, and chronic neurodegenerative diseases.
This review, however, posits that the toxic potential of glutamate extends far beyond the confines of the blood-brain barrier, manifesting as a systemic phenomenon. Emerging evidence reveals the presence and functional significance of glutamate receptors and signaling pathways in a wide array of peripheral tissues. We synthesize the current understanding of how glutamate dysregulation impacts the entire organism. Beyond the CNS, glutamate overconsumption or dysregulation can induce toxicity in the gut, heart, and endocrine system, often through mechanisms involving oxidative stress, mitochondrial dysfunction, and inflammatory responses. Animal studies demonstrate dose-dependent organ damage, including histopathological changes and altered biochemical markers. The interplay between glutamate-induced excitotoxicity, oxidative stress, and inflammation underlies much of the observed systemic toxicity. Understanding these mechanisms is crucial for developing targeted interventions to mitigate glutamate-induced damage throughout the organism. A deeper understanding of these widespread effects could unlock novel, multi-system therapeutic strategies for a variety of acute and chronic conditions.

Keywords: Glutamate, CNS, toxicity, peripheral tissue.

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1. INTRODUCTION

Glutamate is one of the most important excitatory neurotransmitters in the central nervous system. Its role is vital to a vast array of physiological processes. At the synaptic level, the precise and transient release of glutamate and its subsequent binding to ionotropic (NMDA, AMPA, Kainate) and metabotropic receptors initiate the fast excitatory neurotransmission that underpins nearly all aspects of normal brain function. This signaling is critical for synaptic plasticity, the cellular mechanism for learning and memory, through processes like long-term potentiation (LTP) and long-term depression (LTD). Furthermore, glutamate plays an indispensable role in brain development, including neuronal differentiation, migration, and synapse formation. The physiological potency of glutamate necessitates a tightly regulated extracellular concentration, which is meticulously maintained at low levels by a family of high-affinity excitatory amino acid transporters (EAATs) located on both neurons and glial cells (1).

However, this essential molecule possesses a dark side. The failure of homeostatic mechanisms to control extracellular glutamate levels leads to a devastating pathological cascade known as excitotoxicity. This process is initiated by the excessive and prolonged activation of glutamate receptors, particularly the NMDA receptor subtype. This overstimulation results in a massive and uncontrolled influx of calcium (Ca^{2+}) into the neuron, triggering a series of downstream cytotoxic events. These include catastrophic mitochondrial dysfunction, leading to ATP depletion and energy failure; the overproduction of reactive oxygen and nitrogen species (ROS/RNS), causing severe oxidative stress; and the activation of Ca^{2+}-dependent degradative enzymes like proteases (e.g., calpains) and lipases, which dismantle cellular structures. This excitotoxic cascade is a well-documented final common pathway for neuronal death in a wide range of acute and chronic CNS disorders, including ischemic stroke, traumatic brain injury, epilepsy, and neurodegenerative diseases such as Amyotrophic Lateral Sclerosis (ALS), Huntington's disease, and Alzheimer's disease (2,3,4).

While the neurotoxic effects of glutamate are well-established, a growing body of evidence indicates that its toxic potential is not confined to the CNS. Glutamate receptors and signaling components are expressed throughout the body, and their dysregulation can incite pathology in peripheral organs and tissues. In the cardiovascular system, glutamate excitotoxicity contributes significantly to myocardial cell death following ischemia-reperfusion injury (5). In the endocrine system, chronic glutamate overexposure can induce apoptosis in pancreatic beta-cells, potentially contributing to the pathogenesis of diabetes (6). Emerging research has revealed that glutamate can directly modulate the function of immune cells, such as T-lymphocytes, and is implicated in both neuroinflammation and systemic inflammatory conditions (7). The common mechanistic threads of Ca^{2+} overload, mitochondrial stress, and oxidative damage are conserved in these peripheral tissues, suggesting that excitotoxicity should be viewed not merely as a neurological event, but as a systemic vulnerability with far-reaching implications for organism-wide health and disease.

2. THE MOLECULAR MACHINERY of GLUTAMATE EXCITOTOXICITY

The transition of glutamate from an essential signaling molecule to a potent neurotoxin is orchestrated by a well-defined, yet complex, series of molecular events. This cascade is initiated by the failure of homeostatic mechanisms to clear glutamate from the synaptic space, leading to the sustained, pathological activation of its receptors. The ensuing cellular dysfunction is not a single event but a multi-stage process involving ionic imbalance, energy failure, oxidative stress, and the activation of catabolic enzymes, ultimately converging on cell death.

2.1. Glutamate receptor subtypes: the gates to toxicity

While all ionotropic glutamate receptors (iGluRs) contribute to excitation, they are not equally responsible for excitotoxicity. The primary mediators are the N-methyl-D-aspartate receptors (NMDARs) and, to a lesser extent, specific subtypes of α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptors (AMPARs). NMDARs are uniquely suited to act as triggers for excitotoxicity due to their high permeability to calcium (Ca^{2+}) and their slow gating kinetics, which results in prolonged channel opening. Under normal conditions, the NMDAR channel is blocked by a magnesium ion (Mg^{2+}) in a voltage-dependent manner. However, during pathological states involving sustained depolarization often driven by AMPA receptor activation—this Mg^{2+} block is relieved, allowing for a massive and sustained influx of Ca^{2+} upon glutamate binding (2). Furthermore, certain AMPARs that lack the GluA2 subunit are also permeable to Ca^{2+} and can contribute significantly to the initial stages of the excitotoxic cascade, particularly in ischemic conditions (8).

2.2. The central role of calcium overload

The cornerstone of glutamate excitotoxicity is a profound and sustained elevation of intracellular Ca^{2+} concentration, a state known as calcium dyshomeostasis or overload. Under physiological conditions, Ca^{2+} levels are tightly regulated by a sophisticated system of pumps (e.g., PMCA, SERCA) and exchangers (e.g., NCX) that rapidly sequester or extrude Ca^{2+} from the cytoplasm. during excitotoxicity, the continuous influx of Ca^{2+} through NMDARs and Ca^{2+}-permeable AMPARs overwhelms these homeostatic systems. This situation is catastrophically worsened by the concurrent energy failure (ATP depletion), which cripples the ATP-dependent pumps, effectively trapping Ca^{2+} inside the cell and leading to concentrations that are orders of magnitude above the physiological norm (9).

2.3. Downstream pathological cascades

Once inside the cell, Ca^{2+} overload unleashes a torrent of self-propagating destructive pathways, are.

Mitochondrial Dysfunction and the Energy Crisis: Mitochondria act as crucial Ca^{2+} buffers, but they do so at a great cost. Excessive Ca^{2+} uptake into the mitochondrial matrix triggers the opening of the mitochondrial permeability transition pore (mPTP). This event dissipates the inner mitochondrial membrane potential, uncouples oxidative phosphorylation, and halts ATP synthesis, plunging the neuron into an irreversible energy crisis. Critically, mPTP opening also leads to the release of pro-apoptotic factors, most notably cytochrome C, into the cytoplasm, directly linking excitotoxicity to the intrinsic pathway of programmed cell death (10).

Oxidative and Nitrosative Stress: Calcium overload activates a host of enzymes that generate free radicals. The Ca^{2+}-dependent activation of neuronal nitric oxide synthase (nNOS) produces excess nitric oxide (NO). Simultaneously, dysfunctional mitochondria become a major source of superoxide anion (O_2^-). The rapid reaction between NO and O_2^- forms peroxynitrite ($ONOO^-$), a highly potent and destructive oxidant that causes widespread damage to DNA, proteins, and lipids, further crippling cellular function (2,9).

Activation of Proteases and Lipases: Pathological levels of intracellular Ca^{2+} activate degradative enzymes. Calcium-dependent proteases, such as calpains, cleave critical cytoskeletal proteins (e.g., spectrin) and other substrates, leading to the breakdown of cellular architecture. Similarly, phospholipases are activated, degrading membrane lipids, which compromises membrane integrity and can lead to the production of pro-inflammatory mediators (11).

Intrinsic and Extrinsic Apoptotic Pathways: The release of cytochrome c from mitochondria serves as a key activation signal for the intrinsic apoptotic pathway, leading to the formation of the apoptosome and the activation of caspase-9 and the executioner caspase-3. This commits the neuron to a programmed death. While the intrinsic pathway is the primary route, crosstalk with extrinsic (death receptor-mediated) pathways can also occur, amplifying the cell death signal (9).

2.4. The critical role of glial cells and glutamate transporters

Excited astrocytes often secrete diverse substances (generally referred to as gliosignalling molecules) that include classical neurotransmitters such as ATP and glutamate or neuromodulators such as d-serine or neuropeptides. Under healthy conditions, astrocytes are the primary guardians against excitotoxicity. They express high levels of glutamate

transporters EAAT1 (GLAST) and EAAT2 (GLT-1), which are responsible for rapidly clearing over 90% of glutamate from the synaptic cleft. However, in pathological states like ischemia, the energy failure leads to the collapse of the Na^+/K^+-ATPase pump and the dissipation of the transmembrane sodium gradient. This not only impairs the function of the EAATs but can cause them to operate in reverse, releasing glutamate from astrocytes back into the extracellular space and catastrophically exacerbating the excitotoxic condition (12). Thus, glial dysfunction is not merely a consequence but a critical driver of the molecular machinery of excitotoxicity.

3. THE CENTRAL NERVOUS SYSTEM: the CLASSIC EPICENTER of EXCITOTOXICITY

The central nervous system, with its high metabolic rate and dense network of glutamatergic synapses, is uniquely vulnerable to excitotoxic injury. It was within the CNS that the concept of excitotoxicity was first described, and it remains the most extensively studied domain for this pathological process. Excitotoxicity is not a singular disease but rather a fundamental mechanism of neuronal damage that serves as a final common pathway in a wide spectrum of neurological disorders, from acute insults to chronic, progressive degeneration.

3.1. Acute brain injury: ischemic stroke and traumatic brain injury (TBI)

In acute ischemic stroke, the interruption of blood flow deprives neurons of oxygen and glucose, leading to a rapid depletion of ATP. This energy failure cripples the Na^+/K^+-ATPase pump, causing widespread membrane depolarization. This depolarization relieves the Mg^{2+} block on NMDARs and triggers a massive, uncontrolled release of glutamate from presynaptic terminals (2). Traumatic brain injury (TBI) is the major cause of death and disability, and the incidence of TBI continues to increase rapidly. The initial mechanical impact causes immediate cell lysis and membrane damage, releasing vast quantities of glutamate into the extracellular space. This primary insult initiates a secondary wave of injury in adjacent, initially unharmed tissue, where excitotoxicity, neuroinflammation, and oxidative stress propagate damage for hours to days following the trauma, significantly worsening the clinical outcome (13).

3.2. Chronic neurodegeneration: the "slow excitotoxicity" hypothesis

Unlike the rapid cascade in acute injury, many chronic neurodegenerative diseases are characterized by a "slow excitotoxicity." It is caused by a slow but persistent increase in extracellular glutamate or by increased sensitivity of neurons to glutamatergic stimulation. Over months or years, it leads to gradual neuronal dysfunction and death. For explain

Amyotrophic Lateral Sclerosis (ALS): One of the clearest examples of excitotoxicity in neurodegeneration is ALS. A significant portion of ALS cases involves the dysfunction or downregulation of the primary glial glutamate transporter, EAAT2 (also known as GLT-1), leading to impaired glutamate clearance at the synapse. The resulting chronic hyperexcitability is believed to be a key contributor to the selective death of motor neurons (14).

Huntington's and Parkinson's Disease: In Huntington's disease, the mutant huntingtin protein renders striatal neurons, particularly those rich in NMDARs, hypersensitive to glutamate-mediated toxicity. This selective vulnerability is a cornerstone of the disease's pathogenesis. In Parkinson's disease, while the primary pathology is the loss of dopaminergic neurons, evidence suggests that mitochondrial dysfunction in these neurons lowers their threshold for excitotoxic damage, making them more susceptible to glutamatergic insults from corticostriatal pathways (15).

Alzheimer's Disease: Excitotoxicity plays a critical role in the progression of Alzheimer's disease. Soluble amyloid-beta (Aβ) oligomers, key pathological agents in AD, have been shown to disrupt glutamate homeostasis by inhibiting EAAT function and enhancing presynaptic glutamate release. Furthermore, Aβ can directly interact with synaptic NMDARs, leading to dysregulated calcium influx, synaptic depression, and ultimately, neuronal loss. This process is a major contributor to the synaptic failure and cognitive decline that define the disease (16).

3.3. Epilepsy and seizure-induced brain damage

Seizures represent periods of intense, synchronized, and pathological high-frequency neuronal firing. This massive glutamatergic discharge is an excitotoxic event. Prolonged or repeated seizures (status epilepticus) can cause selective neuronal death, particularly in vulnerable regions like the hippocampus. This cell loss, especially of inhibitory interneurons, can disrupt circuit balance and contribute to the development of a chronic epileptic state (epileptogenesis), creating a vicious cycle where excitotoxicity both results from and promotes seizure activity (17).

4. SYSTEMIC MANIFESTATIONS of GLUTAMATE TOXICITY

While the CNS is the most exquisitely sensitive and well-studied site of excitotoxic damage, the molecular components of glutamate signalling are not exclusive to the brain. Functional glutamate receptors, transporters, and metabolic enzymes are expressed in a wide array of peripheral tissues. Consequently, conditions that lead to systemic or localized glutamate

dysregulation can precipitate a cascade of toxic events throughout the organism, mirroring the pathological mechanisms first identified in neurons. This section explores the evidence for glutamate-mediated toxicity in key non-neuronal systems.

4.1. The peripheral nervous system (PNS)

The PNS is a natural extension of the excitotoxicity concept beyond the brain and spinal cord. Glutamate is the primary neurotransmitter for fast excitatory signalling from primary afferent fibers that transmit sensory information, including pain. In pathological states, particularly neuropathic pain, excessive glutamate release in the spinal cord dorsal horn and hyperexcitability of sensory neurons in the dorsal root ganglia (DRG) are key events. The over-activation of NMDARs and AMPARs on these neurons leads to a state of central sensitization, where pain signaling is amplified and maintained. This excitotoxic process underpins the transition from acute to chronic pain and is a major therapeutic target (18).

4.2. The Cardiovascular System

The heart and vasculature express functional NMDARs and AMPARs, implicating glutamate signalling in both cardiac physiology and pathology. The most significant manifestation of glutamate toxicity in this system occurs during myocardial ischemia-reperfusion (I/R) injury. Like an ischemic stroke, oxygen deprivation during a myocardial infarction leads to cellular ATP depletion and massive glutamate release from cardiac nerve endings and potentially cardiomyocytes themselves. This triggers Ca^{2+} overload and subsequent mitochondrial dysfunction, oxidative stress, and apoptosis, contributing significantly to the extent of cardiac muscle damage. Targeting these glutamatergic pathways has emerged as a novel therapeutic strategy for cardio protection (19).

4.3. The endocrine system and metabolism

Glutamate acts as a crucial signaling molecule within the endocrine pancreas, regulating insulin and glucagon secretion. Pancreatic β-cells express glutamate receptors and can co-release glutamate with insulin. However, under conditions of metabolic stress or chronic overstimulation, this system can become pathogenic. Prolonged exposure to high glutamate levels induces β-cell apoptosis via the classic excitotoxic mechanisms of Ca^{2+} dyshomeostasis and mitochondrial stress. This suggests that localized glutamate excitotoxicity within the islet could be a contributing factor to the loss of β-cell mass and the progression of type 2 diabetes (20,21). Furthermore, glutamate is a key regulator of the hypothalamic-pituitary-adrenal (HPA) axis, and its dysregulation is linked to chronic stress pathologies.

4.4. The gastrointestinal system

The enteric nervous system (ENS), often termed "the second brain," contains a complex network of glutamatergic neurons that regulate gut motility, secretion, and blood flow. Excitotoxic insults within the ENS are implicated in motility disorders and visceral hypersensitivity, a key feature of irritable bowel syndrome (IBS). Moreover, systemic glutamate can influence the integrity of the intestinal epithelial barrier. Studies have shown that glutamate dysregulation can disrupt tight junction proteins, leading to increased intestinal permeability ("leaky gut"). This allows luminal antigens and bacteria to enter circulation, potentially driving systemic inflammation and linking gut health to central and peripheral disorders (22).

4.5. The immune system and inflammation

The interface between the nervous and immune systems is profoundly modulated by glutamate. Beyond its role in driving neuroinflammation via microglial activation in the CNS, glutamate directly impacts peripheral immune cells. Lymphocytes, macrophages, and dendritic cells express a range of glutamate receptors. Pathologically high levels of glutamate can dysregulate immune function, for instance, by promoting T-cell activation and proliferation or by inducing apoptosis in certain immune cell populations. This "immunoexcitotoxicity" suggests that systemic conditions associated with high glutamate levels (e.g., severe trauma, sepsis) could lead to a dysregulated immune response, contributing to multi-organ dysfunction (23).

5. THERAPEUTIC STRATEGIES: TARGETING A SYSTEMIC PROBLEM

The widespread and fundamental nature of glutamatergic signalling presents a significant therapeutic paradox: while excitotoxicity is a clear pathological target, the very strategies designed to inhibit it risk disrupting essential physiological processes. The history of developing anti-excitotoxic therapies is a story of moving from broad, direct antagonism to more nuanced, multi-target, and systemic approaches. More detailed studies on organ tissue systems are required for glutamate toxicity to be accepted as a systemic problem.

5.1. The rise and fall of nmda receptor antagonists: a lesson in translation

The initial and most direct strategy for combating excitotoxicity was the development of drugs that directly block the NMDA receptor. In preclinical models of stroke and TBI, non-competitive antagonists like dizocilpine (MK-801) showed remarkable neuroprotective efficacy. The primary reasons for this translational failure were twofold: first, the therapeutic window was extremely narrow, as treatment needed to be initiated almost immediately after the insult; second, and more critically, these antagonists produced severe and intolerable side effects, including psychosis, hallucinations, and memory impairment. This outcome underscored a crucial lesson: globally blocking NMDARs also blocks their vital roles in normal synaptic transmission and plasticity, making such a strategy clinically untenable (2). Memantine, a lower-affinity, uncompetitive NMDAR antagonist, represents a more successful, albeit modest, modification of this approach, primarily used in Alzheimer's disease to dampen tonic pathological activation without severely impairing physiological signalling (24).

5.2. Novel CNS-targeted approaches: targeting downstream pathways

Learning from the failure of direct receptor blockade, research shifted towards more refined strategies targeting the specific downstream molecular events that are unequivocally pathological. This approach aims to leave physiological receptor function intact while intervening in the toxic cascade. Key targets include:

- **Mitochondrial Stabilizers:** Drugs that prevent the opening of the mitochondrial permeability transition pore (mPTP) or that scavenge mitochondrial-specific reactive oxygen species can preserve energy production and prevent the release of apoptotic factors.

- **Calcium Signaling Modulators:** Rather than a full blockade, strategies aim to modulate specific calcium channels or enhance intracellular calcium buffering capacity.

- **Antioxidants and Free Radical Scavengers:** Developing compounds that can effectively cross the blood-brain barrier to neutralize peroxynitrite and other damaging free radicals remains a major area of focus.

- **Inhibitors of Apoptotic Pathways:** Targeting key enzymes in the cell death cascade, such as caspases and calpains, represents another promising avenue to salvage neurons following an excitotoxic insult (25).

5.3. The potential for systemic and multi-target therapies

Given that glutamate toxicity manifests in multiple organ systems (e.g., heart, pancreas, immune cells), therapies with systemic or pleiotropic (multi-target) effects hold promise. A drug that protects the brain from an ischemic insult while also protecting the heart from reperfusion injury would be immensely valuable. Statins are a prime example of this concept; beyond their lipid-lowering effects, they exert potent anti-inflammatory, antioxidant, and endothelial-stabilizing effects that can mitigate excitotoxic damage in both central and peripheral tissues (26). This highlights the importance of developing agents that not only target a single molecule but also modulate broader pathological mechanisms.

5.4. Modulating glutamate homeostasis: diet, exercise, and phytochemicals

An emerging and highly promising frontier involves non-pharmacological and integrative strategies that bolster the body's natural resilience against excitotoxicity. These approaches often work by optimizing energy metabolism and enhancing endogenous defence mechanisms.

- **Ketogenic Diet:** By shifting brain metabolism from glucose to ketone bodies, the ketogenic diet provides an alternative fuel source that can bypass glycolytic impairments during an energy crisis. Ketones have also been shown to have direct neuroprotective effects by reducing oxidative stress and enhancing mitochondrial function (27).

- **Physical Exercise:** Regular exercise is a powerful modulator of brain health. It increases the expression of neurotrophic factors like Brain-Derived Neurotrophic Factor (BDNF), which enhances synaptic plasticity and neuronal resilience. It also upregulates endogenous antioxidant systems and improves cerebral blood flow, collectively increasing the threshold for excitotoxic damage (28).

- **Phytochemicals:** Many plant-derived compounds, such as curcumin (from turmeric) and resveratrol (from grapes), are potent antioxidants and anti-inflammatory agents with pleiotropic effects. Their ability to modulate multiple downstream pathways of excitotoxicity simultaneously makes them attractive candidates for both prevention and adjunct therapy (29).

6. CONCLUSION and FUTURE DIRECTIONS

The evidence synthesized in this review compels a paradigm shift in our understanding of glutamate excitotoxicity. For decades, it has been viewed through a predominantly neurocentric lens, a pathological process largely confined to the central nervous system. We have argued that this perspective is incomplete. The widespread expression of glutamate signalling machinery throughout the body, coupled with the conservation of its downstream toxic cascades—calcium dyshomeostasis, mitochondrial stress, and oxidative damage—in peripheral tissues, solidifies the concept of excitotoxicity as a systemic phenomenon. From the heart to the pancreas, and from the gut to the immune system, the dysregulation of this fundamental signalling pathway can initiate or exacerbate organ-specific pathology. Recognizing this systemic vulnerability is the first step toward developing more holistic and effective diagnostic and therapeutic strategies for a multitude of human diseases.

Despite this progress, significant knowledge gaps remain, presenting fertile ground for future investigation.

- **Firstly, the tissue-specific nuances of the excitotoxic cascade are poorly understood.** While the core mechanisms appear conserved, it is unlikely they are identical. Do different cell types, such as a cardiomyocyte versus a pancreatic β-cell, possess unique vulnerabilities or compensatory mechanisms that alter their response to a glutamatergic insult? Understanding these cell-specific differences is critical for developing targeted therapies (30).

- **Secondly, the nature of inter-organ crosstalk mediated by glutamate dysregulation requires clarification.** The gut-brain-immune axis is a particularly compelling area of inquiry. How does glutamate-induced intestinal hyperpermeability contribute to the neuroinflammatory state seen in chronic neurodegeneration? Elucidating these complex feedback loops will be essential (31).

- **Thirdly, the development of reliable systemic biomarkers of excitotoxicity is a major clinical challenge.** If glutamate-mediated damage is occurring simultaneously in multiple organs, can we identify circulating markers (e.g., specific microRNAs, metabolic byproducts, or protein fragments) that reflect this total "excitotoxic load"? Such a biomarker would be invaluable for patient stratification and monitoring therapeutic efficacy (32).

To address these questions, future research should proceed along several parallel fronts aspects

- **At the preclinical level,** the use of tissue-specific knockout models for glutamate receptor subunits and transporters is essential to dissect their precise physiological and pathological roles in peripheral organs, independent of central effects. Advanced imaging techniques capable of monitoring real-time calcium dynamics and mitochondrial health in peripheral tissues will also be instrumental.

- **Clinically,** there is a pressing need for longitudinal cohort studies. For example, tracking patients with chronic conditions known to involve peripheral glutamate dysregulation (e.g., inflammatory bowel disease, type 2 diabetes) for the emergence of CNS or cardiovascular complications could provide crucial human data on systemic crosstalk.

- **Therapeutically,** the focus must continue to shift away from broad receptor antagonists and towards pleiotropic agents that can modulate the broader pathological environment. Investigating the systemic, multi-organ protective effects of interventions like physical exercise, ketogenic diets, and phytochemicals (e.g., curcumin, resveratrol) that bolster endogenous antioxidant and anti-inflammatory defences represents a particularly promising avenue (28,33).

In conclusion, recognizing glutamate excitotoxicity as a systemic problem requires a new perspective that transcends traditional disciplinary boundaries. A deeper and more comprehensive understanding of how this fundamental signalling pathway affects the entire organism has the potential to pave the way for new treatment strategies that target mechanisms that are not organ-specific, but rather systemic in nature.

REFERENCES

1. Poole-Wilson PA, Langer GA. Effect of pH on ionic exchange and function in rat and rabbit myocardium. Am J Physiol. Eylül 1975;229(3):570-81.
2. Lai TW, Zhang S, Wang YT. Excitotoxicity and stroke: Identifying novel targets for neuroprotection. Prog Neurobiol. Nisan 2014;115:157-88.
3. Lewerenz J, Maher P. Chronic Glutamate Toxicity in Neurodegenerative Diseases—What is the Evidence? Front Neurosci [İnternet]. 16 Aralık 2015 [a.yer 10 Ağustos 2025];9. Erişim adresi: http://journal.frontiersin.org/Article/10.3389/fnins.2015.00469/abstract
4. Neves D, Salazar IL, Almeida RD, Silva RM. Molecular mechanisms of ischemia and glutamate excitotoxicity. Life Sci. Eylül 2023;328:121814.

5. Ehrhart IC, Parker PE, Weidner WJ, Dabney JM, Scott JB, Haddy FJ. Coronary vascular and myocardial responses to carotid body stimulation in the dog. Am J Physiol. Eylül 1975;229(3):754-60.
6. Otter S, Lammert E. Exciting Times for Pancreatic Islets: Glutamate Signaling in Endocrine Cells. Trends Endocrinol Metab. Mart 2016;27(3):177-88.
7. Pacheco R, Gallart T, Lluis C, Franco R. Role of glutamate on T-cell mediated immunity. J Neuroimmunol. Nisan 2007;185(1-2):9-19.
8. Cull-Candy S, Kelly L, Farrant M. Regulation of Ca2+-permeable AMPA receptors: synaptic plasticity and beyond. Curr Opin Neurobiol. Haziran 2006;16(3):288-97.
9. Fricker M, Tolkovsky AM, Borutaite V, Coleman M, Brown GC. Neuronal Cell Death. Physiol Rev. 01 Nisan 2018;98(2):813-80.
10. Wang C, Youle RJ. The Role of Mitochondria in Apoptosis. Annu Rev Genet. 01 Aralık 2009;43(1):95-118.
11. Czogalla A, Sikorski AF. Spectrin and calpain: a 'target' and a 'sniper' in the pathology of neuronal cells. Cell Mol Life Sci. Eylül 2005;62(17):1913-24.
12. Zorec R, Parpura V, Verkhratsky A. Astroglial Vesicular Trafficking in Neurodegenerative Diseases. Neurochem Res. Mart 2017;42(3):905-17.
13. Luo P, Fei F, Zhang L, Qu Y, Fei Z. The role of glutamate receptors in traumatic brain injury: Implications for postsynaptic density in pathophysiology. Brain Res Bull. Temmuz 2011;85(6):313-20.
14. Fontana ACK. Current approaches to enhance glutamate transporter function and expression. J Neurochem. Eylül 2015;134(6):982-1007.
15. Iovino L, Tremblay ME, Civiero L. Glutamate-induced excitotoxicity in Parkinson's disease: The role of glial cells. J Pharmacol Sci. Kasım 2020;144(3):151-64.
16. Revett, T, Baker G, Jhamandas J, Kar S. Glutamate system, amyloid β peptides and tau protein: functional interrelationships and relevance to Alzheimer disease pathology. J Psychiatry Neurosci. 01 Ocak 2013;38(1):6-23.
17. Lach P, Klus W, Zajdel K, Szeleszczuk A, Komorowska E, Burda K, vd. Neuroinflammation in Epilepsy—Diagnostics and Therapeutic Perspectives. Curr Pharmacol Rep. Şubat 2022;8(1):31-5.
18. Liang Z, Li L, Bai L, Gao Y, Qiao Y, Wang X, vd. Spinal nerve transection-induced upregulation of SAP97 via promoting membrane trafficking of GluA1-containing AMPA receptors in the dorsal horn contributes to the pathogenesis of neuropathic pain. Neurobiol Dis. Mayıs 2024;194:106471.
19. Soda T, Brunetti V, Berra-Romani R, Moccia F. The Emerging Role of N-Methyl-D-Aspartate (NMDA) Receptors in the Cardiovascular System: Physiological Implications, Pathological Consequences, and Therapeutic Perspectives. Int J Mol Sci. 15 Şubat 2023;24(4):3914.
20. Duchen MR. Roles of Mitochondria in Health and Disease. Diabetes. 01 Şubat 2004;53(suppl_1):S96-102.
21. Otter S, Lammert E. Exciting Times for Pancreatic Islets: Glutamate Signaling in Endocrine Cells. Trends Endocrinol Metab. Mart 2016;27(3):177-88.
22. Gruenbaum BF, Merchant KS, Zlotnik A, Boyko M. Gut Microbiome Modulation of Glutamate Dynamics: Implications for Brain Health and Neurotoxicity. Nutrients. 22 Aralık 2024;16(24):4405.
23. Ganor Y, Levite M. The neurotransmitter glutamate and human T cells: glutamate receptors and glutamate-induced direct and potent effects on normal human T cells, cancerous human leukemia and lymphoma T cells, and autoimmune human T cells. J Neural Transm. Ağustos 2014;121(8):983-1006.
24. Folch J, Busquets O, Ettcheto M, Sánchez-López E, Castro-Torres RD, Verdaguer E, vd. Memantine for the Treatment of Dementia: A Review on its Current and Future Applications. J Alzheimer's Dis. 13 Mart 2018;62(3):1223-40.
25. Momeni HR. Role of calpain in apoptosis. Cell J. 2011;13(2):65-72.
26. Sirtori CR. The pharmacology of statins. Pharmacol Res. Ekim 2014;88:3-11.
27. López-Ojeda W, Hurley RA. Ketone Bodies and Brain Metabolism: New Insights and Perspectives for Neurological Diseases. J Neuropsychiatry Clin Neurosci. Nisan 2023;35(2):104-9.
28. De La Rosa A, Olaso-Gonzalez G, Arc-Chagnaud C, Millan F, Salvador-Pascual A, García-Lucerga C, vd. Physical exercise in the prevention and treatment of Alzheimer's disease. J Sport Health Sci. Eylül 2020;9(5):394-404.
29. Shoaib S, Ansari MA, Fatease AA, Safhi AY, Hani U, Jahan R, vd. Plant-Derived Bioactive Compounds in the Management of Neurodegenerative Disorders: Challenges, Future Directions and Molecular Mechanisms Involved in Neuroprotection. Pharmaceutics. 23 Şubat 2023;15(3):749.
30. Kunzelmann K. Ion channels in regulated cell death. Cell Mol Life Sci. Haziran 2016;73(11-12):2387-403.
31. Cryan JF, O'Riordan KJ, Cowan CSM, Sandhu KV, Bastiaanssen TFS, Boehme M, vd. The Microbiota-Gut-Brain Axis. Physiol Rev. 01 Ekim 2019;99(4):1877-2013.
32. Cao Y, Xu Y, Cao M, Chen N, Zeng Q, Lai MKP, vd. Fluid-based biomarkers for neurodegenerative diseases. Ageing Res Rev. Haziran 2025;108:102739.
33. Akbari M, Tamtaji OR, Lankarani KB, Tabrizi R, Dadgostar E, Haghighat N, vd. The effects of resveratrol on lipid profiles and liver enzymes in patients with metabolic syndrome and related disorders: a systematic review and meta-analysis of randomized controlled trials. Lipids Health Dis. Aralık 2020;19(1):25.

Lung stress in a wired world: the role of astaxanthin in preventing the toxic effects of a 50 hz electric field

MUSTAFA SAYGIN

Abstract: Objective: Our study aimed to observe the damage caused by electric fields on the lungs and to investigate the effect of astaxanthin, a powerful antioxidant. Thirty female Wistar-Albino rats (350-500 g) aged 11-12 months were used in the study. The rats were randomly divided into three groups of 10 rats each. In the control (K) group, ad libitum feeding and cage cleaning were performed for 30 days. Daily 7-9 cc of olive oil was administered via gavage in proportion to their weight. The electric field group (EA) was exposed to a 50 Hz electric field between parallel plates for 23 hours a day. They were administered 7-9 cc of olive oil per day via gavage, proportional to their weight. The EA+Astaxanthin group was exposed to a 50 Hz electric field for 23 hours per day. They were administered 7-9 cc of astaxanthin per day via gavage, proportional to their weight. One hour was allocated for daily cage cleaning and animal care. After 30 days, the rats were sacrificed to obtain tissue samples. Lung tissue was homogenised, and malondialdehyde (MDA), catalase (KAT), and superoxide dismutase (SOD) enzyme activities were measured. When oxidative stress parameters were evaluated in lung tissue, MDA increased statistically significantly in the EM group compared to the control group ($p=0.001$), CAT decreased ($p=0.001$), and SOD decreased but was not statistically significant ($p>0.005$). Compared to the EA group, MDA decreased significantly in the EA+ Astaxanthin group ($p=0.025$), CAT increased ($p=0.033$), and SOD increased but was not statistically significant ($p>0.005$). EA, to which we are constantly exposed in daily life, causes oxidative stress in lung tissue. Astaxanthin plays a protective role in lung tissue against this stress. This antioxidant, which is more potent than vitamin C, is recommended for prophylactic use against lung damage during the COVID-19 pandemic.

Keywords: Electric field, lung tissue, oxidative stress, astaxanthin

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1. INTRODUCTION

With the development of technology, the use of electromagnetic energy has increased rapidly. As a result, people are constantly exposed to electric and magnetic fields of varying duration, intensity and direction. Numerous studies are being conducted to investigate the effects of electric and magnetic fields on health, and the number of such studies is increasing day by day (1). With the advancement of technology today, people's exposure to magnetic and electric fields has increased. Prolonged exposure to magnetic and electric fields disrupts the physiological electrical currents of cells, causing heat increase and oxidative stress (2). Oxidative stress occurs when reactive oxygen species accumulate in cells (3). These radicals interact with proteins and lipids within the cell, disrupting their structure and activity. The disruption of the structure of lipids and proteins in the cell causes the disruption of many metabolic functions in the cell (4). Astaxanthin is a red-orange pigment found mainly in shellfish (crabs, shrimp, lobsters, salmon, trout) (5). Astaxanthin protects cell membranes and tissues against lipid peroxidation and oxidative stress. It is the most powerful and safest antioxidant known in nature. Its antioxidant activity has been found to be 550 times stronger than vitamin E, 6,000 times stronger than vitamin C, 800 times stronger than Coenzyme Q10, 4 times stronger than lutein, and 10 times stronger than carotene (6). This study aimed to investigate the role of astaxanthin in oxidative stress in lung tissue caused by EA, to which we are constantly exposed in our daily lives.

2. MATERIALS AND METHODS

2.1. Study group

The study was approved by the Local Ethics Committee for Animal Experiments at Burdur Mehmet Akif Ersoy University (Ethics No: 377, 19.07.2018). Thirty female Wistar-Albino rats (350-500 g) aged 11-12 months were used in the study. The animals were kept under standard conditions (temperature: 22±3°C, humidity: 55-60%, and 12 hours of light/12 hours of darkness). The animals were kept in plastic cages without any restrictions. All rats were fed standard feed (Korkuteli feed) and tap water. After a one-week adaptation period, 10 rats were randomly assigned to form three groups. The groups were formed as follows: Control group (C, n:10), Electric Field (EF, n:10), and Electric Field+Astaxanthin (EF+ASX, n:10).

In group C; *ad libitum* feeding and cage cleaning were performed for 30 days. Daily 7-9 cc of olive oil was administered via gavage in proportion to their weight.

Group EF; was exposed to an electric field (50 Hz) between parallel plates for 23 hours a day for 30 days. They were given 7-9 cc of olive oil per day via gavage, proportional to their weight.

In the EF+ASX group; the animals were exposed to an electric field (50 Hz) for 23 hours per day for 30 days, and 1 hour was allocated for daily cage cleaning and animal care. The dosage was adjusted according to their weight. Rats weighing 150-200 g were administered 7 cc, rats weighing 200-250 g were administered 8 cc, and rats weighing 250-300 g were administered 9 cc of Astaxanthin (100 mg/kg) dissolved in olive oil via gavage.

After 30 days, the rats were sacrificed to obtain tissue samples. Lung tissue was removed and stored at -80°C for oxidant/antioxidant analysis. The stored tissues were then homogenised, and malondialdehyde (MDA), catalase (CAT), and superoxide dismutase (SOD) enzymes were analysed.

2.2. Electric field device

The EA device used was designed with the assistance and supervision of the Department of Electronics and Communications Engineering, Faculty of Engineering, Süleyman Demirel University (SDU). The area of the plates was selected as 0.5 m^2 (0.5x1.0m) for the comfortable positioning of the cages. The homogeneity of the area between the plates was tested theoretically and experimentally (7). The EA density value was calculated according to the equation E= V/d. In this equation, d represents distance, V represents the electrical potential difference between the plates, and E represents the EA density in volts per metre. The characteristics of the cages (for 30 animals) to be used in this system are as follows:

1. The cage has a volume of 40x50x20 cm^3 (w x l x h) and is made of plastic. It is positioned so as not to obstruct EA.
2. Stainless chrome-nickel sheet metal is used in the construction of the plates to ensure good conductivity. The corners of the plates are rounded to prevent electromagnetic corner effects.

In the exposure system, a transformer with a rating of 220 Vrms/6500 Vrms and 1000 VA was selected. The plates were placed at intervals of 65 cm. In our study, since no current was drawn from the source, the active field was the electric field rather than the magnetic field, and it was easily visualised. Due to the possibility that the conductive materials within the EA could alter the EA vector intensity and direction, the cages were cleaned daily.

Using the equation (E= V/d), the average electric current density between the plates was calculated to be 6500 V/0.65 m=10,000 V/m (10 kV/m) in the EA group. For the power transformer's input voltage range of 219-229 Vrms, the output is 62506550 Vrms and the average field intensity is in the range of 9951-1045 V/m. The unwanted high-frequency fields in the room where the experimental setup was installed were measured using the HI-3804 Electromagnetic Field Survey Meter-Industrial Compliance meter and its probe (Holaday Industries, Inc, UK) (8).

2.3. Biochemical analyses

Lung tissue collected for antioxidant analyses was homogenised in a homogeniser with 9 times the tissue weight in phosphate buffer, then sonicated. Samples in tubes were centrifuged. After the precipitation process, protein, malondialdehyde (MDA) levels, superoxide dismutase (SOD) and catalase (CAT) activities were measured in the separated supernatants. The analyses were performed in a cold environment.

Total protein levels in the supernatants were determined according to the method reported by Lowry et al. (9). Draper and Hadley's double heating method was used for MDA measurement. Colour absorbance measurements of the obtained samples were performed at 532 nm using a spectrophotometer (Shimadzu UV–1601, Germany). The results were given in µmol/mg protein (10). SOD activity was measured using a spectrophotometric method (Olympus AU 2700, Japan). SOD activity values for lung tissue were calculated in U/mg protein (11). CAT activity was measured according to the method developed by Aebi. The first and second reagents were mixed with the tissue sample, and the absorbance values at 0 and 30 seconds were measured. Absorbance was measured at 240 nm using a spectrophotometer. The results were given as ku/mg protein (12).

2.4 Statistical analysis

Statistical evaluations were made using SPSS 29.0 for Windows. Descriptive statistical analysis was used to present the data of the biochemical analyses. Statistical analysis was conducted). Kolmogorov-Smirnov test was performed to test for normal distribution, and a non-parametric Mann- Whitney U and parametric analysis of variance (ANOVA) test was used for intergroup comparisons of oxidative stress parameters. A P-value of<0.05 was considered statistically significant.

3. RESULTS

When oxidative stress parameters were evaluated in lung tissue, MDA increased significantly in the EM group compared to the control group (p=0.001), CAT decreased (p=0.001), and SOD decreased but was not statistically significant (p>0.005). Compared to the EA group, MDA decreased significantly in the EA+ Astaxanthin group (p=0.025), CAT increased (p=0.033), and SOD levels also increased but were not statistically significant (p>0.005).

Table 1: Analysis of oxidant-antioxidant parameters in lung tissue

Groups	MDA (µmol/mg prt)	SOD (U/mg prt)	CAT (ku/mg prt)	P value
Control	0.9896±0.2462	10,0949±0.2642	2.7471±0.4514	P<0.001
EF	2.0194±0.3131[a]	7.9132±1.6028	1.0265±0.4841 [a]	P<0.001
AF+ASX	1.5684±0.0785[b]	9.6104±5.0761	2.0177±0.6908[b]	P<0.05

malondialdehyde (MDA) levels, superoxide dismutase (SOD) and catalase (CAT) activities
a: compared to control group **b:** compares to EF group

4. DISCUSSION

This study provides compelling evidence that exposure to a 50 Hz electric field (EF) induces a significant state of oxidative stress in pulmonary tissue, and that this damage can be substantially mitigated by the administration of astaxanthin (ASX). Our primary findings demonstrate that EF exposure led to a marked increase in lipid peroxidation, as evidenced by elevated malondialdehyde (MDA) levels, coupled with a significant depletion of the primary antioxidant enzyme, catalase (CAT). Conversely, co-administration of ASX with EF exposure effectively reversed these pathological changes, significantly reducing MDA and restoring CAT activity. These results collectively highlight the potential of ASX as a potent protective agent against environmentally induced oxidative lung injury.

One of the most important effects of electric fields is the formation of free radicals and, consequently, an increase in lipid peroxidation. Studies have shown that extremely low frequency electromagnetic fields (ELF) alter the number and speed of biochemical reactions by forming free radicals (13,14). Seyhan et all., and Lee et all., investigated the effects of static and ELF electric field exposures in the range of 0.3-1.9 kV/m, applied in different directions and for different durations, on free radical formation, antioxidant enzyme levels, and collagen synthesis in the brain, liver, lung, kidney, spleen, testis, and plasma tissues of guinea pigs. It has been reported that the effect of electric fields on tissues is significantly dependent on the type, magnitude, and duration of exposure to the electric field (15,16). It has been demonstrated that EA increases thiobarbituric acid reactive substances (TBARS) and superoxide dismutase (SOD) levels in liver, kidney, and lung tissues (2).

The induction of oxidative stress by extremely low-frequency electromagnetic fields (ELF-EMF) is a well-documented phenomenon across various biological tissues, and our findings in the lung are consistent with this body of literature. The significant increase in MDA in the EF group points to extensive damage to the polyunsaturated fatty acids within cell membranes, a hallmark of oxidative injury. This is likely due to the overproduction of reactive oxygen species (ROS). It is hypothesized that ELF-EMF can disrupt cellular homeostasis by altering the kinetics of ion channels (particularly Ca^{2+} channels) or by interfering with the mitochondrial electron transport chain, leading to electron leakage and the formation of superoxide anions (17). The profound decrease in CAT activity observed in our study suggests that the cellular antioxidant defense system was overwhelmed by the sustained production of ROS, specifically the accumulation of hydrogen peroxide (H_2O_2), which is the substrate for CAT. This depletion of enzymatic defenses renders the lung tissue highly vulnerable to further damage.

The most significant finding of this study is the robust protective effect of astaxanthin. ASX administration not only reduced the EF-induced lipid peroxidation but also significantly increased CAT activity compared to the EF-only group. Astaxanthin, a xanthophyll carotenoid, is renowned for its powerful antioxidant properties, which are attributed to its unique molecular structure with conjugated double bonds and polar end groups. This structure allows it to embed within the cell membrane, spanning its entire width, thereby providing superior protection against lipid peroxidation directly at the site of injury (18). Beyond its direct ROS scavenging activity, ASX has been shown to enhance the body's endogenous antioxidant system. The observed increase in CAT activity in the ASX-treated group suggests that astaxanthin may not only neutralize free radicals itself but may also preserve the functional integrity of key antioxidant enzymes or upregulate their expression, possibly by modulating cellular signaling pathways like the Nrf2 pathway (19). Our results align with studies demonstrating astaxanthin's protective role against other forms of pulmonary injury, such as that induced by cigarette smoke further cementing its potential as a lung-protective agent (20).

An interesting aspect of our results is the non-significant change in superoxide dismutase (SOD) activity in both comparisons. While SOD levels trended downwards with EF exposure and upwards with ASX treatment, they did not

reach statistical significance. This could be interpreted in several ways. It is possible that the primary oxidative burden in this model is driven more by H_2O_2 and hydroxyl radicals, making CAT the more critically depleted enzyme. Alternatively, the kinetics of the antioxidant response could be a factor; SOD is the first line of defense, converting superoxide to H_2O_2. A severe downstream depletion of CAT could create a negative feedback loop to prevent the toxic accumulation of H_2O_2, thus keeping SOD activity stable or only slightly reduced. Future studies measuring activity at multiple time points would be necessary to elucidate these dynamics.

The implications of this study are significant in the context of public health. Chronic exposure to ELF-EMF from power lines, household appliances, and occupational settings is ubiquitous. While the debate on its long-term health effects continues, our findings suggest that pulmonary tissue is a tangible target for oxidative damage. The prophylactic or therapeutic use of potent, safe antioxidants like astaxanthin could represent a viable strategy to mitigate the potential risks associated with this unavoidable environmental stressor, particularly for individuals with pre-existing respiratory conditions or high levels of exposure.

5. CONCLUSION

In conclusion, this study demonstrates that 50 Hz electric field exposure poses a significant oxidative threat to pulmonary tissue, characterized by increased lipid peroxidation and compromised enzymatic antioxidant defenses. More importantly, it establishes astaxanthin as an effective countermeasure, capable of neutralizing this damage and restoring the antioxidant balance. Future research should aim to explore the downstream effects on inflammatory and apoptotic pathways (e.g., NF-κB, caspase-3) to further elucidate the comprehensive protective mechanisms of astaxanthin against ELF-EMF-induced lung injury.

REFERENCES

1. Barriviera ML, Louro SRW, Wajnberg E, Hasson-Voloch A. Denervation alters protein–lipid interactions in membrane fractions from electrocytes of Electrophorus electricus (L.). Biophys Chem. Haziran 2001;91(1):93-104.

2. Güler G, Turkozer Z, Tomruk A, Seyhan N. The protective effects of N-acetyl-L-cysteine and Epigallocatechin-3-gallate on electric field-induced hepatic oxidative stress. Int J Radiat Biol. Ocak 2008;84(8):669-80.

3. Yokus B, Cakir DU, Akdag MZ, Sert C, Mete N. Oxidative DNA damage in rats exposed to extremely low frequency electro magnetic fields. Free Radic Res. Mart 2005;39(3):317-23.

4. Guleken Z, Kula-Maximenko M, Depciuch J, Kılıç AM, Sarıbal D. Detection of the chemical changes in blood, liver, and brain caused by electromagnetic field exposure using Raman spectroscopy, biochemical assays combined with multivariate analyses. Photodiagnosis Photodyn Ther. Haziran 2022;38:102779.

5. Li N, Fan X, Wang Y, Zhang K, Liu R, Xu Y, vd. Investigation of isomerization and oxidation of astaxanthin in ready-to-eat Litopenaeus vannamei during accelerated storage. Food Res Int. Kasım 2024;195:114983.

6. Wu D, Xu H, Chen J, Zhang L. Effects of Astaxanthin Supplementation on Oxidative Stress: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Int J Vitam Nutr Res. Ocak 2020;90(1-2):179-94.

7. Comlekci S. Induced dielectric-force-effect by 50 Hz strong electric field on living tissue. Biomed Mater Eng. 2006;16(6):363-7.

8. Aslankoc R, Gumral N, Saygin M, Senol N, Asci H, Cankara FN, vd. The impact of electric fields on testis physiopathology, sperm parameters and DNA integrity-The role of resveratrol. Andrologia. Mayıs 2018;50(4):e12971.

9. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin phenol reagent. J Biol Chem. Kasım 1951;193(1):265-75.

10. Draper HH, Hadley M. [43] Malondialdehyde determination as index of lipid Peroxidation. Içinde: Methods in Enzymology [Internet]. Elsevier; 1990 [a.yer 11 Ağustos 2025]. s. 421-31. Erişim adresi: https://linkinghub.elsevier.com/retrieve/pii/007668799086135I

11. Woolliams JA, Wiener G, Anderson PH, McMurray CH. Variation in the activities of glutathione peroxidase and superoxide dismutase and in the concentration of copper in the blood in various breed crosses of sheep. Res Vet Sci. Mayıs 1983;34(3):253-6.

12. Aebi H. [13] Catalase in vitro. Içinde: Methods in Enzymology [Internet]. Elsevier; 1984 [a.yer 11 Ağustos 2025]. s. 121-6. Erişim adresi: https://linkinghub.elsevier.com/retrieve/pii/S0076687984050163

13. Güler G, Seyhan N, Aricioğlu A. Effects of static and 50 Hz alternating electric fields on superoxide dismutase activity and TBARS levels in guinea pigs. Gen Physiol Biophys. Haziran 2006;25(2):177-93.

14. Güler G, Türközer Z, Seyhan N. Electric Field Effects on Guinea Pig Serum: The Role of Free Radicals. Electromagn Biol Med. Ocak 2007;26(3):207-23.

15. Seyhan N, Güler G. Review of In Vivo Static and ELF Electric Fields Studies Performed at Gazi Biophysics Department. Electromagn Biol Med. Ocak 2006;25(4):307-23.

16. Lee HJ, Jin H, Ahn YH, Kim N, Pack JK, Choi HD, vd. Effects of intermediate frequency electromagnetic fields: a review of animal studies. Int J Radiat Biol. 01 Şubat 2023;99(2):166-82.

17. Tian H, Zhu H, Gao C, Shi M, Yang D, Jin M, vd. System-level biological effects of extremely low-frequency electromagnetic fields: an in vivo experimental review. Front Neurosci. 06 Ekim 2023;17:1247021.

18. Ambati R, Phang SM, Ravi S, Aswathanarayana R. Astaxanthin: Sources, Extraction, Stability, Biological Activities and Its Commercial Applications—A Review. Mar Drugs. 07 Ocak 2014;12(1):128-52.

19. Kishimoto Y, Yoshida H, Kondo K. Potential Anti-Atherosclerotic Properties of Astaxanthin. Mar Drugs. 05 Şubat 2016;14(2):35.

20. Tang H, Zhang Y, Wang Q, Zeng Z, Wang X, Li Y, vd. Astaxanthin attenuated cigarette smoke extract-induced apoptosis via decreasing oxidative DNA damage in airway epithelium. Biomed Pharmacother. Kasım 2023;167:115471.

Investigation of Motoric Characteristics and Sports Injury Anxiety Levels in Kick Light and Point Fighting Branches

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Abstract: The purpose of this study is to investigate the motor skills and separation anxiety of athletes participating in kicklight and pointfighting, which are sub-branches of kickboxing. In kicklight, athletes apply techniques with controlled contact with their opponents, while in pointfighting, contact is kept to a minimum. The sample of the study consists of athletes from the Kick Light (n=36) and Pointfighting (n=36) branches. The average age of the participants was 16.13 years, the average weight was 62.16 kg, the average training frequency was 3.97 days per week, and the number of training days ranged from 2 to 7 days. The average age of starting the sport was 11.77 years, and the average number of years participating in this branch was 4.44 years. The data collection tools used were a personal information form, a sports injury anxiety scale, balance, flexibility, plank, standing long jump, and vertical jump tests. The data from this study were analyzed using the SPSS 30.0 (v4.2) software package with the Hayes Model 1. According to the research findings, the relationship between the sport and sports injury anxiety regulates the relationship between the athletes' training frequency, duration of sports participation, body weight, sit-up test, and gender. In the relationship between branch and anxiety, it was determined that the variables of age at which sports were started, age, balance, vertical jump, standing long jump, flexibility, and plank test did not statistically significantly affect the relationship ($p>0.05$). In conclusion, it was determined that injury anxiety in sports is related to the sport and that this relationship is influenced by training frequency, duration of participation in sports, body weight, shuttle run test, and gender variables, but no significant differences were found in age, age at which sports were started, and other physical performance measures. To reduce injury anxiety in athletes, branch differences and individual characteristics should be considered in training planning. In particular, weight management processes should be organized in a way that reduces athletes' anxiety and injury risk.

Keywords: Kickboxing, kick light, point fighting, motor skills, injury anxiety

Kick light ve point fighting branşlarinin motorik özelliklerinin ve sporda yaralanması kaygı düzeyinin incelenmesi

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Abstract: Bu çalışmanın amacı Kickboksun alt branşlarından olan kicklight ve pointfighting branş sporcularının motorik özelliklerini ve yaralanma kaygısını araştırmaktır. Kicklight branşında, sporcular rakiplerine kontrollü temasla teknik uygularken, pointfighting'de ise temas minimumda tutulur. Araştırmanın örnekleminin Kick Light ve (n=36) Pointfighting (n=36) branşında yer almaktadır. Katılımcıların yaş ortalaması 16,13 yıl, ortalama kilo 62,16 kg antrenman sıklığı haftada ortalama 3,97 gün, antrenman gün sayısının ise 2 ile 7 gün arasında değiştiği saptanmıştır. Spora başlama yaşı ortalaması 11,77 yıl olup, katılımcıların bu branşı yapma yılı ortalaması ise 4,44 yıldır. Veri toplama aracı olarak kişisel bilgi formu, spor yaralanması kaygı ölçeği, denge, esneklik, plank, durarak uzun atlama, yukarı sıçrama testi uygulanmıştır. Bu çalışmanın verileri, SPSS 30.0 (v4.2) paket programı Hayes Model 1 kullanılarak analiz edilmiştir. Araştırma bulgularına göre branşa ile sporda yaralanma kaygısı sporcuların; antrenman sıklığı, spor yapma süresi, sporcuların vücut ağırlığı, mekik testi, cinsiyetleri ile ilişkili olduğunu göstermektedir. Branş ile kaygı ilişkisinde spora başlama yaşı, yaş, denge, yukarı sıçrama, durarak uzun atlama, esneklik ve plank testi değişkenlerin ilişkiyi istatistiksel olarak anlamlı şekilde etkilemediği belirlenmiştir($p>0.05$). Sonuç olarak, sporda yaralanma kaygısının branş ile ilişkili olduğu ve bu ilişkinin antrenman sıklığı, spor yapma süresi, vücut ağırlığı, mekik testi ve cinsiyet değişkenlerinden etkilendiği, ancak yaş, spora başlama yaşı ve diğer fiziksel performans ölçütlerinde anlamlı bir farklılık bulunmadığı belirlenmiştir. Sporcularda yaralanma kaygısını azaltmak için antrenman planlamasında branş farklılıkları ve bireysel özellikler dikkate alınmalıdır. Özellikle kilo yönetimi süreçleri sporcuların kaygı ve yaralanma riskini azaltacak şekilde düzenlenmelidir.

Keywords: Kickboks, kicklight, point fighting, motorik özellikler, yaralanma kaygısı

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1. GİRİŞ

Kick boks yumruk ve tekme vuruşlarından oluşan, genel olarak kendini savunma amaçlı olarak karate, muaythai ve boks branşlarından geliştirilmiş ve bu teknikleri kendine özgü bir şekilde harmanlayarak ortaya çıkmış popüler bir dövüş sporudur (Gümüşay et al., 2023). Kick Light branşı, genellikle müsabakanın daha yoğun olduğu, sürekli hareket ve kuralların ön planda tutulduğu bir dövüş sporudur. Bu branşta, sporcuların dayanıklılığı, kuvvet ve hız gibi fiziksel kapasitenin yanı sıra, teknik becerilerin de üst seviyede olması gerekmektedir. Kickboks branşında yapılan bir kayıt, tekme kalitesinde hız testinin (FSKT) özellikleri ve deneyimsiz sporcular arasında anlamlı farklılıklar yaratıldığı, özellikle tekme tekniğinin yüksek patlayıcı güç göstergesi ve alt ekstremite kaslarının gücünün sportif başarıda önemli bir parametre olduğu belirtilmiştir (Gümüşdağ et al.,2023).

Point Fighting ise, konsantrasyonun daha kontrollü olduğu, puan odaklı ve hızlı reflekslerin ön planda tutulduğu bir branştır. Bu branşta, sporcuların hızlı karar verme, çeviklik ve reaksiyon zamanı gibi özellikleri ön planda koruma sağlar. Farklı branşlarda yer alan sporcuların reaksiyon zamanı, kuvvet ve esneklik gibi biyomotor değişimlerinin karşılaştırıldığı bir, branşlar arasında anlamlı farklılıklar olduğu ve Point Fighting gibi puan odaklı branşlarda kırılma zamanı ve esnekliğin daha sağlıklı olduğu gösterilmiştir (Gürsoy et al., 2017).

Dövüş sporlarının sosyal ve farklı boyutu da Kick Light ve Point Fighting branşlarının kapsamı artırılmaktadır. Dövüş sporlarının gelişimi ve kültürel etkileri üzerine yapılan bağımsız, sporun ulusal kimliği, disiplin ve yaşam tarzı gibi alanlarda önemli bir rol oynadığı vurgulanmıştır. (Kurtcebe & Poyraz, 2023). Kickboksun temelinde, sporcunun teknik becerilerinin yanı sıra motorik özelliklerinin gelişmiş olması gerekmektedir. Motorik özellikler; kuvvet, sürat, çeviklik, denge, esneklik, dayanıklılık ve reaksiyon zamanı gibi fiziksel uygunluk parametrelerini kapsamaktadır. Kickboks ve benzeri dövüş sporlarında, performans parametrelerinin karşılaştırılması önemli bir araştırma alanıdır. Kickboks branşı kendi içerisinde bulunan farklı müsabaka sistemlerinden dolayı sporcuların antrenman programlarında kuvvet, sürat, dayanıklılık, denge ve esneklik gibi çok farklı parametrelerin sportif performansa önemli düzeyde etki eden özellikler olduğu bilinmektedir (Gümüşay, 2021).

Motorik özelliklerin gelişimi, yalnızca fiziksel performans değil, aynı zamanda sakatlık riskinin azaltılması açısından da önemlidir. Genç futbolcularda yapılan bir çalışmada, 8 haftalık futbol antrenmanının hız, çeviklik, dayanıklılık ve kuvvet performansında anlamlı artışlar sağladığı, ayrıca alt ekstremite kuvvet oranlarının optimal düzeye yaklaşmasıyla sakatlık riskinin azaldığı tespit edilmiştir (Buzdağlı et al., 2023).

Yaralanmaların önlenmesinde çeşitli fiziksel yöntemlerin yanı sıra, yaralanmaya zemin hazırlayabilecek psikolojik faktörler de bulunmaktadır (Andersen & Williams, 1988). Sporda yaralanma, yalnızca fiziksel bir travma olarak değerlendirilmemekte, aynı zamanda bireyin psikolojik, sosyal ve performans boyutlarında da önemli etkiler yaratmaktadır. Spor yaralanması kaygısı, sporcunun olası ya da muhtemel bir yaralanma durumunu sportif faaliyet esnasında bilişsel ya da somatik anksiyete ile karşılama eğilimi şeklinde tanımlanmaktadır (Smith & Smoll, 1990). Spor yaralanması kaygısı, spora katılım motivasyonunu ve tutumunu da etkileyebilmektedir. Özellikle boks gibi yüksek riskli sporlarda, sporcuların ve ebeveynlerin spora yönelik olumsuz tutumlarının arkasında spor yaralanması ve sakatlık korkusu önemli bir yer tutmaktadır (Sarı ve Bulut, 2021).

Kicklight ve pointfighting sporcularının motorik özellikleri üzerine karşılaştırmalı çalışmaların sınırlı olduğu görülmektedir. Mevcut çalışmalar, kickboksu genel bir kategori olarak ele almakta, branşlar arasındaki ince farklılıkları ve bunların sporcuların fiziksel profilleri üzerindeki etkileri incelenmemiştir. Bu durum, her branşa özgü antrenman programlarının geliştirilmesi için gerekli bilimsel verilerin eksik kalmasına neden olmaktadır. Bununla beraber bu sporcularda yaralanma kaygısı konusundaki veriler azdır. Özellikle bu branşların farklı temas düzeyleri ve müsabaka dinamikleri göz önüne alındığında, sporcuların yaşadığı kaygı türleri ve derecelerinin de farklı olabileceği düşünülmektedir. Temasın sürekli olduğu kicklight'ta, sporcuların ani ve ciddi yaralanma riski algısı daha yüksek olabilirken, pointfighting'de hızlı reaksiyon gerektiren durmalar ve kalkışlar, kronik veya tekrarlayan yaralanmalara yönelik farklı bir kaygıya yol açabilir. Bu farklılıkları bilimsel olarak incelenmesi bakımından önemlidir.

2. MATERYAL VE METOT

2.1. Araştırma modeli

Bu araştırmada nicel bir araştırma modeli olan betimsel araştırma deseni kullanılmıştır. Betimsel araştırmalarda örnek olay, gelişimsel, karşılaştırmalı ve tarama yöntemleri uygulanabilmektedir. Bu çalışmada ise mevcut durumu ortaya koymak amacı ile tarama yöntemi tercih edilmiştir (Karakuş, 2018).

2.2. Araştırma grubu

Çalışmanın örneklemi tesadüfü örneklem yöntemlerin olan basit rastgele yöntem seçilmiştir. Kickboksun alt branşlarından olan kicklight ve pointfighting yapan bireylere ulaşılmaya çalışılmıştır. Çalışmanın örneklemi Osmaniye il

merkezindeki kadın ve erkek sporculardan oluşturmaktadır. Araştırmanın örneklemine dahil olmak için kickboks spor dalını aktif olarak yapmak gerekmektedir. Bu araştırma toplam 72 sporcudan oluşmaktadır.

2.3.Veri toplama araçları

Bu çalışmada kişisel bilgi formu, spor yaralanması kaygı ölçeği: Spor Yaralanması Kaygı Ölçeğinin 19 madde ve 6 alt faktörden oluşan ve beşli Likert tipinde bir ölçektir (1: kesinlikle katılmıyorum. 2: katılmıyorum, 3: kararsızım, 4: tamamlanır, 5: kesinlikle). Söz konusu yedi alt faktör; Sporculuk Yeteneğini Kaybetme Kaygısı, Zayıf Algılanma Kaygısı, Acı Çekme Kaygısı, Hayal Kırıklığına Uğratma Kaygısı, Yeniden Yaralanma Kaygısı ve Sosyal Destek Kaybetme Kaygısı şeklindedir. Ölçekte olumsuz madde mevcut değildir (Caz, et al., 2019).

Denge ölçümü: Flamingo Denge Testi, bireyin tek bacağı üzerinde dururken, diğer bacağını bükerek arkaya kaldırmasını ve ayak parmaklarını aynı taraftaki eliyle tutmasını gerektiren bir uygulamadır. Testin temel amacı, bu pozisyonda ne kadar süreyle dengede kalınabildiğini veya belirli bir süre içinde kaç denge kaybı yaşandığını belirlemektir (Gücük & Aydoğmuş 2023).

V-Uzan Eriş Esneklik Testi, yaygın olarak Otur-Uzan Testi olarak bilinen ve özellikle bel altı bölgesi (alt sırt ve hamstring kasları) esnekliğini ölçmek için kullanılan basit ve etkili bir fiziksel uygunluk testidir. Testi yapacak kişi, bacaklarını düz bir şekilde öne doğru uzatarak oturur. Ayak tabanları, ölçüm cihazının ön yüzüne (genellikle 23 cm veya 26 cm'lik başlangıç noktasına) veya yere sabitlenmiş mezuranın sıfır noktasına dayanır. Dizler bükülmeden tamamen düz tutulur. Kollar öne doğru uzatılır ve avuç içleri yere bakacak şekilde eller üst üste konur. Ulaşılan en uzak nokta mezura üzerinden santimetre (cm) cinsinden kaydedilir. Bu mesafe, ayak parmaklarının gerisinde (pozitif değer) veya ayak parmaklarının önünde (negatif değer) olarak kaydedilir (Güler, 2019).

Plank testi: özellikle core adı verilen karın, bel ve kalça bölgesindeki kasların dayanıklılığını ölçmek için kullanılan basit ama etkili bir statik güç testidir. Testi yapacak sporcu yere yüz üstü uzanır. Dirsekler omuz hizasının altında olacak şekilde ön kolları yere koyar. Avuç içleri yere bakabilir veya eller birleştirilebilir. Ayak parmakları yere temas eder. Vücut, baştan topuklara kadar düz bir çizgi halinde tutulur. Belin aşağıya doğru çökmesine veya kalçanın yukarıya doğru kalkmasına izin verilmemelidir. Birey doğru pozisyonu aldığında kronometre başlatılır. Test, birey doğru pozisyonu koruyamadığında, yani belini büktüğünde, kalçasını kaldırdığında veya yere düştüğünde sona erer. Kronometre durdurulur ve bireyin pozisyonu koruyabildiği süre saniye cinsinden kaydedilir (Karataş, 2024).

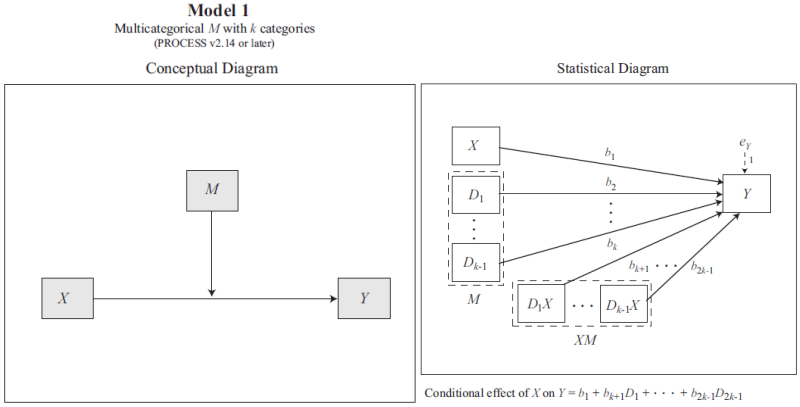
Yukarı sıçrama: Sporcu, bir duvara kenarına yan durur. Ayaklar düz bir şekilde yere basarken, kollarını en yukarı kaldırır ve parmak ucunda durmadan duvarda erişebildiği en yüksek noktayı işaretler. Bu, sporcunun durağan erişim yüksekliğidir (Kasap, et al., 2025).

Durarak uzun atlama: sporcu, düz bir zeminde, ayakları omuz genişliğinde açık olacak şekilde bir başlangıç çizgisinin arkasında durur. Çizgiye ayak parmakları ile basmaması önemlidir. Dizlerini bükerek kollarını geriye doğru sallar ve ileriye doğru mümkün olduğunca uzağa atlar. Bu hareket tek bir, sürekli hareket olmalıdır; koşma veya adım alma gibi ek bir momentum yaratılmamalıdır. Sıçrama sonrası sporcunun topuklarının en gerideki noktası, başlangıç çizgisinden mezura ile ölçülür. Bu mesafe santimetre veya inç cinsinden kaydedilir. Eğer sporcu dengesini kaybeder ve geriye düşerse, en gerideki temas noktası ölçülür (Bilgiç & Koyunlu 2024).

2.4. Veri analizi

Bu çalışmanın verileri, SPSS 30.0 (v4.2) paket programı kullanılarak analiz edilmiştir. Analizler %95 güven aralığında, 5000 bootstrap örneklemesiyle gerçekleştirilmiştir. Hayes Model 1kullanılmıştır. Hayes Model 1'de yer alan Hayes'in (2018) Model 1'i doğrultusunda, X değişkeninin Y üzerindeki etkisinin W değişkenine göre değişip değişmediğini test etmek amacıyla moderasyon analizi gerçekleştirilecektir.

Hayes Model 1 (SPSS 30.0 v4.2)



3. BULGULAR

Tablo 1. Tanımlayıcı özellikler

Değişkenler	**Grup**	**Frekans (n)**	**Yüzde(%)**
Branş	Kick Light	36	50.0
	Pointfighting	36	50.0
Cinsiyet	Erkek	52	72.2
	Kadın	20	27.8
	Mean	**ss**	**Min-max**
Yaş (yıl)	16.13	2.66	12-22 yıl
Kilo (kg)	62.16	12.24	42-83 kg
Antrenman sıklığı (gün)	3.97	1.60	2-7 gün
Spora başlama yaşı (yıl)	11.77	4.00	5-19 yıl
Bu branşı yapma yılı	4.44	3.54	(1-17 yıl)

Tablo 1'degörüldüğü gibi n=72 gönüllünün katılımıyla gerçekleştirilen çalışmada, sporcuların %50'si (n=36) Kick Light ve %50'si (n=36) Pointfighting branşında yer almaktadır. Katılımcıların cinsiyet dağılımı incelendiğinde, %72.2'sinin (n=52) erkek, %27,8'inin (n=20) ise kadın sporculardan oluştuğu görülmektedir. Sporcuların yaş ortalaması 16.13 yıl olup (SS=2.66), ortalama kilo 62,16 kg (SS=12.24) olarak belirlenmiştir. Antrenman sıklığına bakıldığında, sporcuların haftada ortalama 3,97 gün (SS=1,60) antrenman yaptığı, antrenman gün sayısının ise 2 ile 7 gün arasında değiştiği saptanmıştır. Spora başlama yaşı ortalaması 11.77 yıl (SS=4.00) olup, katılımcıların bu branşı yapma yılı ortalaması ise 4.44 yıldır (SS=3.54).

Bağımsız değişken X: Branş (Kick Light:0 - Point Fighting:1), Düzenleyici değişken W: Antrenman Sıklığı ve Bağımlı Değişken Y: Sporda Yaralanma Kaygısı Ölçeği Ortalaması olarak belirlenmiştir.

Tablo 2. Antrenman Sıklığının Branş ile Yaralanma Kaygı Düzeyi İlişkisinde Düzenleyici Rolü (Model 1)

Değişken	B (coeff)	SE	t	p	LLCI	ULCI
Sabit (constant)	1.7790	0.1394	12.7573	0.0000	1.5007	2.0572
Branş	-0.0543	0.1916	-0.2831	0.7779	-0.4366	0.3281
Antreman sıklığı	-0.2987	0.1073	-2.7837	0.0070	-0.5128	-0.0846
Etkileşim terimi (Int_1)	0.3094	0.1290	2.3983	0.0192	0.0520	0.5669

Tablo 2 branş (Kick Light: 0, Point Fighting: 1) ile antrenman sıklığı arasındaki etkileşimin yaralanma kaygısı düzeyi üzerindeki etkisini ortaya koymaktadır. Branş değişkeninin doğrudan etkisi ($p<0.05$ dikkate alındığında) anlamlı değildir ($p = .7779$). Ancak, antrenman sıklığının yaralanma kaygısı üzerinde anlamlı ve negatif bir etkisi bulunmaktadır ($B = -0.2987$, $p = .0070$). Int_1 etkileşim terimi anlamlıdır ($B = 0.3094$, $p = .0192$); bu sonuç, antrenman sıklığının branş ile yaralanma kaygısı arasındaki ilişkiyi düzenlediğini göstermektedir.

Kurulan modelde Modelin genel uyumu ($R = .3479$, $R^2 = .1210$) ve modelin anlamlılığı ($F(3.68) = 3.1205$, $p = .0316$) olarak tespit edilmiştir. Elde edilen sonuçlar modelin açıklayıcılık oranın %12.1 olup, tüm modelin anlamlı olduğunu ($p = .0316$) göstermektedir. Bu durum, branş, antrenman sıklığı ve etkileşim teriminin birlikte yaralanma kaygısı düzeyini anlamlı düzeyde açıkladığını göstermektedir. Bu modelde hangi düzeylerde anlamlılık olduğunun incelendiği analiz sonuçları Tablo 3'te yer almaktadır.

Tablo 3. Branşın Etkisinin Antrenman Sıklığına Göre Koşullu Değerlendirilmesi

Antreman sıklığı (W)	Etki (Branş)	SE	t	p	LLCI	ULCI
-1.60 (düşük)	-0.5496	0.2597	-2.116	0.038	-1.0679	-0.0313
0.00 (ortalama)	-0.0543	0.1916	-0.283	0.778	-0.4366	0.3281
+1.60 (yüksek)	0.4411	0.3021	1.460	0.149	-0.1618	1.0440

Tablo 3'de yer alan koşullu etkiler analizi, branş değişkeninin (Kick Light – Point Fighting) etkisinin farklı antrenman sıklığı düzeylerinde nasıl değiştiğini göstermektedir. Düşük antrenman sıklığında, Point Fighting sporcularının yaralanma kaygı düzeyleri Kick Light sporcularına göre anlamlı düzeyde daha düşüktür (B = -0.5496, p = .038). Ancak bu fark, antrenman sıklığı ortalama düzeyde olduğunda anlamlı değildir (p = .778). Yüksek antrenman sıklığında ise bu fark tersine dönmekte, ancak istatistiksel olarak anlamlılığa ulaşmamaktadır (p = .149). Bu bulgu, branş etkisinin yalnızca düşük antrenman sıklığında anlamlı olduğunu göstermektedir.

Bağımsız değişken X: Branş (Kick Light:0 - Point Fighting:1), Düzenleyici değişken W: Branşı yapma yılı ve Bağımlı Değişken Y: Sporda Yaralanma Kaygısı Ölçeği Ortalaması olarak belirlenmiştir.

Tablo 4. Branşı Yapma Yılının Branş ile Sporda Yaralanma Kaygı Düzeyi İlişkisinde Düzenleyici Rolü (Model 1)

Değişken	B (coeff)	SE	t	p	LLCI	ULCI
Sabit (constant)	1.9547	0.1283	15.2364	.0000	1.6987	2.2107
Branş	-0.3139	0.1842	-1.7046	.0928	-0.6814	0.0536
Branşı yapma yılı	0.0020	0.0298	0.0685	.9456	-0.0575	0.0616
Etkileşim terimi (Int_1)	0.1229	0.0608	2.0210	.0472	0.0015	0.2443

Branş değişkeninin doğrudan etkisi istatistiksel olarak sınırda anlamlılık göstermektedir (B =-0.3139, p = .0928), bu da Point Fighting sporcularında yaralanma kaygı düzeyinin Kick Light sporcularına kıyasla daha düşük olabileceğini düşündürmektedir. Ancak bu fark yalnızca zayıf düzeydedir. Bu branşı yapma yılı değişkeninin doğrudan etkisi anlamsızdır (p = .9456). Ancak etkileşim terimi (Int_1) anlamlıdır (B = 0.1229, p = .0472). Bu durum, branş ile yaralanma kaygısı arasındaki ilişkinin, sporcunun branş tecrübesine göre değiştiğini ortaya koymaktadır. Kurulan modelin genel uyumu R = .3076, R^2 = .0946 olarak hesaplanmıştır. Modelin genel anlamlılığı F (3, 68) = 2.3689, p = .0783 düzeyindedir. Bu sonuçlara göre model genel anlamda istatistiksel olarak anlamlılık sınırında yer almakta (p <.10), açıklayıcılığı ise %9.46 düzeyindedir.

Tablo 5. Branşın Etkisinin Bu Branşı Yapma Yılına Göre Koşullu Değerlendirilmesi

Branşı yapma yılı (W)	Etki (Branş)	SE	t	p	LLCI	ULCI
-3.44 (düşük)	0.7373	0.2955	-2.495	.015	-1.3270	-0.1475
0.00 (ortalama)	-0.3139	0.1842	-1.705	.093	-0.6814	0.0536
+3.54 (yüksek)	0.1212	0.2654	0.456	.649	-0.4085	0.6508

Tablo 5'te yer alan branşın yaralanma kaygısı üzerindeki etkisi, sporcunun o branşı kaç yıldır yaptığına göre değişmektedir. Branşı yapma yılı düşük olan sporcularda, Point Fighting sporcularının yaralanma kaygı düzeyleri anlamlı biçimde daha düşüktür (B =-0.7373, p = .015). Ortalama tecrübe seviyesinde, branş farkı istatistiksel olarak sınırda anlamlılık göstermektedir (p = .093). Yüksek tecrübeye sahip (uzun yıllar yapan) sporcularda ise, branşın yaralanma kaygısına etkisi anlamlı değildir (p = .649). Bu bulgu, branşın yaralanma kaygı üzerindeki etkisinin sadece düşük tecrübeye sahip bireylerde anlamlı olduğunu, tecrübe arttıkça bu farkın ortadan kalktığını göstermektedir.

Bağımsız değişken X: Branş (Kick Light:0- Point Fighting:1), Düzenleyici değişken W: Sporcuların kilosu ve Bağımlı Değişken Y: Sporda Yaralanma Kaygısı Ölçeği Ortalaması olarak belirlenmiştir.

Tablo 6. Sporcu Kilosunun Branş ile Yaralanma Kaygı Düzeyi İlişkisinde Düzenleyici Rolü (Model 1)

Değişken	B (coeff)	SE	t	p	LLCI	ULCI
Sabit (constant)	1.9264	0.1224	15.7338	0.0000	1.6821	2.1708
Branş	-0.0827	0.1726	-0.4788	0.6336	-0.4272	0.2618
Sporcu kilosu	0.0089	0.0106	0.8450	0.4011	-0.0122	0.0300
Etkileşim terimi (Int_1)	0.0287	0.0143	2.0106	0.0483	0.0002	0.0571

Tablo 6, branş (Kick Light: 0, Point Fighting: 1) ile sporcu kilosu arasındaki etkileşimin sporda yaralanma kaygı düzeyi üzerindeki etkisini ortaya koymaktadır. Branş değişkeninin doğrudan etkisi istatistiksel olarak anlamlı değildir (p = .6336). Benzer şekilde, sporcu kilosunun da yaralanma kaygısı üzerindeki doğrudan etkisi anlamlı bulunmamıştır (B =

0.0089, p = .4011). Ancak, Int_1 etkileşim terimi anlamlıdır (B = 0.0287, p = .0483); bu sonuç, sporcu kilosunun branş ile yaralanma kaygısı arasındaki ilişkiyi düzenlediğini göstermektedir.

Kurulan modelin genel uyumu R = .4563, R^2 = .2082 olarak tespit edilmiştir. Modelin anlamlılığı F(3, 68) = 5.9617, p = .0011 düzeyindedir. Bu sonuçlar, modelin açıklayıcılık oranının %20.8 olduğunu ve tüm modelin anlamlı olduğunu göstermektedir. Dolayısıyla, branş, kilo ve bu ikisi arasındaki etkileşim, birlikte değerlendirildiğinde sporda yaralanma kaygısı düzeyini anlamlı düzeyde yordayabilmektedir. Etkileşim teriminin modele eklenmesi açıklanan varyansı %4.7 artırmış ve bu artış da anlamlı bulunmuştur (ΔR^2 = .0471, p = .0483).

Tablo 7. Branşın Etkisinin Sporcu Kilosuna Göre Koşullu Değerlendirilmesi

Branşı yapma yılı (W)	Etki (Branş)	SE	t	p	LLCI	ULCI
-12.25 (düşük)	-0.4338	0.2485	-1.7455	0.0854	-0.9297	0.0621
0.00 (ortalama)	-0.0827	0.1726	-0.4788	0.6336	-0.4272	0.2618
+12.25 (yüksek)	0.2684	0.2426	1.1066	0.2723	-0.2156	0.7525

Tablo 7'de yer alan koşullu etkiler analizi, branş değişkeninin (Kick Light – Point Fighting) etkisinin farklı kilo düzeylerinde sporda yaralanma kaygısına olan etkisini göstermektedir. Bu bağlamda; düşük kilo düzeyinde (–1 SD), Point Fighting sporcularının yaralanma kaygı düzeyleri Kick Light sporcularına göre daha düşük görünmektedir (B = –0.4338), ancak bu fark istatistiksel olarak anlamlılık sınırındadır (p = .0854). Ortalama kilo düzeyinde, branşın etkisi anlamlı değildir (B = –0.0827, p = .6336). Yüksek kilo düzeyinde (+1 SD), bu ilişki tersine dönmekte ve Point Fighting sporcularının yaralanma kaygı düzeylerinin Kick Light sporcularına göre daha yüksek olduğu görülmektedir (B = 0.2684), ancak bu fark da istatistiksel olarak anlamlı değildir (p = .2723). Bu bulgular, branş etkisinin yalnızca düşük kilo düzeyine yakın değerlerde anlamlılığa yaklaştığını, ancak diğer kilo düzeylerinde anlamlı bir fark olmadığını ortaya koymaktadır. Sonuç olarak, sporcu kilosu arttıkça branşın yaralanma kaygı üzerindeki etkisi yön değiştiriyor, fakat bu değişim yalnızca etkileşim düzeyinde istatistiksel olarak anlamlıdır.

Bağımsız değişken X: Branş (Kick Light:0- Point Fighting:1), Düzenleyici değişken W: Mekik sayısı ve Bağımlı Değişken Y: Sporda Yaralanma Kaygısı Ölçeği Ortalaması olarak belirlenmiştir.

Tablo 8. Mekik Sayısının Branş ile Yaralanma Kaygı Düzeyi İlişkisinde Düzenleyici Rolü (Model 1)

Değişken	B (coeff)	SE	t	p	LLCI	ULCI
Sabit (constant)	1.9663	0.1281	15.3523	0.0000	1.7107	2.2219
Branş	-0.2282	0.1811	-1.2602	0.2119	-0.5897	0.1332
Mekik sayısı	-0.0262	0.0150	-1.7448	0.0855	-0.0561	0.0038
Etkileşim terimi (Int_1)	0.0403	0.0210	1.9210	0.0589	-0.0016	0.0822

Tablo 8, branş (Kick Light: 0, Point Fighting: 1) ile mekik sayısı arasındaki etkileşimin sporda yaralanma kaygı düzeyi üzerindeki etkisini ortaya koymaktadır. Branş değişkeninin doğrudan etkisi anlamlı değildir (p = .2119). Mekik sayısı değişkeni ise yaralanma kaygı düzeyini negatif yönde etkileme eğilimi göstermektedir; ancak anlamlılık sınırındadır (B = –0.0262, p = .0855). Etkileşim terimi Int_1 anlamlılık sınırındadır (B = 0.0403, p = .0589); bu bulgu, mekik sayısının branş ile yaralanma kaygı düzeyi arasındaki ilişkiyi düzenleyici bir rol oynayabileceğine işaret etmektedir.

Modelin genel uyumu R = .2732, R^2 = .0746 ve model anlamlılığı F(3, 68) = 1.8276, p = .1504 olarak hesaplanmıştır. R^2 değeri modelin açıklayıcılık oranının %7.5 olduğunu göstermekte; ancak model genel olarak istatistiksel olarak anlamlı bulunmamıştır (p> .05). Etkileşim teriminin modele eklenmesi, açıklanan varyansı %5.0 artırmış ve bu artış da anlamlılık sınırındadır (ΔR^2 = .0502, p = .0589). Bu durum, moderasyon etkisinin marjinal düzeyde var olduğunu göstermektedir.

Tablo 9. Branşın Etkisinin Mekik Sayısına Göre Koşullu Değerlendirilmesi

Mekik sayısı (W)	Etki (Branş)	SE	t	p	LLCI	ULCI
–8.69 (düşük)	–0.5787	0.2572	–2.2497	0.0277	–1.0921	–0.0654
0.00 (ortalama)	–0.2282	0.1811	–1.2602	0.2119	–0.5897	0.1332
+8.69 (yüksek)	0.1222	0.2569	0.4758	0.6358	–0.3904	0.6349

Tablo 9'da yer alan koşullu etkiler analizi, branş değişkeninin yaralanma kaygı düzeyi üzerindeki etkisinin sporcuların mekik performansına göre nasıl değiştiğini göstermektedir. Buna göre, düşük mekik düzeyinde (–1 SD), Point Fighting sporcularının yaralanma kaygı düzeyleri Kick Light sporcularına göre anlamlı düzeyde daha düşüktür (B = –0.5787, p = .0277). Ortalama mekik sayısında, branş farkı anlamlı değildir (p = .2119). Yüksek mekik düzeyinde, bu fark tersine dönmekte ve Point Fighting sporcuları Kick Light'a göre daha yüksek yaralanma kaygı düzeyine sahip gibi görünmektedir; ancak bu fark istatistiksel olarak anlamlı değildir (p = .6358).

Bu bulgular, mekik performansının düşük olduğu durumlarda branşın yaralanma kaygısı üzerindeki etkisinin belirginleştiğini göstermektedir. Etki yönü ise mekik sayısı arttıkça tersine dönmekte, ancak bu değişim yalnızca düşük düzeylerde anlamlılık taşımaktadır.

Bağımsız değişken X: Branş (Kick Light:0- Point Fighting:1), Düzenleyici değişken W: cinsiyet (0: erkek, 1: kadın) ve Bağımlı Değişken Y: Sporda Yaralanma Kaygısı Ölçeği Ortalaması olarak belirlenmiştir.

Tablo 10. Cinsiyetin Branş ile Yaralanma Kaygı Düzeyi İlişkisinde Düzenleyici Rolü (Model 1)

Değişken	**B (coeff)**	**SE**	**t**	**p**	**LLCI**	**ULCI**
Sabit (constant)	18.138	0.1503	120.649	0.0000	15.138	21.138
Branş	-0.0040	0.2126	-0.0190	0.9849	-0.4283	0.4202
Cinsiyet	0.5020	0.2852	17.600	0.0829	-0.0672	10.712
Etkileşim terimi (Int_1)	-0.7854	0.4034	-19.471	0.0557	-15.904	0.0195

Tablo 10, branş (Kick Light: 0, Point Fighting: 1) ile cinsiyet (0 = erkek, 1 = kadın) arasındaki etkileşimin sporda yaralanma kaygı düzeyi üzerindeki etkisini göstermektedir. Branş değişkeninin doğrudan etkisi anlamlı değildir ($p = .9849$). Cinsiyet değişkeni anlamlılık sınırında bir etki göstermektedir ($B = 0.5020$, $p = .0829$); bu, kadın sporcuların genel olarak daha yüksek yaralanma kaygı düzeyine sahip olabileceğini düşündürmektedir, ancak bu fark kesin değildir. Etkileşim terimi (Int_1) istatistiksel olarak anlamlılık sınırındadır ($B = -0.7854$, $p = .0557$). Bu bulgu, cinsiyetin, branş ile yaralanma kaygı düzeyi arasındaki ilişkiyi düzenleyici bir rol oynayabileceğini ortaya koymaktadır.

Modelin genel uyumu $R = .2758$, $R^2 = .0761$ olup; model anlamlılık düzeyine ulaşmamıştır ($F(3.68) = 1.8658$, $p = .1436$). Ancak, etkileşim teriminin açıklanan varyansa katkısı %5.1'dir ($\Delta R^2 = .0515$) ve bu artış anlamlılık sınırında yer almaktadır ($p = .0557$). Bu durum, cinsiyetin düzenleyici rolü açısından dikkat çekici bir eğilime işaret eder.

Tablo 11. Branşın Etkisinin Cinsiyete Göre Koşullu Değerlendirilmesi

Cinsiyet (W)	Etki (Branş)	SE	t	p	LLCI	ULCI
Erkek (0)	–0.0040	0.2126	–0.0190	0.9849	–0.4283	0.4202
Kadın (1)	–0.7895	0.3428	–2.3029	0.0243	–1.4736	–0.1054

Tablo 11'deki koşullu etkiler analizi, branş değişkeninin yaralanma kaygısı düzeyi üzerindeki etkisinin cinsiyete göre nasıl farklılaştığını göstermektedir. Buna göre erkek sporcular için branşın yaralanma kaygısı üzerindeki etkisi anlamlı değildir ($p = .9849$). Kick Light ve Point Fighting branşları arasında yaralanma kaygı düzeyi açısından fark yoktur. Kadın sporcular için ise bu etki anlamlıdır ($B = –0.7895$, $p = .0243$). Bu sonuç, kadın sporcularda Point Fighting branşında yaralanma kaygısı düzeyinin Kick Light branşına göre anlamlı biçimde daha düşük olduğunu göstermektedir.

Bu bulgular, branş etkisinin yalnızca kadın sporcular arasında anlamlı olduğunu ve cinsiyetin bu ilişkide düzenleyici bir rol üstlendiğini göstermektedir. Diğer bir deyişle, branşın yaralanma kaygısı düzeyine etkisi kadınlarda belirginleşirken, erkeklerde anlamlı bir farklılık gözlenmemektedir.

Tablo 12. Branş ile Yaralanma Kaygısı İlişkisinde Anlamlı Düzenleyici Rol Göstermeyen Değişkenler (Etkileşim Terimleri, $p > .05$)

Etkileşim Terimi (Int_1)	**B**	**SE**	**t**	**p**
Spora başlama yaşı	-0.0485	0.0553	-0.8762	0.384
Ebeveynin bu sporu yapması	-0.6416	0.6235	-1.0292	0.307
Yaş	0.0706	0.0793	0.8897	0.3767
Denge testi	-0.012	0.0307	-0.3903	0.6975
Yukarı sıçrama	0.0428	0.0405	1.0569	0.2943
Durarak uzun atlama	0.0107	0.0102	1.0507	0.2971
Esneklik	-0.0024	0.0427	-0.0551	0.9562
Plank	0.0332	0.0579	0.5739	0.5679

Tablo 12'de yer alan etkileşim terimleri üzerinden yapılan analizler sonucunda aşağıda detayları verilen düzenleyici değişkenlerin branş ile yaralanma kaygı düzeyi arasındaki ilişkiyi istatistiksel olarak anlamlı şekilde etkilemediği belirlenmiştir ($p > .05$). Spora başlama yaşı, branş ile yaralanma kaygı düzeyi arasındaki ilişkiyi anlamlı şekilde etkilememektedir ($B = –0.0485$, $p = .384$). Bu, spora erken ya da geç başlama durumunun, branşa göre yaralanma kaygısı

değişimini etkilemediğini göstermektedir. Ebeveynin bu sporu yapma durumu, branş- yaralanma kaygısı ilişkisini istatistiksel olarak etkilememektedir (B = –0.6416, p = .307). Yani, ebeveynin spor geçmişine sahip olması, çocuğun yaralanma kaygı düzeyinin branşlara göre farklılaşmasına neden olmamaktadır. Yaş değişkeni ile branş arasında anlamlı bir etkileşim görülmemiştir (B = 0.0706, p = .3767). Bu durum, yaş ilerledikçe branşın yaralanma kaygısı üzerindeki etkisinin değişmediğini göstermektedir. Denge testi sonuçları ile branş arasında anlamlı bir etkileşim gözlenmemiştir (B = –0.012, p = .6975). Denge düzeyi farklılıkları, branşlar arasında yaralanma kaygısı açısından belirleyici bir faktör değildir. Yukarı sıçrama performansı, yaralanma kaygısı düzeyi ile branş ilişkisini anlamlı düzeyde etkilememektedir (B = 0.0428, p = .2943). Yani sıçrama kabiliyeti yüksek veya düşük olan sporcularda branş temelli kaygı farkı gözlenmemiştir. Durarak uzun atlama testinin etkileşim katsayısı da anlamlı değildir (B = 0.0107, p = .2971). Bu, alt ekstremite patlayıcı kuvvetinin branş- yaralanma kaygısı ilişkisinde belirleyici olmadığını göstermektedir. Esneklik, branş ve yaralanma kaygısı arasındaki ilişkiyi anlamlı şekilde düzenlememektedir (B = –0.0024, p = .9562). Bu sonuç, esnekliğin yüksek ya da düşük olmasının branş farkına dayalı kaygı düzeylerini etkilemediğini ortaya koymaktadır. Plank süresi ile yaralanma kaygı düzeyi arasındaki ilişki, branşa göre anlamlı bir farklılık göstermemektedir (B = 0.0332, p = .5679). Bu da kor stabilitesinin, branşa göre değişen yaralanma kaygısı üzerinde anlamlı bir etkisi olmadığını göstermektedir.

4. TARTIŞMA VE SONUÇLAR

Bu çalışmanın amacı Kickboksun alt branşlarından olan kicklight ve pointfighting branş sporcularının motorik özelliklerini ve yaralanma kaygılarını araştırmaktır. Mevcut literatür, kickboksu genellikle genel bir kategori olarak ele almakta, ancak bu çalışmada elde edilen bulgular, Kick Light ve Pointfighting gibi alt branşların, sporcuların motorik özellikleri üzerinde belirgin farklılıklar yarattığını ortaya koymaktadır. Bu tür branşlara katılımın ve sporcuların temel demografik özelliklerinin, spora başlama yaşı, antrenman sıklığı ve spor yapma yılı gibi değişkenlerle birlikte değerlendirilmesi, sporcu profilinin bütüncül olarak anlaşılması açısından önem taşımaktadır. Sporcuların yaş ortalaması ve spora başlama yaşı, sportif gelişimin ve performansın belirleyicileri arasında yer almaktadır. Çolak ve arkadaşlarının Türkiye'deki lisanslı sporcu sayısının yıllara göre incelediği çalışmada, sporun çocukluk ve ergenlik döneminde başlanmasının, sportif başarı ve branşlaşma açısından önemli olduğu vurgulanmıştır (Çolak et al., 2024). Gümüşdağ ve arkadaşlarının Kick Boks sporcuları üzerinde yaptığı çalışmada, antrenman deneyimi ve sıklığının, sportif performans üzerinde doğrudan etkili olduğu, özellikle patlayıcı güç gerektiren branşlarda antrenman yoğunluğunun başarıyı artırdığı belirtilmiştir (Gümüşdağ et al., 2023).

Yaralanma kaygısı, sporcuların performansını ve psikolojik iyi oluşunu etkileyen önemli bir faktördür. Özellikle dövüş sporlarında, sporcuların karşılaştığı fiziksel riskler ve bu risklerin yol açtığı kaygı düzeyleri, branşın özelliklerine, antrenman sıklığına ve bireysel farklılıklara göre değişkenlik gösterebilmektedir. Tanyeri'nin farklı branş sporcuları üzerinde yaptığı çalışmada, sporun hem fiziksel hem de zihinsel faydalarına rağmen, spor sırasında yaşanan yaralanmaların zamanla yaralanma korkusuna dönüştüğü ve bu korkunun demografik değişkenlere göre farklılık gösterebildiği belirtilmiştir (Tanyeri, 2019). Başka bir araştırmada takım ve bireysel spor branşlarında lisanslı sporcuların yaralanma kaygısı ve mental antrenman düzeyleri değerlendirilmiştir. Bulgulara göre, cinsiyet değişkenine göre yaralanma kaygısı ölçeğinde kadın sporcular lehine istatistiksel olarak anlamlı farklar bulunmuştur (Andre & Kaplan, 2021). Branş değişkeninin doğrudan etkisi istatistiksel olarak anlamlı olmasa da antrenman sıklığı ve etkileşim terimleriyle birlikte değerlendirildiğinde, yaralanma kaygısı düzeyini anlamlı bir şekilde açıklayabilmektedir.

Yaralanma kaygısının branşa göre farklılaşmasında, sporcunun branşı yapma yılı yani tecrübe düzeyi de önemli bir rol oynamaktadır. Tecrübe arttıkça, sporcunun yaralanma kaygısı ile başa çıkma becerilerinin gelişebileceği ve kaygı düzeyinin azalabileceği düşünülmektedir. Profesyonel ve amatör güreşçiler üzerinde yapılan çalışmada, profesyonelleşme düzeyinin spor yaralanma kaygısının nedeni olabileceği, tecrübeli sporcuların yaralanma kaygısı ile başa çıkmada daha başarılı olabileceği vurgulanmıştır (Sağıroğlu et al., 2023). Sporcuların yaralanma kaygısı düzeylerinin, branşın gerektirdiği fiziksel temas ve risk düzeyine göre de değişebileceği vurgulanmaktadır. Tanyeri'nin çalışmasında, sporcuların daha önce kol veya bacaktan ameliyat geçirenler ile geçirmeyenler arasında yaralanma kaygısı açısından anlamlı bir fark bulunmadığı, ancak cinsiyet değişkeninin anlamlı farklılık yarattığı belirtilmiştir (Tanyeri, 2019). Bu bulgular, branş ile yaralanma kaygısı arasındaki ilişkinin, sporcunun branş tecrübesine göre değiştiğini ve özellikle düşük tecrübeye sahip bireylerde branş farkının daha belirgin olduğunu göstermektedir (Şensoy et. al., 2021). Sporcu kilosu da yaralanma kaygısı üzerinde etkili olabilecek bir diğer önemli değişkendir. Özellikle kilo kontrolünün ve hızlı kilo kaybının yaygın olduğu dövüş sporlarında, sporcu kilosunun yaralanma riski ve kaygısı üzerindeki etkisi dikkat çekicidir. Elit güreşçilerde yapılan bir araştırmada, hızlı kilo kaybının kadın ve erkek sporcularda sırasıyla %98,6 ve %85 oranında görüldüğü, kilo kaybı sayısı ile acı çekme kaygısı arasında zayıf negatif korelasyon bulunduğu belirtilmiştir (Bayındır, et, al,. 2023). Rekabet kaygısının spor yaralanma düzeyi üzerindeki etkisini inceleyen bir çalışmada, rekabet kaygısının spor yaralanması üzerinde anlamlı ve pozitif bir etkisi olduğu, rekabet kaygısı arttıkça spor yaralanma düzeyinin de arttığı gösterilmiştir (Sajedi & Kirkbir, 2020). Sonuç olarak, spor branşı, sporcu kilosu ve bu iki değişken arasındaki etkileşim, sporda yaralanma kaygısı düzeyinin anlaşılmasında ve modellenmesinde önemli rol oynamaktadır. Branş ve kilo değişkenlerinin doğrudan etkileri her zaman anlamlı olmayabilir, ancak bu değişkenler arasındaki etkileşim, yaralanma kaygısının açıklanmasında kritik bir öneme sahiptir.

Tablo 8 ve Tablo 9'da sunulan bulgular, branş (Kick Light ve Point Fighting) ile mekik sayısı arasındaki etkileşimin, sporda yaralanma kaygı düzeyi üzerindeki etkisini ortaya koymaktadır. Özellikle mekik gibi dayanıklılık ve core kas gücünü ölçen testler, sporcuların genel fiziksel uygunluğunu ve yaralanma riskini belirlemede önemli göstergelerden biridir. Kayhan ve arkadaşlarının kadın sporcular üzerinde yaptığı çalışmada, spor yaralanma kaygısı ile spor deneyimi ve spor branşı arasında anlamlı ilişkiler bulunmuştur (Kayhan, et,al,. 2019). Dövüş sanatları sporcularında karın kaslarının güçlendirilmesinin patlayıcı güç antrenmalarının olumlu düzeyde geliştiğini bildirmiştir (Pang & Ge 2023). Kickboks'ta bir dövüşçünün başarısı için hem üst hem de alt uzuvlardaki kas gücü çok önemlidir. İnceleme, kickboksçuların tekmeleme, yumruklama, bloklama, tutma ve itme gibi teknik ve taktiksel hareketleri etkili bir şekilde gerçekleştirip sürdürebilmeleri için güç ve dayanıklılıklarına ihtiyaç duyduklarını vurgulamaktadır (Slimani et al., 2017). Spor yaralanma kaygısının sadece tek bir faktörden değil, birden fazla fiziksel, psikolojik ve sosyal değişkenin etkileşimiyle şekillendiğini göstermektedir. Bu nedenle, spor yaralanma kaygısı düzeylerinin değerlendirilmesinde, branş farklılıkları, fiziksel performans göstergeleri ve psikososyal faktörlerin birlikte ele alınması gerekmektedir. Cinsiyetin yaralanma kaygısı üzerindeki etkisi, farklı spor dallarında ve farklı düzeylerdeki sporcular arasında değişkenlik gösterebilmektedir. Akcan ve arkadaşlarının elit sporcular üzerinde yaptıkları araştırmada, kadın sporcuların kaygı düzeylerinin erkek sporculara kıyasla daha yüksek olduğu ortaya konmuştur (Akcan et.al.,2023). Sonuç olarak, spor yaralanma kaygısı tek bir faktörden değil; branş farklılıkları, fiziksel performans göstergeleri ve psikososyal etkiler sonucunda birçok değişkenden etkilenmektedir. Spor yaralanma kaygısını azaltmaya yönelik çalışmalarda branş farklılıkları dikkate alınmalı, özellikle deneyimsiz ve yüksek kaygı düzeyine sahip sporcular için core güçlendirme, dayanıklılık ve psikolojik dayanıklılık antrenmanları entegre edilmelidir. Ayrıca, kilo yönetimi süreçleri sporcuların kaygı ve yaralanma riskini azaltacak şekilde düzenlenmelidir.

Teşekkür
Çalışmaya katılan tüm sporculara teşekkür ederim.

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KAYNAKLAR

Adar Yiğit, Y., Sağıroğlu, İ., Erduğan, F., & Saç, A. (2023). Examination of the sports injury anxiety levels between professional and amateur wrestlers. *Mediterranean Journal of Sport Science, 6*(3), 748–760. https://doi.org/10.38021/asbid.1261029

Akcan, İ. O., Yılmaz, P., Şar, H., & Ölmez, C. (2023). Sporda elit sporcuların akılcı olmayan performans inançları ile kaygı düzeyleri arasındaki ilişkinin incelenmesi. *Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi, 12*(4), 1967–1978. https://doi.org/10.37989/gumussagbil.1366923

Andersen, M. B., & Williams, J. M. (1988). A model of stress and athletic injury: Prediction and prevention. *Journal of Sport & Exercise Psychology, 10*(3), 294–306.

Bayındır, O., Can, S., & Demirkan, E. (2023). Elit güreşçilerde spor yaralanması tarihi ve spor yaralanması kaygı düzeyinin incelenmesi: Tanımlayıcı bir araştırma. *Türkiye Klinikleri Spor Bilimleri Dergisi, 15*(1).

Bilgiç, M., & Koyunlu, A. (2024). 12 haftalık yürüyüş temelli hareket eğitiminin seçilmiş motorik özelliklere etkisi. *International Journal of Social and Humanities Sciences Research (JSHSR), 11*(114 Erken Görünüm).

Buzdağlı, Y., Uçan, İ., Eyipınar, C. D., Şıktar, E., Ozan, M., & Uçar, H. (2023). Genç futbolcuların hız, çeviklik, dayanıklılık ve kuvvet performanslarının incelenmesi: H/Q ve D/ND oranlarının değerlendirilmesi. *CBÜ Beden Eğitimi ve Spor Bilimleri Dergisi, 18*(1), 228–241.

Caz, C., Kayhan, R. F., & Bardakci, S. (2019). Spor yaralanması kaygısı ölçeğinin Türkçeye uyarlanması: Geçerlilik ve güvenilirlik çalışması. *Turkish Journal of Sports Medicine, 54*(1), 52–63.

Güler, U. (2019). *Dinamik ve FIFA 11+ ısınma yöntemlerinin futbol oyuncularının esneklik, dikey sıçrama ve çeviklik performansları üzerine akut etkisi* [Yüksek lisans tezi, Marmara Üniversitesi].

Gümüşay, M. (2021). *Kick boks sporcularında core antrenman programlarının sportif performans parametreleri üzerine etkilerinin incelenmesi* [Yüksek lisans tezi, Çukurova Üniversitesi].

Gümüşay, M., Koç, M. C., & Turhan, M. (2023). Kick boks sporcularının rekreasyonel spor iyi oluş düzeylerinin incelenmesi. *Uluslararası Spor Bilimleri Öğrenci Çalışmaları, 5*(1), 46–59.

Gümüşdağ, H., Tekçe, H. K., & Ervüz, E. (2023). Kick boks sporcularının tekme sıklığı hız testi üzerine bir araştırma. *Uluslararası Hakemli Beşeri ve Akademik Bilimler Dergisi, 0*(29).

Gürsoy, R., Akarsu, S., & Hazar, K. (2017). Farklı branşlarda yer alan sporcular ve sedanterlerde bazı biyomotor özellikler ve reaksiyon zamanı arasındaki ilişkilerin incelenmesi. *İnsan Bilimleri Dergisi, 14*(4), 3282–3296.

Gücük, S., & Aydoğmuş, M. (2023). 12–14 yaş grubu futbolculara uygulanan 8 haftalık core antrenmanının sürat ve denge üzerine etkisinin incelenmesi. *Herkes için Spor ve Rekreasyon Dergisi, 5*(2), 94–98.

Hayes, A. F. (2018). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (2nd ed.). The Guilford Press.

Kaplan, E., & Andre, H. (2021). Investigation of the relationship between mental training and sports injury anxiety. *Turkish Journal of Sport and Exercise, 23*(1), 1–8.

Karakuş, C. (2018). *Araştırma yöntemleri*. http://ckk.com.tr/ders/arastirmayon/00%20Araştırma%20Yöntemleri.pdf

Karataş, M. (2024). Üniversite öğrencilerinin plank testi performansının çeşitli değişkenlere göre incelenmesi. *Sportif Bakış: Spor ve Eğitim Bilimleri Dergisi, 11*(S1), 112–128.

Kayhan, R. F., Yapıcı, A., & Üstün, Ü. D. (2019). Kadın sporcuların sakatlanma kaygısının çeşitli değişkenlere göre incelenmesi. *Sportif Bakış: Spor ve Eğitim Bilimleri Dergisi, 6*(S1), 276–287. https://doi.org/10.33468/sbsebd.109

Kurtcebe, M., & Poyraz, T. (2023). Sosyal boyutlarıyla geçmişten günümüze beden tasarımında sporun uluslaşma ve modernleşme ile ilişkisi. *Hacettepe Üniversitesi Edebiyat Fakültesi Dergisi, 40*(1), 1–17.

Pang, H., Jia, H., & Ge, Q. (2023). Influences of abdominal core strengthening on explosive strength in martial arts athletes. *Revista Brasileira de Medicina do Esporte, 29*. https://doi.org/10.1590/1517-8692202329012022_0726

Sajedi, H., & Kirkbir, F. (2020). The effect of competitive anxiety on the injury level of student-athletes of Karadeniz Technical University. *Journal of Educational Issues, 6*(2), 98–106.

Sarı, İ., & Bulut, Ü. (2021). Boks antrenörlerinin perspektifinden sporcular ve ebeveynlerin boksa yönelik tutumları. *Spormetre Beden Eğitimi ve Spor Bilimleri Dergisi, 19*(2), 135–155.
Şenol, H., Çolak, H., & Çolak, E. (2024). Türkiye'de gelecek yıllarda yapay sinir ağlarını kullanan toplam lisanslı sporcu sayısının analizi. *Karadeniz Fen Bilimleri Dergisi, 14*(4), 2153–2171. https://doi.org/10.31466/kfbd.1531019

Şensoy, C., Şenel, Ö., & Akarçeşme, C. (2021). Farklı spor branşlarında spor yaralanma çeşitleri ile yaralanma kaygısı arasındaki ilişkinin belirlenmesi. *Ulusal Kinesyoloji Dergisi, 2*(2), 27–41.

Slimani, M., Chaabene, H., Miarka, B., Franchini, E., Chamari, K., & Chéour, F. (2017). Kickboxing review: Anthropometric, psychophysiological and activity profiles and injury epidemiology. *Biology of Sport, 34*(2), 185–196. https://doi.org/10.5114/BIOLSPORT.2017.65338

Smith, R. E., Smoll, F. L., & Schutz, R. W. (1990). Measurement and correlates of sport-specific cognitive and somatic trait anxiety: The Sport Anxiety Scale. *Anxiety Research, 2*(4), 263–280.

Tanyeri, L. (2019). Farklı branş sporcularında yaralanma kaygısının incelenmesi. *OPUS International Journal of Society Researches, 13*(19), 577–591. https://doi.org/10.26466/opus.588668

Adventure based learning as a supporting technique for mental training

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Abstract: Research in the field of sport psychology has shown that mental training enhances performance and supports athletes' psychological well-being. Within mental training, methods such as imagery, self-talk and breathing techniques are applied individually or at the team level enabling athletes to mentally rehearse future performance scenarios and gain experiential insights. In the literature, adventure-based learning (ABL), grounded in the experiential learning approach, has similarly been demonstrated to improve mental skills such as concentration, problem solving, stress regulation, communication and teamwork. In this context, the aim of the present study is to examine whether ABL can be used as a supporting technique for mental training in athletes. The review revealed that both mental training and ABL foster similar psychological skills, suggesting that ABL may be considered a complementary method to mental training.

Keywords: Nature Based Learning, Experiential Learning, Mental Skills, Psychological Skills Training.

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1. INTRODUCTION

Sport is not only a field of physical performance but also a life practice that encompasses intense cognitive, emotional, and social processes. The success of athletes on the field is often associated not only with their physical capacities but also with their mental resilience, focusing skills, and stress management strategies (Vealey, 2007). Therefore, modern sport psychology attaches special importance to the systematic teaching and development of psychological skills in order to support athletic performance.

Mental training is one of the most widely applied practices in sport psychology. Techniques such as imagery, self-talk, concentration exercises, breathing methods, and relaxation strategies enable athletes to be psychologically prepared both during training and in competitive settings (Weinberg & Gould, 2019). Meta-analytical studies have demonstrated that mental training enhances self-confidence, strengthens motivation, and improves athletes' ability to cope with stress (Birrer & Morgan, 2010).

Nevertheless, it is increasingly recognized that athletes need to develop not only individual mental skills but also team dynamics, communication abilities, and problem-solving capacities. Particularly in team sports, no matter how strong an individual's mental preparation may be, if team cohesion is weak, performance outcomes may fall short of expectations. At this point, alternative methods are needed that can foster both individual and collective psychological skills of athletes.

One such alternative is the Adventure Based Learning (ABL) approach. Since the second half of the 20th century, ABL has been widely employed in education, leadership development, and personal growth programs (Hattie, Marsh, Neill & Richards, 1997). Grounded in Kolb's (1984) experiential learning theory, this approach encourages individuals to learn directly through experience. In ABL programs, participants are typically confronted with physical, cognitive, and social tasks carried out in outdoor environments. Through these activities, individuals are provided opportunities to enhance their risk perception, problem-solving abilities, communication, resilience, and leadership skills (Priest & Gass, 2018).

The literature reports that ABL yields outcomes such as improved self-confidence, strengthened interpersonal communication, better stress regulation, and enhanced team spirit (Neill & Richards, 1998). When these outcomes are examined, it becomes evident that ABL shares important intersections with mental training practices. While mental training tends to emphasize internal individual processes (e.g., concentration, anxiety regulation), ABL primarily addresses experiential, social, and environmental dimensions. Nevertheless, both approaches ultimately aim to enhance athletes' psychological resilience.

In this context, unveiling the complementary relationship between mental training and ABL may allow for the development of a holistic approach that supports athletes' growth both individually and collectively. Considering the performance demands under which elite athletes operate, it can be anticipated that experiential learning activities may play a supportive role in strengthening mental preparation.

In conclusion, the main purpose of this study is to examine the applicability of adventure-based learning as a supportive technique for mental training in athletes and to discuss the intersections of these two approaches in the light of the existing

literature. While emphasizing the importance of mental training, the study also seeks to draw attention to the potential role of ABL within sport psychology practices.

2. THEORETICAL FRAMEWORK

2.1. Theoretical foundations of mental training

Mental training refers to the systematic cultivation of cognitive and emotional processes with the aim of enhancing athletes' performance. The theoretical basis of this approach can be grouped into three main lines: (a) psychological skills training (PST), (b) cognitive-behavioral approaches, and (c) neurophysiological explanations. Weinberg and Gould's (2019) PST model encompasses goal setting, imagery, self-talk, attentional strategies, self-confidence, and anxiety regulation within a comprehensive framework.

The effectiveness of psychological skills training has also been supported by research conducted in different contexts. For instance, Yıldız, Önal, and Kaçay (2023) demonstrated that athletes' mindfulness levels played a significant role in the development of psychological skills. This finding suggests that mental training can be enriched not only through classical techniques but also by incorporating mindfulness-based strategies.

Imagery theories lie at the core of mental training. The PETTLEP model (Physical, Environment, Task, Timing, Learning, Emotion, Perspective), developed by Holmes and Collins (2001), proposes that imagery should be made as functionally equivalent to physical execution as possible. This framework emphasizes that imagery scenarios should be integrated with the actual performance conditions in terms of environment, timing, and emotional intensity.

Meta-analytic evidence further supports this theoretical framework. Driskell, Copper, and Moran (1994) demonstrated that mental practice significantly enhances performance across a wide variety of tasks. Meta-analyses conducted specifically on self-talk (Hatzigeorgiadis, Zourbanos, Galanis, & Theodorakis, 2011) revealed that self-talk is particularly effective in fine motor tasks and when task-related content is employed. These findings affirm the role of cognitive-behavioral approaches in influencing sport performance.

2.2. Theoretical foundations of adventure based learning (ABL)

Adventure Based Learning is grounded in Kolb's (1984) experiential learning theory. The cycle consists of four stages: (1) concrete experience, (2) reflective observation, (3) abstract conceptualization, and (4) active experimentation. In ABL programs, participants initially engage in a physical or social task, then reflect on the experience in structured sessions, develop abstract principles, and finally apply these principles in new situations.

The impact of ABL on the development of self-efficacy and resilience can also be explained through Bandura's (1977) social learning theory. As individuals successfully complete challenging tasks, their sense of efficacy is strengthened; peer observation and feedback processes reinforce social learning. Consequently, leadership, communication, and teamwork skills emerge naturally through the learning process (Priest & Gass, 2018).

Research conducted in the Turkish context also supports this approach. For example, Yıldız, Bostancı, and Kaçay (2022) found that a one-day indoor adventure education program had significant effects on the creative personality traits of young participants. This finding suggests that ABL can foster not only leadership and communication but also higher-order cognitive skills such as flexibility and creativity.

Meta-analytic findings in the literature also corroborate the effectiveness of ABL. Hattie, Marsh, Neill, and Richards (1997) demonstrated that ABL programs produce significant improvements in self-concept, leadership, problem-solving, and interpersonal relationships. More recent studies have indicated that ABL positively influences stress regulation, self-awareness, and psychological resilience (Bowen & Neill, 2013).

2.3. Conceptual intersections and complementarity

Although mental training and ABL are grounded in different theoretical frameworks, they ultimately aim at the development of similar skills. Mental training focuses primarily on individual-level outcomes such as concentration, emotional regulation, and self-confidence, whereas ABL, through experiential and social processes, cultivates leadership, communication, and resilience.

Thus, ABL can be regarded as a complementary method that reinforces the individual gains of mental training within social contexts. In sport psychology, the combined use of these two approaches within hybrid programs can provide a holistic model for both individual and group-based development.

3. LITERATURE REVIEW

3.1. Research on mental training in sport psychology

Mental training is one of the most widely used psychological skills training methods aimed at enhancing athletes' performance. Techniques such as imagery, self-talk, breathing exercises, and anxiety regulation strategies constitute the foundation of this approach (Vealey, 2007; Weinberg & Gould, 2019).

Imagery: Moran (2016) emphasized that mental imagery plays a critical role in the acquisition of motor skills and the enhancement of performance. The PETTLEP model, developed by Holmes and Collins (2001), highlights that imagery should approximate the physical, environmental, and emotional dimensions of actual performance. The meta-analysis by Driskell, Copper, and Moran (1994) revealed that imagery has significant positive effects on performance across different task types.

Self-Talk: Hardy (2006) explained the role of self-talk in attentional control, motivation, and self-confidence. A meta-analysis conducted by Hatzigeorgiadis, Zourbanos, Galanis, and Theodorakis (2011) demonstrated that self-talk exerts a moderate positive effect on performance, particularly when task-related content is employed.

Anxiety Regulation and Mindfulness: Williams and Krane (2021) reported that breathing techniques and relaxation strategies help regulate anxiety in athletes. Similarly, Yıldız, Önal, and Kaçay (2023) found that athletes' mindfulness levels were a significant determinant of psychological skill development. This finding suggests that integrating mindfulness-based approaches into mental training may be critical for athletic performance.

These studies indicate that mental training strengthens not only athletes' performance but also their psychological resilience and well-being (Birrer & Morgan, 2010; Brown & Fletcher, 2017).

3.2. Studies on adventure based learning (ABL)

Adventure Based Learning, rooted in the experiential learning approach, aims to improve individuals' self-efficacy, communication, problem-solving, and resilience (Kolb, 1984; Priest & Gass, 2018).

Classical Research: Hattie, Marsh, Neill, and Richards (1997), in a comprehensive meta-analysis of ABL and Outward Bound programs, found lasting effects on self-confidence, leadership, interpersonal communication, and academic achievement. Neill and Richards (1998) further emphasized that the effects of outdoor education are not only short-term but may also lead to long-term developmental outcomes.

Recent Findings: Bowen and Neill (2013) published a meta-analysis showing that ABL positively influences psychosocial adjustment, self-concept, and stress management. Allison and Pomeroy (2000) highlighted epistemological diversity in ABL research, underlining the importance of focusing not only on quantitative outcomes but also on the process of learning.

Turkish Context: Yıldız, Bostancı, and Kaçay (2022) found that indoor adventure education practices had significant positive effects on creative personality traits. This research indicates that ABL supports not only social and communication skills but also higher-order cognitive processes such as creativity and flexibility.

Collectively, this literature demonstrates that ABL provides multidimensional outcomes and represents a valuable method for athlete development.

3.3. Applications of ABL in sports

The integration of ABL into sport settings has been increasing in recent years. In team sports, ABL activities are often applied in pre-season camps to foster communication and trust, whereas in individual sports they are used to enhance resilience and stress management (Priest & Gass, 2018).

Team Sports: Farias, Hastie, and Mesquita (2017) found that ABL-based activities improved communication and cooperation among soccer players.

Individual Sports: Allison and Pomeroy (2000) reported that outdoor activities (e.g., climbing, canoeing) enhanced athletes' anxiety management and problem-solving skills.

Youth Athletes: McKenzie (2003) demonstrated that ABL interventions increased commitment to sport and motivation among adolescents.

These findings suggest that ABL is applicable not only in general educational contexts but also across different branches of sport.

3.4. Intersections between mental training and ABL

The literature indicates that mental training and ABL achieve similar outcomes through different mechanisms:

Mental training focuses on individual-level outcomes such as concentration, anxiety control, and motivation. ABL emphasizes group-level outcomes such as communication, leadership, problem-solving, and resilience.

Both approaches contribute to the development of self-efficacy, self-confidence, and psychological resilience (Bandura, 1977; Bowen & Neill, 2013). Therefore, within sport psychology practice, ABL can be regarded as an experiential dimension that complements mental training.

4. DISCUSSION

The literature demonstrates that both mental training and improve to the psychological development of athletes. Mental training particularly enhances individual processes such as concentration, self confidence, self regulation, and anxiety control (Weinberg & Gould, 2019; Williams & Krane, 2021), while ABL produces primarily experiential and group based skills. Especially social cognitive skills such as communication, cooperation, leadership, and problem-solving are among the critical gains of ABL programs (Hattie et al., 1997; Priest & Gass, 2018).

The fundamental distinction between the two approaches lies in their learning mechanisms. Mental training mainly focuses on the athlete's internal processes such as imagery, self-talk, breathing exercises, while ABL exposes individuals to concrete experiences and enables them to derive meaning from those experiences. Thus, ABL may serve as a "bridge" in transferring the skills developed through mental training into real life conditions.

Yıldız and collagues (2023), demonstrated that mindfulness plays a critical role in the development of psychological skills in athletes. This result suggests that mental training can be enriched not only with classical techniques but also with mindfulness-based approaches. Similarly, Yıldız and collagues (2022), found that ABL improved creative personality traits. This finding indicates that ABL may be effective not only on social but also on mental processes such as cognitive flexibility and creativity.

Generally, the evidence suggests that mental training and ABL can be used complementarily. For example, in pre-season preparation camps, imagery practices can be supported by ABL activities conducted during the same period. In this way, athletes can develop not only mentally but also experientially in areas such as stress management, focus, and intra-team communication, mental toughness.

Some challenges must be considered from a practical perspective. Implementing ABL activities typically requires planning in terms of cost, time, and safety. Also, the structure of each sport is different; for example, in individual sports, the contribution of ABL may be more limited to stress management and personal resilience, while in team sports, communication and leadership dimensions may come to the fore. So, it is of great importance to consider contextual factors when integrating ABL into sport psychology programs.

In conclusion, the discussion section highlights that mental training and ABL develop similar skills through different mechanisms; when applied together, they provide athletes with a holistic opportunity for psychological development.

5. CONCLUSIONS

This study emphasizes that mental training and ABL are complementary methods in terms of the psychological skills development of athletes. Based on the findings in the literature, the following conclusions can be drawn:

1. Mental training (imagery, self-talk, breathing techniques, mindfulness) strengthens athletes' concentration, self-confidence, anxiety control, and self-regulation skills (Driskell et al., 1994; Hatzigeorgiadis et al., 2011; Yıldız, Önal & Kaçay, 2023).

2. ABL, through experiential and group-based processes, develops communication, leadership, resilience, and problem-solving skills (Hattie et al., 1997; Priest & Gass, 2018; Yıldız, Bostancı & Kaçay, 2022).

3. Both approaches create positive effects on self-efficacy and self-confidence, although their learning mechanisms differ.

4. The combined use of mental training and ABL offers strong potential for hybrid programs that can effectively foster the psychological skills of athletes at both the individual and team levels.

In light of these results, it is recommended that sport psychologists and coaches incorporate not only mental training but also adventure-based learning into athlete development programs. This combined approach can enable athletes to become stronger both individually and socially.

6. LIMITATIONS AND FUTURE RESEARCH

This study is based on a literature review and does not include experimental findings. Future research should conduct empirical studies across different sports disciplines and age groups. The effectiveness of programs that integrate mental training and ABL should be systematically tested.

7. PRACTICAL IMPLICATIONS FOR PRACTITIONERS

Sport psychologists and coaches may enrich mental training programs by incorporating ABL activities. In team sports, ABL activities can be implemented during pre-season camps to enhance cohesion and communication. For youth athletes, the educational dimension of ABL can be utilized to increase motivation and engagement in sport.

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REFERENCES

Allison, P., & Pomeroy, E. (2000). How shall we “know?” Epistemological concerns in research in experiential education. *Journal of Experiential Education*, *23*(2), 91-98.

Bandura, A., & Walters, R. H. (1977). *Social learning theory* (Vol. 1, pp. 141-154). Englewood Cliffs, NJ: Prentice hall.

Birrer, D., & Morgan, G. (2010). Psychological skills training as a way to enhance an athlete's performance in high-intensity sports. *Scandinavian journal of medicine & science in sports*, *20*, 78-87.

Bowen, D. ve Neill, J. (2013). Macera terapisi sonuçları ve moderatörlerinin bir meta-analizi. *Açık Psikoloji Dergisi* , *6* (1), 28-53.

Brown, D. J., & Fletcher, D. (2017). Effects of psychological and psychosocial interventions on sport performance: A meta-analysis. *Sports Medicine*, *47*(1), 77-99.

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology, 79*(4), 481–492.

Farias, C., Hastie, P., & Mesquita, I. (2017). Towards a more equitable and inclusive learning environment in sport education. *Sport, Education and Society, 22*(4), 460–476.

Hattie, J., Marsh, H. W., Neill, J. T., & Richards, G. E. (1997). Adventure education and Outward Bound: Out-of-class experiences that make a lasting difference. *Review of Educational Research, 67*(1), 43–87.

Hatzigeorgiadis, A., Zourbanos, N., Galanis, E., & Theodorakis, Y. (2011). Self-talk and sport performance: A meta-analysis. *Perspectives on Psychological Science, 6*(4), 348–356.

Holmes, P. S., & Collins, D. J. (2001). The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists. *Journal of Applied Sport Psychology, 13*(1), 60–83.

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs: Prentice Hall.

McKenzie, M. (2003). Beyond “the Outward-Bound process”: Rethinking student learning. *Journal of Experiential Education, 26*(1), 8–23.

Moran, A. P. (2016). *The psychology of concentration in sport performers: A cognitive analysis*. Psychology Press.

Neill, J. T., & Richards, G. E. (1998). Does outdoor education really work? A summary of recent meta-analyses. *Australian Journal of Outdoor Education, 3*(1), 2–9.

Priest, S., & Gass, M. A. (2018). *Effective leadership in adventure programming*. Human Kinetics.

Vealey, R. S. (2007). *Mental skills training in sport*. In G. Tenenbaum & R. C. Eklund (Eds.), Handbook of Sport Psychology (pp. 287–309). Wiley.

Weinberg, R. S., & Gould, D. (2019). *Foundations of Sport and Exercise Psychology*. Human Kinetics.

Williams, J. M., & Krane, V. (2021). *Applied sport psychology: Personal growth to peak performance*. McGraw Hill.

Yıldız, N. O., Önal, A., & Kaçay, Z. (2023). The Effect of Athlete Mindfulness on the Development of Athlete Psychological Skills. *Turkish Journal of Sport and Exercise, 25*(2), 289–302.

Yıldız, N. O., Bostancı, T. G., & Kaçay, Z. (2022). Bir Günlük İç Mekan Macera Eğitim Uygulamalarının Yaratıcı Kişilik Özellikleri Üzerine Etkisi. *Mediterranean Journal of Sport Science (MJSS), 5*, 818–828.

The role of experiential learning in ensuring sports manager employability

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Abstract: Today, the concept of employability defined as an individual's ability to work in a job and make changes when desired has become increasingly important in the field of sports management, as in many other areas, due to the transformations brought by globalization. One of the main reasons behind this issue is that the competencies of prospective employees often fail to meet employers' expectations. This challenge has become a major concern for educational institutions and a subject of numerous studies. Accordingly, both educational institutions and scientific research recommend complementing traditional teaching methods with experiential learning which plays a key role in transforming knowledge into practice. In this context, the present study examines the importance of experiential learning in ensuring the employability competence of prospective sports managers. A review of the literature on employability and experiential learning reveals that graduates of institutions with strong experiential learning practices possess both soft and core skills which in turn enhances their employability competence. As a result, it can be argued that the integration and expansion of experiential learning methods such as internships, projects, active learning and metaphor-based learning into the sports management curriculum would effectively contribute to increasing the employability competence of graduates.

Keywords: Soft Skills, Active Learning, Higher Education, Competence of Employability.

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1. INTRODUCTION

Human beings tend to use the resources they possess effectively in order to achieve their goals. This behavior is today expressed as "management." Most organizations around the world must be managed in order to achieve pragmatic outcomes. The more flawless the management, the higher the quality of the results obtained. Therefore, in every managed context, people and resources must interact at the maximum level and objectives should be reached in an effective and efficient way (Tortop et al., 2010). Management may take place in small structures such as families, schools and businesses, as well as in larger structures such as states and international organizations (Güçlü, 2003).

The sports industry, a widespread global industry, also extensively employs management functions, from amateur sports clubs to international sports organizations (Lu, 2021). In this regard, management is addressed within the scope of "sports management." Sports management, as a subfield of management, emerged in the 1960s, first in the Americas and later in Europe, as an increasingly recognized field (Parlar & Çon, 2020). Generally speaking, sports management is defined, in parallel with the definition of management, as the use of effective connections among the resources of sports organizations and their orientation toward objectives (Doğar, 1997). In a broader sense, sports management can be defined as the efforts of each sports entity to achieve objectives in line with the vision of the organization, by applying management processes (planning, organizing, staffing, directing, coordinating, reporting and budgeting) (Gulick, 1935) through rational and scientific principles. It also encompasses the development of sports programs and physical education, the administration and supervision of sports facilities and the training of personnel (Parlar & Çon, 2020).

Those who manage sports are sports managers. Sports managers are defined as individuals who direct the organization in terms of resources and oversee the management process from beginning to end. In this context, contemporary sports managers must be knowledgeable about the principles of management, capable of synthesizing and interpreting information logically, understanding both individuals and athletes and prioritizing the interests of the organization over personal interests while serving management objectives (Bayter & Alaca, 2014; Ko et al., 2011). In addition, sports managers are expected to possess soft skills such as problem-solving, teamwork, communication, adaptability, willingness to learn and creativity (Tushar & Sooraksa, 2023).

Furthermore, higher education institutions, which are responsible for developing future sports managers, transfer to these students all the knowledge necessary for them to succeed as professionals. At this point, Awad and Ghaziri (2004) argue that knowledge is acquired through experience or practice (Bayter & Alaca, 2014). For sports managers to be trained in a knowledgeable manner, they must gain experience by being assigned to internships and projects developed through industry–academia collaboration (Lee & Lupi, 2010; Lu, 2021; Peretto Stratta, 2004). Today, developing sports managers through this approach is of crucial importance for employability (Lu, 2021; Tsitskari et al., 2017). This is because the rapid development of the economy and technology has increased demand for managers who can integrate into the

uncertain environment of the sports industry (Brown & Rich, 2021; Datar et al., 2011; Haritas & Harini, 2025; Navarro, 2008).

Consequently, managers who can cope with these challenges will contribute significantly to solving problems by complementing the theoretical education they receive in educational institutions with field experience acquired through in-class and extracurricular applications. This situation highlights the importance of experiential learning (Lu, 2021). Studies in the literature emphasize the significance of this matter, noting that candidates to be employed fail to meet employers' expectations due to the inability to transform knowledge into experience (Haritas & Harini, 2025).

Experiential learning is a multidisciplinary educational process drawing on fields such as education, management, and psychology that is based on the idea of acquiring knowledge through experience as a means of holistic learning (Bevan & Kipka, 2012). Experiential learning, assumed to facilitate learning through the reflection of experiences (Schon, 1987), is proposed as an important pedagogical approach for producing innovative strategies and enabling individuals to realize their own potential (Bevan & Kipka, 2012). Accordingly, the experiential learning model equips prospective sports managers to become experienced, well-prepared and suitable for management roles by engaging with real-world problems rather than focusing solely on theory (Haritas & Harini, 2025; Prince et al., 2005; Schmidt et al., 2011).

In light of this information, the aim of the study is to investigate the importance of experiential learning an educational method that practically develops employability skills in enhancing sports managers' soft skills such as leadership, problem-solving, and decision-making (Bevan & Kipka, 2012).

2. THEORETICAL FRAMEWORK

2.1. Experiential learning

Researchers such as Dewey (1938), Lewin (1957), and Piaget (1970) argued that learning should be acquired through experience (Dewey, 1986; Hedin, 2010; Kolb, 1984; Miettinen, 2000; Roberts, 2003). Similarly, the permanence of knowledge acquired through experiential learning was expressed by Confucius in the words: "I hear and I forget; I see and I remember; I do and I understand" (Vaillancourt, 2009). As these words suggest, in order for knowledge to be understood and transformed into lasting behavior, an individual must practice, perform, or experience it (Yıldız, 2020). Therefore, the knowledge acquired through experience is of great significance.

Influenced by these ideas, Kolb (1984) developed the Experiential Learning Cycle model. As one of the most widely used models in the field of education, experiential learning theory is explained through the interaction between action, reflection, concept, and abstraction. According to Kolb, knowledge emerges from the integration of individuals' processes of understanding, grasping, and transforming lived experience. In this process, knowledge is first acquired through the apprehension of experience and later transformed through interpretation and application. As a result of this synthesis, individuals learn knowledge through experiential methods (Kolb, 2014; Parlar & Çon, 2020).

According to the experiential learning cycle model, the ways of learning are addressed at four fundamental levels:
1. Concrete Experience: Represents the knowledge individuals obtain directly from action.
2. Reflective Observation: Refers to the presence of different perspectives developed in the process of understanding and grasping knowledge.
3. Abstract Conceptualization: Refers to the situation in which the acquired knowledge is understood within a conceptual framework.
4. Active Experimentation: Involves the practical use of acquired knowledge (Evin-Gencel, 2007).

According to this model, individuals who complete the cycle of concrete experience, reflective observation, abstract conceptualization and active experimentation will gain practical experiences in practice and demonstrate effective behaviors (Grant, 2022; Peterson et al., 2015; Vinales, 2015). The experiential learning cycle provides numerous benefits for sports management students, such as the acquisition of workplace skills, instructional support from teachers, learning experiences from the student perspective and case study applications (Donnelly, 2009; Fry et al., 2008; Grant, 2022; Groves et al., 2010; Ha-Brookshire, 2008; Kreber, 2001; Kosnik et al., 2013; Peterson et al., 2015).

One of the most desirable outcomes for sports managers is a high level of employability. Since sports management students will experience a more advanced educational process through experiential learning, it is expected that the skills they must possess will also be more advanced. Therefore, it is argued that training students through experiential learning will provide them with an advantage in entering the workforce after graduation (Lu, 2021). In conclusion, experiential learning is of great importance for the employability of sports managers (Parlar & Çon, 2020).

3. THE CONTRIBUTION OF EXPERIENTIAL LEARNING TO SPORTS MANAGERS

For the past three decades, employers have expected sports managers to possess qualities such as leadership, decision-making, problem-solving, strong communication, and adaptability, all of which are important in terms of employability (Tushar & Sooraksa, 2023). Unfortunately, the transmission of these skills through traditional teaching methods does not appear to be very effective (Yıldız et al., 2022). Studies conducted on experiential learning have revealed that individuals trained through experiential learning develop employability skills including those mentioned above more successfully (Hattie et al., 1997; Martin et al., 2008).

There are many practices used as methods of experiential learning, such as adventure education, active learning, team-based learning, and problem-based learning (Yıldız, 2020). One of these is problem-based learning. Within this practice, students are expected to solve an existing problem in an applied manner (Ajmal et al., 2016). In solving the problem, students first use the knowledge obtained from concrete experience to develop different perspectives. They then engage in abstract conceptualization to consolidate the knowledge learned. Finally, they become ready for application and, in practice, generate solutions to eliminate the problem. In this sense, learning occurs through the transformation of experiences into knowledge. Learners actively participate in the task, reflect on what they have done, develop new insights, and apply them in different contexts (Ulger, 2018). Thus, in addition to theoretical knowledge, practical gains are also achieved.

As a result, the permanence of knowledge increases for students, while their analytical intelligence, critical thinking, problem-solving and rational thinking skills improve (Duncan & Al-Nakeeb, 2006; Duncan et al., 2007; Haritas & Harini, 2025; Lu, 2021; Martin et al., 2008; Synder, 2003). Similarly, individuals who reinforce their knowledge through experience also develop leadership and decision-making skills, since students encounter various and complex situations in practice that they would not face in theory. Thus, by experiencing different circumstances, they learn to address situations comprehensively (Haritas & Harini, 2025). As a result, they will make more informed and accurate decisions by employing situation-specific decision-making strategies (Chandra et al., 2024; Fassbender et al., 2022; Rousseau & McCarthy, 2007).

This instructional method likewise encourages students to actively engage with real-world challenges, while integrating critical and creative thinking to prepare them to become effective leaders in the unpredictable environment of the contemporary business world (Haritas & Harini, 2025). Recent studies have also indicated that active experiential learning leaves more positive effects on students (Kapur, 2012; Kapur & Bielaczyc, 2012; Lu, 2021; Westermann & Rummel, 2012). Among these positive effects is the notion that learners are more motivated because they are involved in the process of creating and sharing knowledge (Brown et al., 2018; Chan, 2012; Grant, 2022; Lu, 2021; Martin & Leberman, 2005; Rambocas & Sastry, 2017).

In conclusion, through experiential learning methods, individuals learn knowledge more permanently by experiencing it, thereby becoming more proficient in the field. In addition, through methods such as internships or problem-based learning, they acquire more advanced metacognitive skills for solving problems they may encounter in real work environments. Moreover, individuals who complete the learning process will possess a more autonomous structure and more developed employability skills (Abdulwahed & Nagy, 2009; Martin et al., 2008; Şahin, 2022).

4. APPLICATIONS OF EXPERIENTIAL LEARNING IN SPORTS MANAGEMENT

There are many educational practices within the scope of experiential learning. These include internships, problem-based applications, case studies, simulations, workshops, and project-based studies (Grant, 2022; Haritas & Harini, 2025; Kolb, 2014). Individuals with internship experience are considered more advantageous for employability as prospective sports managers. This is because, for employers, internships represent an important learning method that enables individuals to learn actively and become more conscious (Brown et al., 2018; Grant, 2022; Gault et al., 2010). An internship is defined as the completion of the learning process through the application of knowledge acquired in schools to the real working environment, thereby developing skills and experience (Barbarash, 2016; Duran & Dolmacı, 2017). Accordingly, instructors integrate experiential applications such as internships into curricula to train more effective sports managers. Thus, while enhancing students' skills and increasing their self-confidence, they also provide employers with the opportunity to have qualified employees (Lu, 2021).

Internships, projects, and other field-based applications serve as a bridge between the theoretical knowledge previously acquired and practical knowledge by creating a real-world perception for students. By synthesizing this knowledge, prospective sports managers will be able to adopt a proactive attitude toward future situations. At the same time, these experiences will contribute positively to designing a roadmap for their career development (Jackson & Tomlinson, 2022).

5. CHALLENGES AND LIMITATIONS

It is known that the experiential learning model develops the skills that students need; however, in some experiential learning practices, outcomes contrary to expectations are observed. For example, within the scope of internship practices, some difficulties prevent students from achieving their intended outcomes. These difficulties generally arise from communication problems between the school, the enterprise, and the student, or from the lack of monitoring mechanisms (Petruzziello et al., 2022). As a result of these problems, students undertaking internships may complete the process formally without achieving the true purpose of the internship. Consequently, students graduate without acquiring field-specific skills, and therefore their employability levels remain low. This constitutes one of the main problems in the field (Duran & Dolmacı, 2017).

Another limitation is the restricted availability of internship opportunities in regions where higher education institutions are located. This leads to a lack of experience. To overcome this limitation, the content of certain courses should be transformed into practice-oriented forms through projects or metaphorical applications (Yıldız et al., 2022).

6. CONCLUSION AND RECOMMENDATIONS

Since sports management is a profession carried out in the field, important outcomes such as ensuring the permanence of knowledge are needed in terms of students' learning processes. The literature reveals the existence of many learning models. However, experiential learning has attracted considerable attention in terms of ensuring effective learning. This is because experiential learning refers to the reinforcement of theoretical knowledge through practice. Moreover, it is known that employability skills—demanded by employers—are more advanced when developed through experiential learning (Grant, 2022; Haritas & Harini, 2025; Lu, 2021).

In conclusion, it can be argued that, according to both sports managers and employers, sports managers trained through experiential learning are more successful in the field.

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REFERENCES

Abdulwahed, M., & Nagy, Z. K. (2009). Applying Kolb's experiential learning cycle for laboratory education. *Journal of engineering education*, *98*(3), 283-294.

Ajmal, F., Jumani, N. B. & Malik, S. (2016). Utilizing problem based learning in pre-service teacher education: Experiences of prospective teachers in Pakistan. *Journal of Education and Human Development, 5*(2), 215-222.

Awad, E. & Ghaziri, H. (2004). Knowledge management, New Jersey: Prentice Hall Publishing.

Barbarash, D. (2016). Knowledge and Skill Competency Values of an Undergraduate University Managed Cooperative Internship Program: A Case Study in Design Education. *Asia-Pacific Journal of Cooperative Education*, *17*(1), 21-30.

Bayter, M., & Alaca, E. (2014). Spor yöneticiliğinde bilgi yönetiminin önemi. *Electronic Turkish Studies*, *9*(2).

Bevan, D., & Kipka, C. (2012). Experiential learning and management education. *Journal of Management Development*, *31*(3), 193-197.

Brown, A., & Rich, M. (2021). Pedagogy and evaluation: The challenge for business and management degree courses in the 21st century. *Electronic Journal of Business Research Methods*, 18(2), 84–99.

Brown, C., Willett, J., Goldfine, R., & Goldfine, B. (2018). Sport management internships: Recommendations for improving upon experiential learning. *Journal of Hospitality, Leisure, Sport & Tourism Education*, *22*, 75-81.

Chan, R. Y. (2016). Understanding the purpose of higher education: An analysis of the economic and social benefits for completing a college degree. *Journal of Education Policy, Planning and Administration*, *6*(5), 1-40.

Chandra, A., Stewart, C. M., & Meyer, C. (2024). An eclectic problem-based learning model in an entrepreneurship capstone course. *The International Journal of Management Education*, *22*(3), 101034.

Datar, S. M., Garvin, D. A., & Cullen, P. G. (2011). Rethinking the MBA: Business education at a crossroads. *Journal of Management Development*, *30*(5), 451-462.

Dewey, J. (1938). Experience and education. New York, NY: Macmillan.

Dewey, J. (1986). Experience and education. *In The educational forum*, 50 (3), 241-252).

Doğar, Y. (1997). Spor Yönetiminde Özel Analiz. *Malatya: Öz Akdeniz Ofset*.

Donnelly, R. (2009). Supporting Teacher Education through a Combined Model of Philosophical, Collaborative and Experiential Learning. *Journal of the Scholarship of Teaching and Learning*, *9*(1), 35-63.

Duncan, M. J., & Al-Nakeeb, Y. (2006). Using problem based learning in sports related courses: An overview of module development and student responses in an undergraduate Sports Studies module. *Journal of Hospitality, Leisure, Sport and Tourism Education*, *5*(1), 50-57.

Duncan, M. J., Lyons, M., & Al-Nakeeb, Y. (2007). You have to do it rather than being in a class and just listening': The impact of problem-based learning on the student experience in sports and exercise biomechanics'. *Journal of Hospitality, Leisure, Sport and Tourism Education*, *6*(1), 71-80.

Duran, Y., & Dolmacı, N. (2017). Ön Lisans Düzeyinde Öğrenim Gören Öğrencilerin Zorunlu Staj Uygulamasına İlişkin Görüşleri, Sorunları ve Çözüm Önerileri: Isparta Meslek Yüksekokulu Örneği. *Mehmet Akif Ersoy University Journal Of Social Sciences Institute*, *9*(21), 254-267.

Fassbender, U., Papenbrock, J., & Pilz, M. (2022). Teaching entrepreneurship to life-science students through problem based learning. *International Journal of Management in Education,* 20(3), 100685.

Finch Brown, T. (2019). The Impact Program: Increasing Employability Skills of High School Students Through Adventure Based Learning. *PCOM Psychology Dissertations*. 496. https://digitalcommons.pcom.edu/psychology_dissertations/496

Fry, H., Ketteridge, S., & Marshall, S. (2008). *A handbook for teaching and learning in higher education: Enhancing academic practice*. Routledge.

Hattie, J., Marsh, H. W., Neill, J. T., & Richards, G. E. (1997). Adventure education and Outward Bound: Out-of-class experiences that make a lasting difference. *Review of educational research, 67*(1), 43-87.

Jackson, D., & Tomlinson, M. (2022). The relative importance of work experience, extra-curricular and university-based activities on student employability. *Higher Education Research & Development*, *41*(4), 1119-1135.

Lu, H. F. (2021). Enhancing university student employability through practical experiential learning in the sport industry: An industry-academia cooperation case from Taiwan. *Journal of Hospitality, Leisure, Sport & Tourism Education*, *28*, 100301.

Gencel, İ. E. (2007). Kolb'un deneyimsel öğrenme kuramına dayalı öğrenme stilleri envanteri-III'ü Türkçeye uyarlama çalışması. *Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 9*(2), 120-139

Grant, M. T. (2022). Practical Experiences that Signal the Employability of Graduates from Undergraduate Sport Management Programs During Job Recruitment and Selection *(Unpublished Doctoral dissertation, Victoria University).*

Groves, M., Bowd, B., & Smith, J. (2010). Facilitating experiential learning of study skills in sports students. *Journal of Further and Higher Education*, *34*(1), 11-22.

Gulick, L. (1935, June). Saturday afternoon session. In *Minutes of the Proceedings of the Conference on Training for the Public Service, Princeton, NJ, June 22* (Vol. 24).

Güçlü, N. (2003). Stratejik yönetim*. Gazi Üniversitesi Gazi Eğitim Fakültesi Dergisi, 23(2).*

Ha-Brookshire, J. (2008). Exploring learning experience in textile and apparel management: study abroad in El Salvador. *International Journal of Fashion Design, Technology and Education*, *1*(3), 113-123.

Haritas, I., & Harini, K. N. (2025). 'Solving'as a key course learning outcome (CLO) in postgraduate (PG) management education. *The International Journal of Management Education*, *23*(3), 101225.

Hedin, N. (2010). Experiential learning: Theory and challenges. *Christian education journal*, *7*(1), 107-117.

Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, 40(4), 651–672.

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *The Journal of the Learning Sciences, 21*(1), 45–83.

Ko, L. M., Henry, I., & Kao, J. C. H. (2011). The perceived importance of sport management competencies by academics and practitioners in the cultural/industrial context of Taiwan. *Managing Leisure*, *16*(4), 302-317.

Kolb, D. (1984). Experiential Learning: turning experience into learning. *Englwood Cliffs: Prentice Hall*.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT press.

Kosnik, R. D., Tingle, J. K., & Blanton III, E. L. (2013). Transformational learning in business education: The pivotal role of experiential learning projects. *American Journal of Business Education*, *6*(6), 613.

Kreber, C. (2001). Learning experientially through case studies? A conceptual analysis. *Teaching in higher education*, *6*(2), 217-228.

Lee, J. W., & Lupi, M. H. (2010). Issues in international internships. *A practical guide to sport management internships*, 103-120.

Lewin, K. (1957). Field theory in social science: Selected theoretical papers (2nd ed.). London, England: Tavistock.

Lu, H. F. (2021). Enhancing university student employability through practical experiential learning in the sport industry: An industry-academia cooperation case from Taiwan. Journal of Hospitality, Leisure, Sport & Tourism Education, 28, 100301.

Martin, A. J., & Leberman, S. I. (2005). Keeping up with the play: Practicum, partnership and practice. *Asia-Pacific Journal of Cooperative Education*, *6*(2), 17-25.

Martin, L., West, J., & Bill, K. (2008). Incorporating problem-based learning strategies to develop learner autonomy and employability skills in sports science undergraduates. *Journal of Hospitality, Leisure, Sport & Tourism Education.*, *7*(1), 18-30.

Miettinen, R. (2000). The concept of experiential learning and John Dewey's theory of reflective thought and action. *International journal of lifelong education*, *19*(1), 54-72.

Navarro, P. (2008). The MBA core curricula of top-ranked US business schools: a study in failure?. *Academy of management learning & education*, *7*(1), 108-123.

Parlar, F. M., & Çon, M. (2020). Spor yöneticisi adaylarının öğrenme stilleri ile yaratıcı kişilik özellikleri arasındaki ilişki. *Turkish Studies, 15(5), 3607-3626.*

Peretto Stratta, T. M. (2004). The needs and concerns of students during the sport management internship experience. *Journal of Physical Education, Recreation & Dance*, *75*(2), 25-29.

Peterson, K., DeCato, L., & Kolb, D. A. (2015). Moving and learning: Expanding style and increasing flexibility. *Journal of Experiential Education*, *38*(3), 228-244.

Piaget, J. (1970). Piaget's theory (G. Gellerier & J. Langer, Trans.). In P. H. Mussen (Ed.), Carmichael's manual of child psychology (3rd ed., Vol. 1, pp. a-b). New York, NY: Wiley.

Prince, K. J., Van Eijs, P. W., Boshuizen, H. P., Van Der Vleuten, C. P., & Scherpbier, A. J. (2005). General competencies of problem-based learning (PBL) and non-PBL graduates. *Medical education*, *39*(4), 394-401.

Petruzziello, G., Mariani, M. G., Guglielmi, D., van der Heijden, B. I. J. M., de Jong, J. P., & Chiesa, R. (2022). The role of teaching staff in fostering perceived employability of university students. *Studies in Higher Education, 48*(1), 20–36. https://doi.org/10.1080/03075079.2022.2105830

Rambocas, M., & Sastry, M. K. (2017). Teaching business management to engineers: The impact of interactive lectures. *IEEE Transactions on Education*, *60*(3), 212-220.

Roberts, T. G. (2003). An Interpretation of Dewey's Experiential Learning Theory. *Knowledge Acquisition.*

Rousseau, D. M., & McCarthy, S. (2007). Educating managers from an evidence-based perspective. *Academy of Management Learning & Education*, *6*(1), 84-101.

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. (2011). The process of problem-based learning: what works and why. *Medical education*, *45*(8), 792-806.

Schön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions.* Jossey-Bass.

Stuhr, P. T., & Denny, A. L. (2022). The lived experience of mindfulness in adventure-based learning. *Education Sciences*, *12*(9), 630.

Şahin, Ç. Ç. (2022). Öğretmenlerin deneyimsel öğrenme ile ilgili görüşlerinin incelenmesi. *Çağdaş Yönetim Bilimleri Dergisi, 9(2), 60-71.*

Tortop, N., İsbir, E. G., Aykaç, B., Yayman, H., & Özer, M. A. (2010). *Yönetim bilimi*. Nobel Akademik Yayıncılık.

Tushar, H., & Sooraksa, N. (2023). Global employability skills in the 21st century workplace: A semi-systematic literature review. *Heliyon*, *9*(11).

Tsitskari, E., Goudas, M., Tsalouchou, E., & Michalopoulou, M. (2017). Employers' expectations of the employability skills needed in the sport and recreation environment. *Journal of hospitality, leisure, sport & tourism education*, *20*, 1-9.,

Ulger, K. (2018). The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. *Interdisciplinary Journal of Problem-Based Learning, 12(*1), 1-21. https://doi.org/10.7771/1541-5015.1649

Vaillancourt, R. (2009). I Hear And I Forget, I See And I Remember, I Do And I Understand. *The Canadian Journal Of Hospital Pharmacy*, *62*(4), 272.

Vinales, J. J. (2015). The learning environment and learning styles: a guide for mentors. *British Journal of Nursing*, *24*(8), 454-457.

Yıldız, N. O. (2020). Sporda yönetsel macera eğitim uygulamalarının zihinsel süreçler üzerine etkisi. *Yayınlanmamış Doktora Tezi. Bolu Abant İzzet Baysal Üniversitesi, Lisansüstü Eğitim Enstitüsü*.

Yıldız, N. O., Bostancı, T. G., & Kaçay, Z. (2022). Bir Günlük İç Mekan Macera Eğitim Uygulamalarının Yaratıcı Kişilik Özellikleri Üzerine Etkisi. *Mediterranean Journal of Sport Science*, *5*(Özel Sayı 2), 818-828.

The relationship between perceived organizational deviance behavior and alienation from academics: The example of a faculty of sports sciences

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Abstract: This study examined the relationship between perceived organizational deviance behavior and levels of alienation from academics among academics working at a faculty of sports sciences, and evaluated differences across several demographic variables. This study, conducted using a correlational survey model, a quantitative research method, comprised a total of 215 academics (130 male and 85 female) working in various departments of the Faculty of Sports Sciences. Data were collected using a personal information form, the Perceived Organizational Deviance Scale, and the Alienation from Academics Scale. Data were analyzed using t-tests, Mann Whitney U tests, One-Way ANOVA, Kruskall Wallis-H test, and Pearson product-moment correlation analysis. The findings revealed differences in some sub-dimensions of Alienation from Academics and Organizational Deviance Behaviors based on demographic characteristics. Conversely, it has been found that deviant behaviors in educational activities decrease as self-alienation increases, and that deviant behaviors in educational activities increase as isolation increases. Consequently, even though academics may feel alienated from their professional identity, they may still maintain a commitment to educational activities such as course preparation, student interaction, and social responsibility. This can be considered an important outcome in terms of academic ethics.

Keywords: Academician, organization, perceived organizational deviance, alienation

Algılanan örgütsel sapma davranışı ile akademisyenden yabancılaşma arasındaki ilişki: spor bilimleri fakültesi örneği

Özet: Bu çalışmada spor bilimleri fakültesinde iş gören akademisyenlerin algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeyleri arasındaki ilişki incelenerek, bazı demografik değişkenler arasındaki farklılıklar değerlendirilmiştir. Nicel araştırma yöntemlerinden ilişkisel tarama modeliyle gerçekleştirilen bu araştırmada, çalışma grubunu Spor Bilimleri Fakültesinin farklı bölümlerinde iş gören 130 erkek ve 85 kadından oluşan toplam 215 akademisyen oluşturmuştur. Verilerin toplanmasında kişisel bilgi formu, Algılanan Örgütsel Sapma Ölçeği ve Akademisyenliğe Yabancılaşma Ölçeği kullanılmıştır. Verilerin analizinde T-Testi ve Mann Whitney U testleri ile One Way Anova testi ve Kruskall Wallis-H testi, Pearson Momentler Çarpımı Korelasyon analizi kullanılmıştır. Bulgular sonucunda, Akademisyenliğe Yabancılaşma ile Örgütsel Sapma Davranışları bazı demografik özelliklere göre bazı alt boyutlarında farklılık görülmüştür. Diğer taraftan, kendine yabancılaşma arttıkça eğitsel etkinliklere yönelik sapma davranışlarının azaldığı tespit edilmiştir ve yalıtılmışlık arttıkça eğitsel etkinliklere yönelik sapma davranışlarının da arttığı ortaya konulmuştur. Sonuç olarak, akademisyenler mesleki kimliğinden uzaklaşmış hissetseler de ders hazırlığı, öğrencilerle etkileşim, sosyal sorumluluk gibi eğitsel etkinliklere karşı bağlılık gösterebilirler. Bu da akademik etik açısından önemli bir sonuç olarak düşünülebilir.

Keywords: Akademisyen, örgüt, algılanan örgütsel sapma, yabancılaşma

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1. GİRİŞ

Spor, insanlık tarihi boyunca fiziksel hareketlerle hayatta kalma ve yaşamı sürdürme amacı taşıyan bir kavram olarak tanımlanmaktadır. Sporun tarihsel gelişimine bakıldığında, kökenlerinin avcılık ve toplayıcılıkla geçimini sağlayan ilk insan topluluklarının doğada hayatta kalmak için gösterdiği çabalara dayandığı görülmektedir. İlk spor türleri genellikle aletli ya da aletsiz olarak, bireyin kendini koruma ve tehlikelere karşı savunma ihtiyacından ortaya çıkmıştır (Dağlı Ekmekçi ve ark., 2012).

Bireylerin yalnızca fiziksel etkinliklerle sınırlı kalmadığı, aynı zamanda disiplinler arası niteliği, örgütsel yapısı ve kültürel boyutlarıyla ele alan spor, yükseköğretim kurumlarında özgün bir kurumsal alan oluşturmaktadır. Spor bilimleri fakültelerinde görev yapan akademisyenler, kuramsal yapının yanında uygulamaya dönük çeşitli sorumlulukları eş zamanlı olarak üstlenmektedir. Bu durum, örgütsel yapıların analiz edilmesi açısından kendine özgü imkânlar sunmaktadır. Ancak içinde bulunulan akademik çevreler, zaman zaman akademisyenler tarafından etik dışı ya da kurumsal normlara aykırı davranışların yaygın olduğu yönünde bir algının, yani algılanan örgütsel sapma davranışının

ortaya çıkmasına neden olabilmektedir. Bu kavram, çalışanların kurumsal normların ihlal edildiğini gözlemlemesi ya da bu tür davranışların sistematik hâle geldiğini düşünmesi sonucunda ortaya çıkmaktadır (Ağalday, 2022).

Demir (2009) sapma davranışını; yasalara, kurallara, toplumsal normlara, gelenek ve göreneklere uymayan, bu uygulama ve kuralların aksine yönde gerçekleştirilen her türlü davranış olarak tanımlanmaktadır. Thomas (2003) ise sapma davranışını; genel kabul görmüş norm ve kurallara uymayan, içerisinde ihlali barındıran ilişkili taraflar ve toplum tarafından olumsuz olarak nitelendirilen davranışlar olarak ele alınmaktadır. En genel tanımıyla örgütsel sapma davranışı (Dunlop ve Lee, 2004), örgütün etkinliğini ve performansını olumsuz etkileme ya da bir örgütün kabul ettiği kural veya normlardan bilinçli olarak uzaklaşma durumu olarak ifade edilmektedir.

Husu (2001)'e göre akademisyenler, üniversitelerin yönetim, eğitim, araştırma-geliştirme ve topluma hizmet gibi temel işlevlerinde görev alan uzman kişiler olarak tanımlanmaktadır. "Akademisyenlik" terimi ise köken olarak, Platon'un öğrencilerine ders verdiği yer olan "Academeia" sözcüğünden gelmektedir. Bu kavram, üniversitelerden beklenen toplumsal işlevleri yerine getirme çabası içinde olan bireyleri tanımlamaktadır (Balon, 2010). Akademisyenliğe yabancılaşma, bireyin mesleki kimliğinden uzaklaşması, yaptığı işi anlamlı görmekte zorlanması ya da sadece bir zorunluluk olarak algılaması ve bunun sonucunda motivasyon kaybı yaşaması şeklinde açıklanmaktadır. Çalışanların mesleklerine duydukları aidiyetin zayıflaması ya da yaptıkları işe karşı yabancılaşma hissetmeleri, akademik meslek grubu için özgün bir durum olarak ortaya çıkmaktadır (Şimşek vd., 2012; Silah, 2005). Akademisyenler ve öğrenciler eğitim süreçlerinin temel bileşenlerini oluşturmaktadır. Öğrencilerin eğitim sürecine yönelik yabancılaşma durumları çoğunlukla akademisyenlerin tutumlarıyla şekillenmektedir. Sınıf ortamında beklentileri karşılanmayan ya da akademisyenlerle etkili iletişim kuramayan öğrencilerde yabancılaşma eğilimleri gözlemlenmektedir (Kaya, 2008). Eğitimde yabancılaşma kavramında akademisyenler temel bir unsur olarak öne çıkmaktadır. Eğitimin tüm kademelerinde gözlemlenebilen yabancılaşma olgusu, iş yaşamında özellikle eğitimin bir parçası olan üniversitelerde karşılaşılması muhtemel bir durum olarak değerlendirilmektedir. Bu bağlamda, üniversite düzeyinde yaşanan yabancılaşma sürecinin öznesini akademisyenler oluşturmaktadır (Yıldız, 2019).

Yapılan çalışmada spor bilimleri fakültesindeki akademisyenlerin algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeylerinin bazı demografik değişkenler açısından incelenmesi yararlı olacaktır. Çünkü söz konusu fakültelerde akademisyenlerin akademik alandaki misyonları, algılanan örgütsel sapma algısını etkilemesinin yanında, mesleki aidiyet duygusunun kopmasına ve akademik alana yabancılaşmasına zemin hazırlayabilir. Dolayısıyla spor bilimleri fakültesindeki akademisyenlerin algılanan örgütsel sapma algısı ile akademisyenliğe yabancılaşma arasındaki ilişkinin; iş doyumu değişkenleri, yükseköğretim yönetimi, örgütsel davranış ve spor bilimleri alanıyla birlikte analiz edilmesi literatüre oldukça değerli bilgiler sağlayabilir.

Hipotezler;

Yukarıda belirtilen literatür kapsamında ve çalışmanın amacı doğrultusunda, geliştirilen hipotezler şu şekildedir:

H1: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışı, cinsiyet değişkenine göre anlamlı düzeyde farklılık göstermektedir.

H2: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışı, medeni durum değişkenine göre anlamlı düzeyde farklılık göstermektedir.

H3: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışı, unvan değişkenine göre anlamlı düzeyde farklılık göstermektedir.

H4: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışı, hizmet yılı değişkenine göre anlamlı düzeyde farklılık göstermektedir.

H5: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin **akademisyenliğe yabancılaşma düzeyi, cinsiyet değişkenine göre** anlamlı düzeyde farklılık göstermektedir.

H6: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin **akademisyenliğe yabancılaşma düzeyi,** medeni durum **değişkenine göre** anlamlı düzeyde farklılık göstermektedir.

H7: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin **akademisyenliğe yabancılaşma düzeyi,** unvan **değişkenine göre** anlamlı düzeyde farklılık göstermektedir.

H8: Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin **akademisyenliğe yabancılaşma düzeyi,** hizmet yılı değişkenine **göre** anlamlı düzeyde farklılık göstermektedir.

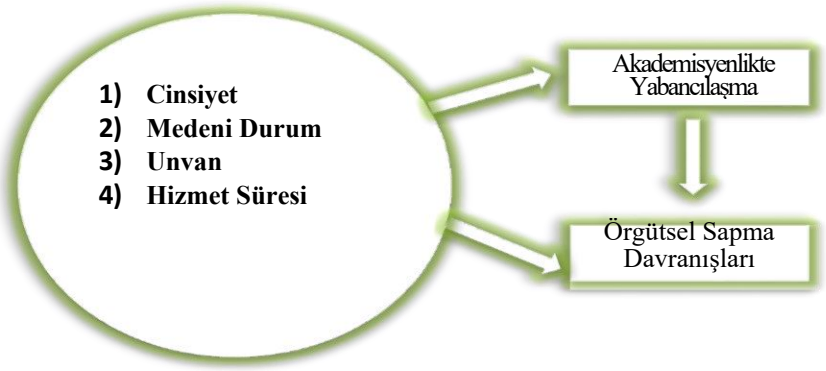
H₉:Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeyleri arasında anlamlı bir ilişki vardır.

2. MATERYAL VE METOT

2.1.Araştırma modeli

İlişkisel tarama modelinde tasarlanan bu araştırmada, Spor Bilimleri Fakültesinde İş gören akademisyenlerin akademisyenlikte yabancılaşma düzeyleri ile Örgütsel Sapma Davranışları arasındaki ilişkiler incelenmiştir. "Bu modelde, iki ya da daha fazla sayıdaki değişken arasındaki birlikte değişimin varlığının ve/veya derecesinin belirlemesi amaçlanır (Fraenkel ve ark 2012, Creswell ve Creswell 2017)." Araştırma kapsamında oluşturulan model Şekil 1'de sunulmuştur.

Şekil 1. Araştırma modeli



2.2. Araştırma grubu

Araştırmaya 85'i (%39.5) kadın, 130'u (%60.5) erkek olmak üzere toplam 215 katılımcı gönüllü olarak katılmıştır. Katılımcılara ilişkin demografik bilgilerin dağılımı Tablo 1'de sunulmuştur.

Tablo 1. Araştırma grubuna ilişkin tanimlayici istatistiki bilgiler

Değişkenler		**N**	**%**
Cinsiyet	Kadın	85	39.5
	Erkek	130	60.5
Medeni Durum	Evli	102	47.4
	Bekar	113	52.6
Ünvan	Profesör	24	11.2
	Doçent	29	13.5
	Dr. Öğr. Üyesi	31	14.4
	Öğretim Görevlisi	41	19.1
	Araştırma Görevlisi	90	41.9
Hizmet Süresi	0-5 Yıl	100	46.5
	6-10 Yıl	46	21.4
	11-15 Yıl	33	15.3
	16 ve üzeri	36	16.7

N=215

2.3.Veri toplama araçları

2.3.1. Kişisel bilgi formu

Araştırmacı tarafından geliştirilen Kişisel Bilgi Formu 4 sorudan oluşmaktadır. Kişisel Bilgi formu katılımcıların cinsiyet, medeni durum, unvan ve hizmet yılı değişkenlerine ilişkin bilgi toplamak amacıyla hazırlanmıştır.

2.3.2. Akademisyenlikte yabancılaşma ölçeği

Bu ölçek formu akademisyenlerin mesleklerine yabancılaşma düzeylerini belirlemek amacıyla Yıldız ve Alıcı (2019) tarafından geliştirilmiştir. Ölçek formu, beş alt boyut (kendine yabancılaşma 7 madde, bilimsel araştırmaya yabancılaşma 5 madde, öğretime yabancılaşma 3 madde, yalıtılmışlık 3 madde ve güçsüzlük 3 madde) ve 21 maddeden oluşmaktadır. Araştırmada 5'li Likert ölçek kullanılmıştır. Ölçekte yer alan maddelerin puanlanmasında, (Kesinlikle katılmıyorum, katılmıyorum, kararsızım, katılıyorum ve kesinlikle katılıyorum) skalalarından yararlanılmıştır.

2.3.3. Örgütsel sapma davranışları

Bu ölçek formu, akademisyenlerin çalıştıkları kurumdaki örgütsel sapma davranışlarını algılama düzeylerini belirlemek amacıyla **Türkkaş Anasız ve Iliman Püsküllüoğlu (2018)** tarafından geliştirilmiştir. Ölçek formu, dört alt boyut **(örgütsel ilişkilere yönelik sapma davranışları – 7 madde, örgütsel işleyişe yönelik sapma davranışları – 5 madde, eğitsel etkinliklere yönelik sapma davranışları – 7 madde ve araştırma ile yayına yönelik sapma davranışları – 7 madde)** ve toplam **26 maddeden** oluşmaktadır. Araştırmada **5'li Likert ölçek** kullanılmıştır. Ölçekte yer alan maddelerin puanlanmasında, **"Hiçbir zaman, nadiren, bazen, sık sık, her zaman"** derecelendirme skalasından yararlanılmıştır.

2.4. Verilerin çözümlenmesi

Ölçeklerden elde edilen verilerin istatistiksel analizi için Microsoft Excel ve SPSS 25.0 bilgisayar programı kullanılmıştır. Bu aşamadan sonra araştırma kapsamında kullanılan ölçeklere ilişkin Cronbach Alpha iç tutarlık katsayısı incelenmiş ve değerlerin güvenilir olduğu görülmüştür (Tablo 2) Ölçeklerin iç tutarlık katsayıları belirlendikten sonra ilk olarak normallik varsayımları için öne çıkan çarpıklık basıklık değerleri incelenmiş ve dağılımın bazı alt boyutlarda normal olduğu tespit edilmiştir (George & Mallery 2010; Tablo 2).Bu doğrultuda cinsiyet ve medeni durum değişkenlerine göre ölçeklerden alınan puanlara arasındaki farkları belirlemek için T-Testi ve Mann Whitney U testleri kullanılmıştır. Ayrıca unvan ve hizmet süresi değişkenlerine göre katılımcıların ölçeklerden almış olduğu puanlar arasında fark olup olmadığını belirlemek için One Way Anova testi ve Kruskall Wallis-H Testleri kullanılmıştır. Bu analizler neticesinde farkın kaynağını belirlemek adına ise Post-Hoc Tukey ve Spearman testlerinden yararlanılmıştır. Araştırma kapsamında değişkenler arasındaki ilişkileri belirlemek için ise Pearson Momentler Çarpımı Korelasyon analizi kullanılmıştır. Bu analiz neticesinde katsayılar Schober ve ark., (2018)'e göre değerlendirilmiştir (.00-.10: önemsiz, .10-.39: zayıf, .40-.69: orta, .70-.89: güçlü, .90-1: çok güçlü)

3. BULGULAR

Tablo 2. Akademisyenliğe yabancılaşma ile örgütsel sapma davranışına ilişkin ölçeğine ilişkin ortalama, standart sapma, çarpıklık, basıklık ve cronbach alpha değerleri

Ölçekler	**Alt Boyutlar**	**N**	$\bar{x}$	**Ss**	**Çarpıklık**	**Basıklık**	**CR (α)**
Akademisyenliğe Yabancılaşma Ölçeği	Kendine Yabancılaşma	215	27.64	5.36	-.74	1.37	.90
	Bilimsel Araştırmaya Yabancılaşma	215	15.61	3.38	.61	1.73	.60
	Öğretime Yabancılaşma	215	9.09	2.12	.95	1.95	.77
	Yalıtılmışlık	215	7.02	2.73	.56	.06	.84
	Güçsüzlük	215	7.92	1.99	.61	2.79	.40
	Akademisyenliğe Yabancılaşma Toplam	215	67.28	10.90	.22	5.18	.84
Örgütsel Sapma Davranışı Ölçeği	Örgütsel İlişkilere Yönelik Sapma Davranışları	215	9.60	4.68	2.75	7.55	.94
	Örgütsel İşleyişe Yönelik Sapma Davranışları	215	6.03	2.37	3.22	10.82	.90
	Eğitsel Etkinliklere Yönelik Sapma Davranışları	215	9.40	4.07	2.36	5.48	.92
	Araştırma ve Yayına Yönelik Sapma Davranışları	215	8.95	3.69	2.62	6.60	.89
	Örgütsel Sapma Davranışı Toplam	215	33.97	13.78	2.79	7.52	.97

Tablo 2'de çarpıklık değerlerinin-.74. ile 3.22 arasında basıklık değerlerinin ise .06 ile 10.82 arasında olduğu tespit edilmiştir. George & Mallery (2010) önerdiği- 2. +2 çarpıklık basıklık değerleri dikkate alındığında dağılımın bazı alt boyutlarda normal olduğu tespit edilmiştir. Bununla birlikte araştırma kapsamında kullanılan Akademisyenliğe Yabancılaşma Ölçeğinin toplam puan ve alt boyutlarından elde edilen iç tutarlık katsayılarının .60 ile .90 arasında değiştiği görülmektedir. Örgütsel Sapma Davranışı Ölçeği toplam puan ve alt boyutlarından elde edilen iç tutarlık katsayılarının .89 ile .97 arasında değiştiği görülmektedir.

Tablo 3. Cinsiyet değişkenine göre akademisyenliğe yabancılaşma ile örgütsel sapma davranış ölçeğine ilişkin sonuçlar

Ölçekler	**Alt Boyutlar**	**Cinsiyet**	**N**	$\overline{X}$	**Ss**	**t**	**df**	**p**
Akademisyenliğe Yabancılaşma Ölçeği	Kendine Yabancılaşma	Kadın	85	27.62	6.08	-.04	213	,97
		Erkek	130	27.65	4.86			
	Bilimsel Araştırmaya Yabancılaşma	Kadın	85	15.61	3.62	.01	213	.99
		Erkek	130	15.61	3.22			
	Öğretime Yabancılaşma	Kadın	85	9.25	2.35	.86	213	.39
		Erkek	130	8.99	1.95			
	Yalıtılmışlık	Kadın	85	7.07	2.97	.23	213	.82
		Erkek	130	6.98	2.57			
				Sıra Ort.	**Sıra Top.**	**Z**	**U**	**P**
	Güçsüzlük	Kadın	85	108.28	9204.00	-.06	5501.00	.96
		Erkek	130	107.82	14016.00			
	Akademisyenliğe Yabancılaşma Toplam	Kadın	85	112.65	9575.00	-.89	5130.00	.37
		Erkek	130	104.96	13645.00			
Örgütsel Sapma Davranışı Ölçeği	Örgütsel İlişkilere Yönelik Sapma Davranışları	Kadın	85	99.89	8491.00	-1.63	4836.00	.10
		Erkek	130	113.30	14729.00			
	Örgütsel İşleyişe Yönelik Sapma Davranışları	Kadın	85	105.19	8941.50	-.66	5286.50	.51
		Erkek	130	109.83	14278.50			
	Eğitsel Etkinliklere Yönelik Sapma Davranışları	Kadın	85	104.15	8852.50	-.79	5197.50	.43
		Erkek	130	110.52	14367.50			
	Araştırma ve Yayına Yönelik Sapma Davranışları	Kadın	85	105.36	8955.50	-.55	5300.50	.58
		Erkek	130	109.73	14264.50			
	Örgütsel Sapma Davranışı Toplam	Kadın	85	101.75	8648.50	-1.21	4993.50	.23
		Erkek	130	112.09	14571.50			

Tablo 3'te katılımcıların Akademisyenliğe Yabancılaşma ile Örgütsel Sapma Davranışı cinsiyet değişkenine göre incelendiğinde anlamlı farklılık tespit edilmemiştir ($p>0.05$).

Tablo 4. Medeni Durum değişkenine göre Akademisyenliğe Yabancılaşma ile Örgütsel Sapma Davranış Ölçeğine İlişkin Sonuçları

Tablo 4'te katılımcıların Akademisyenliğe Yabancılaşma ölçeği medeni durum değişkenine göre farklılaşma durumu

Ölçekler	**Alt Boyutlar**	**Cinsiyet**	**N**	**$\overline{X}$**	**Ss**	**t**	**df**	**p**
Akademisyenliğe Yabancılaşma Ölçeği	Kendine Yabancılaşma	Bekar	102	26.75	6.07	-2.35	213	**.02**
		Evli	113	28.45	4.51			
	Bilimsel Araştırmaya Yabancılaşma	Bekar	102	15.07	3.41	-2.25	213	**.03**
		Evli	113	16.10	3.28			
	Öğretime Yabancılaşma	Bekar	102	8.72	1.91	-.2.51	213	**.01**
		Evli	113	9.43	2.25			
	Yalıtılmışlık	Bekar	102	6.81	2.47	-1.05	213	.30
		Evli	113	7.20	2.94			
				Sıra Ort.	**Sıra Top.**	**Z**	**U**	**P**
	Güçsüzlük	Bekar	102	110.83	11304.50	-.65	5474.50	.52
		Evli	113	105.45	11915.50			
	Akademisyenliğe Yabancılaşma Toplam	Bekar	102	100.36	10236.50	-1.72	4983.50	.09
		Evli	113	114.90	12983.50			
Örgütsel Sapma Davranışı Ölçeği	Örgütsel İlişkilere Yönelik Sapma Davranışları	Bekar	102	102.65	10470.00	-1.27	5217.00	.20
		Evli	113	112.83	12750.00			
	Örgütsel İşleyişe Yönelik Sapma Davranışları	Bekar	102	101.70	10373.50	-1.73	5120.50	.08
		Evli	113	113.69	12846.50			
	Eğitsel Etkinliklere Yönelik Sapma Davranışları	Bekar	102	103.93	10600.50	-.98	5347.50	.33
		Evli	113	111.68	12619.50			
	Araştırma ve Yayına Yönelik Sapma Davranışları	Bekar	102	111.86	11410.00	-.95	5369.00	.34
		Evli	113	104.51	11810.00			
	Örgütsel Sapma Davranışı Toplam	Bekar	102	105.35	10745.50	-.60	5492.50	.55
		Evli	113	110.39	12474.50			

incelendiğinde, kendine yabancılaşma, bilimsel araştırmaya yabancılaşma, öğretime yabancılaşma alt boyutlarında evliler lehine anlamlı farklılık görülmüştür ($p<0.05$). Ancak güçsüzlük alt boyutunda ve akademisyenliğe yabancılaşma toplam puanlarında anlamlı farklılık görülmemiştir ($p>0,05$). Diğer taraftan Örgütsel Sapma Davranışı ölçeği alt boyut ve toplam puanlarında anlamlı farklılık tespit edilmemiştir ($p>0.05$).

Tablo 5. Ünvan değişkenine göre akademisyenliğe yabancılaşma ile örgütsel sapma davranış ölçeğine ilişkin sonuçlar

Ölçekler	Alt Boyutlar	Unvan	$\bar{X}$	Ss	df	F	p	Farkın Kaynağı
		A: Profesör	30.178	4.21				
		B: Doçent	27.792	3.77				
	Kendine Yabancılaşma	C: Dr. Öğretim Üyesi	28.35	5.00	4 210 214	2.62	**.03**	**A>E**
		D: Öğretim Görevlisi	28.02	4.63				
		E: Araştırma Görevlisi	26.50	6.22				
		A: Profesör	16.888	4.67				
		B: Doçent	15.312	2.30				
	Bilimsel Araştırmaya Yabancılaşma	C: Dr. Öğretim Üyesi	17.26	3.27	4 210 214	3.90	**.04**	**C>D**
		D: Öğretim Görevlisi	15.27	2.64				
		E: Araştırma Görevlisi	14.96	3.39				
Akademisyenliğe Yabancılaşma Ölçeği		A: Profesör	10.718	2.66				
		B: Doçent	8.622	1.52				
	Öğretime Yabancılaşma	C: Dr. Öğretim Üyesi	9.61	2.72	4 210 214	5.46	**.00**	**A>B** **A>D** **A>E**
		D: Öğretim Görevlisi	8.83	1.79				
		E: Araştırma Görevlisi	8.76	1.82				
		A: Profesör	8.048	3.24				
		B: Doçent	6.902	2.60				
	Yalıtılmışlık	C: Dr. Öğretim Üyesi	7.65	3.14	4 210 214	1.80	**.12**	**---**
		D: Öğretim Görevlisi	6.49	2.59				
		E: Araştırma Görevlisi	6.81	2.48				
			Sıra Ortalaması	**H**	**df**	**p**		**Fark**
		A: Profesör	116.088					
		B: Doçent	106.412					
	Güçsüzlük	C: Dr. Öğretim Üyesi	104.37	.85	4	.93	**--**	**-**
		D: Öğretim Görevlisi	103.49					
		E: Araştırma Görevlisi	109.66					

	Akademisyenliğe Yabancılaşma Toplam	A: Profesör	133.38				
		B: Doçent	104.95				
		C: Dr. Öğretim Üyesi	129.87	10.80	4	**.03**	**A>B-C-D-E**
		D: Öğretim Görevlisi	97.61				
		E: Araştırma Görevlisi	99.42				
Örgütsel Sapma Davranışı Ölçeği	Örgütsel İlişkilere Yönelik Sapma Davranışları	A: Profesör	112.19				
		B: Doçent	117.38				
		C: Dr. Öğretim Üyesi	118.37	3.54	4	.48	----
		D: Öğretim Görevlisi	108.88				
		E: Araştırma Görevlisi	99.89				
	Örgütsel İşleyişe Yönelik Sapma Davranışları	A: Profesör	112.71				
		B: Doçent	118.16				
		C: Dr. Öğretim Üyesi	121.66	5.74	4	.21	----
		D: Öğretim Görevlisi	103.50				
		E: Araştırma Görevlisi	100.82				
	Eğitsel Etkinliklere Yönelik Sapma Davranışları	A: Profesör	117.60				
		B: Doçent	120.76				
		C: Dr. Öğretim Üyesi	125.98	8.09	4	.09	----
		D: Öğretim Görevlisi	100.05				
		E: Araştırma Görevlisi	98.76				
	Araştırma ve Yayına Yönelik Sapma Davranışları	A: Profesör	106.77				
		B: Doçent	119.64				
		C: Dr. Öğretim Üyesi	104.40	1.51	4	.82	----
		D: Öğretim Görevlisi	104.66				
		E: Araştırma Görevlisi	107.34				
	Örgütsel Sapma Davranışı Toplam	A: Profesör	116.63				
		B: Doçent	116.91				
		C: Dr. Öğretim Üyesi	117.56	3.51	4	.55	----
		D: Öğretim Görevlisi	103.74				
		E: Araştırma Görevlisi	101.47				

A: Profesör N=24, B: Doçent N=29, C: Dr. Öğr. Üyesi N=31, D: Öğretim Görevlisi N=41, E: Araştırma Görevlisi N= 90

Tablo 5'te Akademisyenliğe Yabancılaşma Ölçeği unvan değişkenine göre incelendiğinde, Kendine Yabancılaşma alt boyutunda (A>E), Bilimsel Araştırmaya Yabancılaşma alt boyutunda (C>D), Öğretime Yabancılaşma alt boyutunda (A>B-D-E) ve toplam puanlarında (A>B-C-D-E) istatistiksel olarak anlamlı farklılık tespit edilmiştir ($p<0.05$). Ancak Akademisyenliğe Yabancılaşma Ölçeği güçsüzlük alt boyutunda anlamlı farklılık görülmemiştir ($p>0.05$). Diğer taraftan Örgütsel Sapma Davranışı Ölçeği alt boyut ve toplam puanlarında istatistiksel olarak anlamlı farklılık görülmemiştir ($p>0.05$).

Tablo 6. Hizmet yılı değişkenine göre akademisyenliğe yabancılaşma ile örgütsel sapma davranış ölçeğine ilişkin sonuçlar

Ölçekler	Alt Boyutlar	Bölüm	$\overline{X}$	Ss	df	F	p	Farkın Kaynağı
		A: 0-5 Yıl	27.09	5.87				
		B: 6-10 Yıl	27.74	5.93				
	Kendine Yabancılaşma	C: 11-15 Yıl	27.45	3.94	4 211 214	1.42	**.24**	---
		D: 16 Yıl ve üzeri	29.22	3.93				-
		A: 0-5 Yıl	15.16	3.34				
		B: 6-10 Yıl	15.96	3.29				
	Bilimsel Araştırmaya Yabancılaşma	C: 11-15 Yıl	16.27	3.47	4 211 214	1.22	**.30**	----
		D: 16 Yıl ve üzeri	15.81	3.47				
		A: 0-5 Yıl	8.73	1.77				
		B: 6-10 Yıl	9.48	2.43				
Akademisyenliğe Yabancılaşma Ölçeği	Öğretime Yabancılaşma	C: 11-15 Yıl	8.97	2.38	4 211 214	2.63	**.05**	---
		D: 16 Yıl ve üzeri	9.72	2.20				
		A: 0-5 Yıl	6.83	2.45				
		B: 6-10 Yıl	7.43	3.13				
	Yalıtılmışlık	C: 11-15 Yıl	6.73	2.71	4 211 214	.74	**.52**	---
		D: 16 Yıl ve üzeri	7.28	2.95				
			Sıra Ortalaması	**H**	**df**	**p**		**Fark**
		A: 0-5 Yıl	110.38					
		B: 6-10 Yıl	103.52					
	Güçsüzlük	C: 11-15 Yıl	108.55	.43	3	.93	---	
		D: 16 Yıl ve üzeri	106.61					
	Akademisyenliğe Yabancılaşma Toplam	A: 0-5 Yıl	103.40					
		B: 6-10 Yıl	114.45					

		C: 11-15 Yıl	103.62	1.90	3	.59	----
		D: 16 Yıl ve üzeri	116.57				
	Örgütsel İlişkilere Yönelik Sapma Davranışları	A: 0-5 Yıl	101.46	9.46	3	**.02**	**D>C;B>A**
		B: 6-10 Yıl	112.29				
		C: 11-15 Yıl	94.91				
		D: 16 Yıl ve üzeri	132.69				
	Örgütsel İşleyişe Yönelik Sapma Davranışları	A: 0-5 Yıl	103.26	5.26	3	.15	----
		B: 6-10 Yıl	116.51				
		C: 11-15 Yıl	98.05				
		D: 16 Yıl ve üzeri	119.42				
Örgütsel Sapma Davranışı Ölçeği	Eğitsel Etkinliklere Yönelik Sapma Davranışları	A: 0-5 Yıl	100.14	7.62	3	.05	----
		B: 6-10 Yıl	112.29				
		C: 11-15 Yıl	101.88				
		D: 16 Yıl ve üzeri	129.97				
	Araştırma ve Yayına Yönelik Sapma Davranışları	A: 0-5 Yıl	106.06	2.23	3	.53	----
		B: 6-10 Yıl	111.49				
		C: 11-15 Yıl	98.58				
		D: 16 Yıl ve üzeri	117.57				
	Örgütsel Sapma Davranışı Toplam	A: 0-5 Yıl	102.83	8.44	3	**.04**	**D>C;B>A**
		B: 6-10 Yıl	111.61				
		C: 11-15 Yıl	92.58				
		D: 16 Yıl ve üzeri	131.90				

A: 0-5 Yıl N=100, B: 6-10 Yıl N=46, C: 11-15 Yıl N=33, D: 16 Yıl ve üzeri N=36

Tablo 6' da Akademisyenliğe Yabancılaşma Ölçeği hizmet yılı değişkenine göre incelendiğinde, alt boyut ve toplam puanlarda istatistiksel olarak anlamlı farklılık görülmemiştir ($p>0.05$). Örgütsel Sapma Davranışı Ölçeğinde ise Örgütsel İlişkilere Yönelik Sapma alt boyutu (D>C; B>A) ile toplam puanında (D>C; B>A) istatistiksel olarak anlamlı farklılık tespit edilmiştir ($p<0.05$).

Tablo 7. Akademisyenliğe yabancılaşma ölçeği ile örgütsel sapma davranışı ölçeği arasındaki ilişkiye ait korelasyon testi sonuçları

		Örgütsel İlişkilere Yönelik Sapma Davranışları	Örgütsel İşleyişe Yönelik Sapma Davranışları	**Eğitsel Etkinliklere Yönelik Sapma Davranışları**	Araştırma ve Yayına Yönelik Sapma Davranışları	Örgütsel Sapma Davranışı Toplam
Kendine Yabancılaşma	R	-.113	-.085	**-.156***	-.101	-.127
	P	.097	.213	**.022**	.138	.064
	N	215	215	215	215	215
Bilimsel Araştırmaya Yabancılaşma	R	-.020	.028	.015	.001	.003
	P	.776	.687	.827	.993	.968
	N	215	215	215	215	215
Öğretime Yabancılaşma	R	.008	.073	-.011	.008	.014
	P	.907	.287	.869	.903	.836
	N	215	215	215	215	215
Yalıtılmışlık	R	.126	.110	**.141***	.111	.133
	P	.066	.108	**.039**	.103	.052
	N	215	215	215	215	215
Güçsüzlük	R	-.015	.024	-.017	.005	-.005
	P	.832	.723	.805	.947	.947
	N	215	215	215	215	215
Akademisyenliğe Yabancılaşma Toplam	R	-.031	.013	-.042	-.019	-.026
	P	.646	.853	.537	.778	.702
	N	215	215	215	215	215

Tablo 7' de katılımcıların Akademisyenliğe Yabancılaşma Ölçeği toplam puanı ve alt boyutları ile Örgütsel Sapma Davranışı ölçeği alt boyutları ve toplam puanı arasındaki korelasyon analiz sonuçları incelendiğinde, kendine yabancılaşma alt boyutu ile eğitsel etkinliklere yönelik sapma davranışları alt boyutu arasında negatif yönlü düşük düzeyde anlamlı bir ilişki olduğu görülmüştür ($R=-.156$; $p<0.05$). Yalıtılmışlık alt boyutu ile eğitsel etkinliklere yönelik sapma davranışları alt boyutu arasında pozitif yönlü düşük düzeyde anlamlı bir ilişki olduğu görülmüştür ($R=.141$; $p<0.05$).

3. TARTIŞMA VE SONUÇLAR

Katılımcıların demografik değişkenlerine göre Spor Bilimleri Fakültesindeki akademisyenlerin algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeyleri arasındaki ilişkinin incelenmesi amaçlanmıştır. Yapılan tez çalışmamızda Spor Bilimleri Fakültesindeki akademisyenlerin algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeylerinin cinsiyet, medeni durum, unvan ve hizmet durumu gibi demografik değişkenlere göre farklılaşıp farklılaşmadığı araştırılmış ve çalışmaya (Erkek: 130 Kadın: 85) toplamda 215 öğrenci katılım sağlamıştır. Bulgular doğrultusunda konumuzla ilgili literatür taraması sonucunda hipotezler yorumlanmıştır.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışının cinsiyet değişkenine göre anlamlı düzeyde farklılık göstermediği bulgusu elde edilmiştir (Tablo 3.) ve Hipotezimiz (H_1) reddedilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Ancak farklı örneklem gruplarıyla yapılan çalışmada farklı meslek grupları (öğretmen, sağlık çalışanı ve banka personeli) algılanan örgütsel sapma davranışı ile cinsiyet değişkeni arasında anlamlı düzeyde farklılık görülmemiştir. (Chullen vd., 2010; Bayın ve Yeşilaydın, 2014; Gültaç, 2019) tarafından yapılan çalışma bulgularını destekler niteliktedir. Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır (Kobbs ve Arvey, 1993; Gutek vd., 1996; Grasmick ve Kobayashi, 2002; Avcı vd., 2007; Yamuç ve Türker, 2015). Bulgu sonuçlarına bakıldığında anlamlı farklılık çıkmamasının sebebi, örgütsel sapma davranışlarının cinsiyet üzerinde herhangi bir etkisinin olmaması, kadın ve erkek akademisyenlerin çalışma koşullarının zor olması, özel hayatlarındaki rollerin etkili olması, çalışılan kurumda kadın ve erkeklerin grup içinde aynı tavrı sergilemeleri, cinsiyetler arası davranış kalıplarının giderek benzeştiği, kurumsal kültürün bireysel farklılıkları dengelediğini ve yapısal stres faktörlerinin tüm çalışanları benzer şekilde etkilediği, çalışma koşullarının zor olması, özel hayatlarındaki rolleri ve sergilenen ortak tavırların bir yansıması olduğu düşünülebilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışının medeni durum değişkenine göre incelendiğinde, algılanan örgütsel sapma ölçeğin alt boyut ve toplam puanlarında anlamlı farklılık görülmemiştir

(Tablo 4.) ve Hipotezimiz (H_2) reddedilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Fakat farklı örneklem gruplarıyla yapılan çalışmada (öğretmen, sağlık çalışanı ve banka personeli) öğretmenlerin algılanan örgütsel sapma davranışı ile medeni durum değişkeni arasında anlamlı düzeyde farklılık görülmemiştir (Yeşilaydın, 2014; Yalap, 2016; Gültaç, 2019 ve Öztürk, 2023). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalara ulaşılamamıştır. Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin algılanan örgütsel sapma davranışının medeni durum değişkenine göre anlamlı farklılık çıkmasının sebebi, akademisyenlik mesleğinin diğer birçok meslek grubundan farklı olarak daha özerk, bireysel sorumluluğun yüksek olduğu ve görevlerin kişisel inisiyatife dayandığı bir yapıya sahip olması, örgütsel sapma davranışları genellikle işle ilgili stres, adaletsizlik algısı, örgütsel bağlılık gibi işle ilgili faktörlerle daha güçlü ilişkilisi olması, üniversiteler gibi kamu kurumlarında çalışan akademisyenler, diğer bazı sektörlere kıyasla daha esnek çalışma saatlerine, akademik izinlere ve evden çalışma imkânlarına sahip olaması, medeni duruma dayalı ayrımcılığın veya farklılaşmanın yaygın olmaması; üniversitede hem evli hem bekar bireylerin benzer iş yükü, sorumluluk ve beklentilere maruz kalması anlamlı farklılığın çıkmamasına neden olabilir

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışının unvan değişkenine göre algılanan örgütsel sapma ölçeğin alt boyut ve toplam puanlarında istatistiksel olarak anlamlı farklılık görülmemiştir (Tablo 5.) ve Hipotezimiz (H_3) reddedilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Fakat farklı örneklem gruplarıyla yapılan çalışmada (öğretmen, sağlık çalışanı ve banka personeli) algılanan örgütsel sapma davranışı ile unvan değişkeni arasında anlamlı düzeyde farklılık görülmemektedir (Bayın 2014; Yeşilaydın, 2014). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır (Hollinger vd., 1992; Appelbaum vd., 2005; Chullen vd. 2010 ve Wolff vd., 2010). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin algılanan örgütsel sapma davranışının unvan değişkenine göre anlamlı farklılık çıkmamasının sebebi, akademik unvanlar farklı olsa da **yükseköğretim kurumlarında çalışan akademisyenler genellikle benzer örgütsel iklimde, benzer baskılar ve kurumsal kısıtlamalar altında çalışması,** etik dışı davranışlara karşı eğilimlerini açıklamada adaletsizlik algısı geliştirdiğinde benzer tepki biçimleri gösterilmesi, yüksek unvana sahip bireylerin daha etik, sorumluluk sahibi ve kurallara uygun davranma algısının ortadan kalkması gibi durumlardan kaynaklandığı düşünülebilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin algılanan örgütsel sapma davranışının hizmet yılı değişkenine göre durumu incelendiğinde, algılanan örgütsel sapma davranışı ölçeğinin örgütsel ilişkilere yönelik sapma alt boyutu ile toplam puanında istatistiksel olarak anlamlı farklılık tespit edilmiştir (Tablo 6.) ve Hipotezimiz (H_4) kabul edilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Fakat farklı örneklem gruplarıyla (öğretmen, sağlık çalışanı ve kamu çalışanlarıyla) yapılan çalışmada algılanan örgütsel sapma davranışı ile medeni durum değişkeni arasında anlamlı düzeyde farklılık görülmektedir (Sarıoğlu Uğur, 2019; Gürbüz ve Şahin, 2018; Girgin Köse, 2013). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır (Bayın, 2014; Yeşilaydın, 2014). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin algılanan örgütsel sapma davranışının hizmet yılı değişkenine göre anlamlı farklılık çıkmasının sebebi, kıdemli çalışanlar, yıllar içinde karşılaştıkları tekrar eden sorunlar, adaletsizlik algısı veya ödüllendirme eksiklikleri nedeniyle **örgüte yönelik negatif davranışlara eğilimli** hale gelmesi, kariyerlerinin basamaklarının başında olan akademisyenlerin geleceğe dair beklentileri ve yükselme istekleri nedeniyle **örgütsel sapma davranışlarından kaçınma eğilimi**, proseför ve doçentlerin zaman içinde **kurum kurallarını esnetme**, **sistemden kopma**, hatta **örgütsel ilişkilere zarar verebilecek davranışlar sergileme** eğilimleri, sistemin eksikliklerini **eleştirel tutuml**a yaklaşmaları **örgütsel sapma davranışları ilişkilerde gerilimlere neden olabilir.**

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin, akademisyenliğe yabancılaşma ölçeğinin cinsiyet değişkenine göre durumu incelendiğinde anlamlı farklılık göstermediği bulgusu elde edilmiştir (Tablo 3.) ve Hipotezimiz (H_5) reddedilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgularda erkek öğretim elemanları ile kadın öğretim elemanlarının işe yabancılaşma düzeyleri arasında istatistiksel açıdan anlamlı bir fark bulunmamaktadır (Kesen, 2016). Fakat farklı örneklem gruplarıyla (öğretmen, sağlık çalışanı ve kamu çalışanlarıyla) yapılan çalışmada cinsiyetin işe yabancılaşma ve tükenmişlik üzerinde anlamlı bir etkisi olmadığı sonucuna ulaşılmıştır (Sayıl vd. 1997; Naktiyok ve Karabey, 2005 ve Ardıç ve Polatçı, 2008 ve Meral, 2010). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır (Fırat (2005; Avşaroğlu vd., 2005; Üngüren vd., 2010 ve Çağlar, 2012). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin akademisyenliğe yabancılaşma ölçeğinin cinsiyet değişkenine göre anlamlı farklılık çıkmasının sebebi, akademik yayın, idari pozisyonlara erişim ve araştırma fırsatlarında kadınların da erkeklerle eşit koşullarda yer bulabilmesi, yayın yapma zorunluluğu, proje ve bütçe sorumlulukları, akademik yükselme kriterlerinin stresi gibi başlıklar cinsiyet ayrımını gölgede bırakarak, her bireyin benzer şekilde akademisyenliğe yabancılaşma hissi yaşamasına neden olabilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin, akademisyenliğe yabancılaşma ölçeğinin medeni durum değişkenine göre farklılaşma durumu incelendiğinde, kendine yabancılaşma, bilimsel araştırmaya yabancılaşma, öğretime yabancılaşma alt boyutlarında evliler lehine anlamlı farklılık görülürken, güçsüzlük alt boyutunda ve akademisyenliğe yabancılaşma toplam puanlarında anlamlı farklılık görülmemiştir (Tablo 4.) ve Hipotezimiz (H_6) kısmen kabul edilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubunda bulunan öğretim elemanlarının işe yabancılaşma

düzeylerini incelediği çalışmada, öğretim elemanlarının medeni durumlarının genel işe yabancılaşma düzeyleri üzerinde anlamlı bir farklılık bulunmamaktadır (Sayıl vd., 1997; Kayabaşı, 2008 ve Halaçoğlu (2008). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmada öğretmenlerin medeni durumlarının hem genel mesleki yabancılaşma, hem de güçsüzlük ve anlamsızlık alt boyutlarında anlamlı bir fark bulunmaktadır Elma, 2003; Şimşek vd., 2012; Avşaroğlu vd., 2005 ve Üngüren vd., 2010). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin akademisyenliğe yabancılaşma ölçeğinin medeni durum değişkenine göre farklılaşma durumu incelendiğinde anlamlı farklılık çıkmasının sebebi, akademisyenin kendisine duygusal anlamda destek sağladığında, kendini daha az yalnız hissettiği, işine karşı daha anlamlı bir bakış açısı geliştirdiği ve mesleki tatminin artması **duygusal ve bilişsel yabancılaşma boyutlarında** evli bireylerin lehine olumlu bir farklılık yaratabilir. **Karar alma süreçlerine etkisi olmadığını hissetmesi**, **denetim eksikliği**, **yetersiz yetki** ve **biçimsel yapıya karşı çaresizlik** hisleriyle anlamlı farklılık çıkmamasına neden olabilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin, akademisyenliğe yabancılaşma ölçeğinin unvan değişkenine göre durumu incelendiğinde, kendine yabancılaşma alt boyutunda, bilimsel araştırmaya yabancılaşma alt boyutunda, öğretime yabancılaşma alt boyutunda ve toplam puanlarında unvan değişkenine göre istatistiksel olarak anlamlı farklılık görülürken, akademisyenliğe yabancılaşma ölçeği güçsüzlük alt boyutunda anlamlı farklılık görülmemiştir (Tablo 5.) ve Hipotezimiz (H_7) kısmen kabul edilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubunda bulunan öğretim elemanlarının işe yabancılaşma düzeylerini incelediği çalışmada, öğretim elemanlarının unvanları arasındaki farklılığın ise işe yabancılaşma düzeyleri arasında anlamlı farklılık bulunmuştur (Kesen, 2016). Fakat farklı örneklem gruplarıyla (Türkçe ve sosyal bilgiler öğretmen adaylarının) yapılan çalışmada unvanın işe yabancılaşma üzerinde anlamlı bir etkisi olmadığı sonucuna ulaşılmıştır (Tezcan, 1985 ve Uygun, 2004). Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır (Fırat Meral, 2010). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin akademisyenliğe yabancılaşma ölçeğinin unvan değişkenine göre anlamlı farklılık çıkmasının sebebi, bilimsel araştırma ve öğretim faaliyetlerinde daha yüksek beklentilerle karşı karşıya kalmaları, bu kişilerin profesör ve doçentlerin **araştırmaya veya öğretime karşı yabancılaşmasına, a**kademik performans baskısı, yayın yapma zorunluluğu nedeniyle **bilimsel üretimi bir anlamda zorunlu kılmasına, akademik ideallerinden sapma** ya da **rutinleşen görevler** nedeniyle mesleki doyumda azalma alt boyutlarda anlamlı farklılık çıkmasına rağmen güçsüzlük alt boyutunda Akademik hiyerarşide yer fark etmeksizin, karar alma süreçlerine katılım eksikliği, üniversite politikalarının merkeziyetçiliği veya akademik özerklik eksikliği gibi durumlar, tüm akademik unvanlardaki bireylerde benzer düzeyde güçsüzlük hissine neden olması anlamlı farklılığın çıkmamasına neden olduğu düşünülebilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin, akademisyenliğe yabancılaşma ölçeğinin hizmet yılı değişkenine göre durumu incelendiğinde, alt boyut ve toplam puanlarda istatistiksel olarak anlamlı farklılık görülmemiştir (Tablo 6.) ve Hipotezimiz (H_8) reddedilmiştir. Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Fakat farklı örneklem gruplarıyla (öğretmen ve otel çalışanı) üzerine yapılan çalışmada, mesleki hizmet süresinin yabancılaşma duygusu üzerinde anlamlı bir fark oluşturmamıştır (Halaçoğlu, 2008 ve Aşık, 2018). Öğretmenlerle ilgili yapılan çalışmada 25 yıl ve üzerinde hizmet süresi olan öğretmenlerdeki yabancılaşmanın genel olarak daha az olduğunu bulunmuştur (Yılmaz ve Sarpkaya, 2009; Kesen, 2016; Bilici ve Yıldız, 2020). Bulgu sonuçlarına bakıldığında iş gören akademisyenlerin akademisyenliğe yabancılaşma ölçeğinin hizmet yılı değişkenine göre farklılaşma durumu incelendiğinde anlamlı farklılık çıkmasının sebebi, akademik ortamda **yayın baskısı, performans değerlendirme sisteminin sıklığı, idari görev yükü, üniversite yönetimiyle olumsuz ilişkiler,** hizmet yılı ile **akademik tatmin ve güç arasındaki bağın zayıf olması vb. duru**mlardan dolayı akademisyenliğe yabancılaşmanın hizmet yılı değişkeni üzerinde anlamlı farklılık çıkmamasına neden olduğu düşünülebilir.

Spor Bilimleri Fakültesi'nde iş gören akademisyenlerin, algılanan örgütsel sapma davranışı ile akademisyenliğe yabancılaşma düzeyleri arasında kendine yabancılaşma alt boyutu ile eğitsel etkinliklere yönelik sapma davranışları alt boyutu arasında negatif yönlü düşük düzeyde anlamlı bir ilişki olduğu, yalıtılmışlık alt boyutu ile eğitsel etkinliklere yönelik sapma davranışları alt boyutu arasında pozitif yönlü düşük düzeyde anlamlı bir ilişki olduğu görülmüştür. (Tablo 7.) ve Hipotezimiz (H_9) kabul edilmiştir. Literatürde yer alan çalışmalara bakıldığında, Literatürde yer alan çalışmalara bakıldığında, örneklem grubumuza uygun bulgulara rastlanmamıştır. Fakat farklı örneklem gruplarıyla üzerine yapılan çalışmada, Fu (2009), Çin'de dört üniversitede okuyan 790 öğrenci ile yaptığı çalışmasında psikolojik sermaye ile öğrenme stratejileri arasında pozitif korelasyon olduğu sonucuna ulaşmıştır. Örgüte yönelik sapma ve bireylerarası sapma boyutlarının birbirleriyle ilişkilerine bakıldığında, aralarında istatistiksel olarak anlamlı, pozitif ve orta derecede güçlü bir ilişki olduğu saptanmıştır. Diğer bir deyişle, bireylerarası sapma davranışı arttıkça, örgüte yönelik sapma davranışı da artmaktadır (Bayın vd., 2014). Atı hastanedeki tüm sağlık çalışanlarına yönelik yapmış oldukları çalışmada da benzer şekilde, iki boyut arasında pozitif yönlü korelasyon bulunmuştur. (Tütüncü vd. 2008). Lian, Ferris ve Brown'un (2012) yapmış oldukları çalışma, iş tatmini, lider-üye etkileşimi ve iş tatmini ile sapma arasında negatif ve istatistiksel olarak anlamlı bir ilişki olduğunu göstermektedir. Mulki, Jaramillo ve Locander (2006), iş tatmini, örgütsel bağlılık, çalışan-iş uyumu ve katılımcı liderlik ile sapma davranışı arasındaki istatistiksel olarak anlamlı ilişkiye dikkat çekmişler; sağlık kurumuna ilişkin bağlılığı ve memnuniyeti daha yüksek olan, sorumlu olduğu iş ile uyumu yeterli düzeyde olan ve katılımcı liderliğin yüksek olduğu çalışanların daha az sapma davranışı göstereceklerini öne sürmüşlerdir. Diğer taraftan, literatürde farklı bulgular elde eden ve çalışmamıza tezat olduğu düşünülen araştırmalar da bulunmaktadır. Küçük ölçekli gıda işletmelerde çalışanlara yönelik yapılan analizde, **bireylerarası sapma davranışı** ile **örgütsel güven** ve **tükenmişlik**

değişkenleri arasında **ara değişken olarak anlamlı bir ilişki görülmemiştir** (Çelik, Turunç & Begenirbaş, 2011). Machiavellian eğilim, rol genişliği, kaynaklara erişim ve sosyo-politik destek gibi bazı bağımsız değişkenlerin sapma biçimleriyle anlamlı ilişkisi incelenmiştir. Ancak **rol genişliği kendine yabancılaşmayla ilişkili bulunmamış;** ayrıca sosyo-politik desteğin ve kaynaklara erişimin bazı sapma türleriyle ilişkisi anlamlı çıkmamıştır (Galperin, 2011). Bulgu sonuçlarına bakıldığında, **kendine yabancılaşma alt boyutunda**, kişinin yaptığı işi **anlamsız, amaçsız ve kişisel değerleriyle uyumsuz** görmesi, eğitsel etkinliklerden kaçınmasına veya sadece zorunlu işleri yerine getirmesinde etkili olduğu düşünülebilir. Yalıtılmışlık alt boyutunda akademisyenlerin **meslektaşlarıyla, yöneticilerle veya öğrencilerle bağ kuramaması** eğitsel sürece olan bağın azalmasına neden olacağı söylenebilir.

Öneriler

- İş gören akademisyenlere yetki ve sorumluluk verilirken bilgi, beceri ve yetenekleri ile doğru orantılı olacak şekilde karar verilebilir.
- İş gören akademisyenlerin diğer çalışanlar gibi değerli olduğu hissettirilmesinin yanında kurum içerisinde ekip üyeleri veya kurumun tüm birimlerindeki çalışanlara eşit davranabileceği iş ortamı oluşturulabilir.
- İş gören akademisyenlerin birbirini daha iyi tanıması sağlayan oryantasyon çalışmasının yanında kişilerarası etkileşimi ve iletişimi olumlu yönde geliştirecek etkinlikler düzenlenebilir.
- İş gören akademisyenlerin akademik teşvik ödeneği konusunda desteklenmeli ve akademik çalışmaları özendirecek ödüllendirme yöntemleri kullanılabilir.

KAYNAKLAR

Agalday, B. (2022). Exploring the Relationship between Alienation from Academic Profession and Organizational Deviance: The Mediation Role of Job Satisfaction. *Pedagogical Research*, *7*(4).

Appelbaum, S. H., Deguire, K. J., & Lay, M. (2005). The relationship of ethical climate to deviant workplace behaviour. *Corporate Governance: The international journal of business in society*, *5*(4), 43-55. https://doi.org/10.1108/14720700510616587

Ardıç, K., & Polatcı, S. (2008). Tükenmişlik sendromu akademisyenler üzerinde bir uygulama (GOÜ Örneği). *Gazi Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, *10*(2), 69-96.

Avcı, N., Küçükusta, D., &Tütüncü, Ö. (2007). İşyeri sapma davranışı: konaklama işletmelerinde bir uygulama. *Çeşme Ulusal Turizm Sempozyumu*, İzmir.

Avşaroğlu, S., Deniz, M. E. ve Kahraman, A. (2005). "Teknik Öğretmenlerde Yaşam Doyumu İş Doyumu ve Mesleki Tükenmişlik Düzeylerinin İncelenmesi". *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, Sayı 14, 115-129.

Balon, R., Coverdale, J., & Roberts, L. W. (2010). Academician: What's in a Name?. *Academic Psychiatry*, *34*(3), 169-171.

Bayın, G. ve Terekli Yeşilaydın, G. (2014). Hemşirelerde Örgütsel Sapma Davranışının Analizi: Bir Üniversite Hastanesi Örneği. *İşletme Araştırmaları Dergisi, 6*(3), 81-107.

Bilici, A., & Yıldız, H. (2020). Genç akademisyenlerde mesleki yabancılaşma: Nitel bir inceleme. *Eğitim ve Toplum Araştırmaları Dergisi, 7*(3), 89–105. https://doi.org/10.14783/edu-socres.2020.73.89.

Chullen, L. C., Dunford, B. B., Angermeier, I., Boss, W. R., & Boss, A. D. (2010). Minimizing deviant behavior in healthcare organizations: The effects of supportive leadership and job design. *Journal of Healthcare Management*, *55*(6), 381-398.

Çağlar, Ç. (2012). Öğrenci yabancılaşma teknolojisinin (ÖYÖ) geliştirilmesi. *Eğitim ve Bilim* , *37* (166).

Çelik, M., Turunç, Ö., & Begenirbaş, M. (2011). The role of organizational trust, Burnout and interpersonal deviance for achieving organizational performance. *International Journal of Business and Management Studies*, *3*(2), 179-189.

Dağlı Ekmekçi, Y. A., Ekmekçi, R. ve İrmiş, A. (2013). Küreselleşme ve Spor Endüstrisi. *Pamukkale Journal of Sport Sciences, 4*(1), 91-117. http://pjss.pau.edu.tr.

Demir, M. (2009). *Konaklama işletmelerinde duygusal zeka, örgütsel sapma, çalışma yaşamı kalitesi ve işten ayrılma eğilimi arasındaki ilişkinin analizi* (Doctoral dissertation, Dokuz Eylul Universitesi (Türkiye)).

Dunlop, P. D. ve Lee, K. (2004). Workplace deviance, organizational citizenship behavior,and business unit performance: the bad apples do spoil the whole barrel. *Journal of Organizational Behavior*, *25*, 67–80.

Fu, L. F. (2009). *The Relations Among Learning Strategies, Positive Psychological Capital, Learning Burnout of Undergraduate Students.* (Master Tezi). Nankai Üniversitesi, Çin.

Galperin, B. L. (2011). Exploring the nomological network of workplace deviance: *Developing and validating a measure of constructive deviance. Journal of Applied Psychology, 96*(2), 396–419.

Girgin Köse, S. (2013). Ortaokul Öğretmenlerinin Örgütsel Sapma ve Stratejik Liderlik Arasındaki İlişki Üzerine Algıları: İzmir İli Örneği. (Yayınlanmamış Yüksek Lisans Tezi). Dokuz Eylül Üniversitesi Eğitim Bilimleri Enstitüsü, İzmir.

Gözde, B. & Gözde Terekli, Y., (2014). Hemşirelerde Örgütsel Sapma Davranışının Analizi: Bir Üniversite Hastanesi Örneği. *Journal of Business Research-Türk 6*(3), 81-107.

Grasmick, H. G., & Kobayashi, E., (2002). Workplace deviance in Japan: applying an extended model of deterrence. *Deviant Behavior: An Interdisciplinary Journal*, 23(1), 21–43.

Gutek, Barbara A.B.A. Cohen, Aaron, G. and Tsui, A. (1996). 2Reactions to Perceives Discrimination. *Human Relations,* 49(6): 791-814.

Gültaç, S. A. (2019). *Örgütsel sapma ve nezaketsizlik davranışları ilişkisinde işyerinde dışlanmanın aracı rolü: sağlık kurumlarında bir araştırma.* (Yayımlanmamış Yüksek Lisans Tezi). Hacettepe Üniversitesi, Ankara.

Gürbüz, S. ve Şahin, F. (2018). *Sosyal Bilimlerde Araştırma Yöntemleri* (5. Baskı). Ankara: Seçkin Yayıncılık.

Halaçoğlu, B. (2008). Üniversitelerdeki akademik personelin mesleki yabancılaşma düzeylerinin çok boyutlu incelenmesi (İstanbul İli Örneği). *Yayınlanmamış Yüksek Lisans Tezi*. Yeditepe Üniversitesi Sosyal Bilimler Enstitüsü, Ankara.

Hollinger, R. C., Slora, K. B., & Terris, W. (1992). Deviance in the fast-food restaurant: Correlates of employee theft, altruism and counter productivity. *Deviant Behavior*, 13(2), 155–184.

Husu, L. (2001). "On metaphors on the position of women in academia and science". Taylor & Fracis, 3 (9), 172-182.

Kaya, F. (2008). Öğretmen ve öğrenci arasındaki iletişim sürecinin öğrencinin eğitime yabancılaşma durumu üzerindeki rolü. *Eğitim ve Bilim*, 33(151), 165–180.
Kayabaşı, Y. (2008). "Bazı Değişkenler Açısından Öğretmenlerin Mesleki Tükenmişlik Düzeyleri*". Sosyal Bilimler Dergisi*, 20, 191-212.

Kesen, M. (2016). Öğretim elemanlarının işe yabancılaşmasının etik liderlik ve demografik değişkenler açısından incelenmesi: uygulamalı bir çalışma. *The Journal of Academic Social Science, 4* (22), 118-134.

Kesen, M. (2016). Öğretim elemanlarının işe yabancılaşmasının etik liderlik ve demografik değişkenler açısından incelenmesi: Uygulamalı bir çalışma. *Akademik Sosyal Araştırmalar Dergisi, 4*(22), 118–134.

Kızıldağ, D. (2010). *Örgütlerde Problemli Davranışlar ve Davranışsal Risk Yönetimi.* (Yayınlanmamış Doktora Tezi). Afyonkarahisar Üniversitesi Sosyal Bilimler Enstitüsü, Afyonkarahisar.

Kobbs, S. W., & Arvey, R. D. (1993). Distinguishing deviant and non-deviant nurses using the personnel reaction blank. *Journal of Business and Psychology,* 8(2), 255-264.

Lian, H., Ferris, D.L., Brown, D.J., (2012). "Does taking the good with the bad make things worse? How abusive supervision and leader–member exchange interact to impact need satisfaction and organizational deviance", Organizational Behavior and Human Decision Processes, Vol.117, 41–52.

Meral, S., (2010). *Öğretim Elemanlarının Tükenmişlik Ölçeğinin Geçerlilik ve Güvenirlik Çalışması: Amasya Üniversitesi Örneği.* On Dokuz Mayıs Üniversitesi, Yüksek Lisans Tezi.

Mulki, J.P., Jaramillo, F., Locander, W.B., (2006). "Emotional exhaustion and organizational deviance: can the right job and a leader's style make a difference", *Journal Of Business Research,* Vol.59, 1222-1230.

Naktiyok, A. ve Karabey, C. N. (2005). "İşkoliklik ve Tükenmişlik Sendromu". *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 19 (2), 179-198.

Öztürk, C. (2019). *Otel işletmelerinde kuşaklara göre örgütsel sapmanın belirlenmesi*. (Yayımlanmamış Yüksek Lisans Tezi). Dokuz Eylül Üniversitesi, İzmir.

Öztürk, T. (2023). Öğretmenlerin Algılanan Örgütsel Sapma Davranışlarının İncelenmesi. *International Social Sciences Studies Journal, 9*(108), 5422-5428.

Sarıoğlu Uğur, S. (2019). Örgütsel Bağlılık ile Örgütsel Sapma Davranışı Arasındaki İlişki: Banka Çalışanlarına Yönelik Bir Araştırma. *Journal of EBOR, 1*(1), 85-96.

Sayıl, I., Haran, S., Ölmez, Ş. ve Özgüven, H. D. (1997). Ankara Üniversitesi Hastanelerinde Çalışan Doktor ve Hemşirelerin Tükenmişlik Düzeyleri. *Kriz Dergisi*, 5 (2): 71-77.

Silah, (2005). *Yabancılaşma kuramına ilişkin kontrol odağı ve motivasyon ilişkisi üzerine* (çalışma referansı).

Şimşek vd., (2012). İlköğretim Sınıf Öğretmenlerinde Mesleki Yabancılaşma *Eğitim Bilimleri Araştırmaları Dergisi – Journal of Educational Sciences Research, 2(1), 54-72.*

Şimşek, H., Balay, R., & Şimşek, A. S. (2012). İlköğretim sınıf öğretmenlerinde mesleki yabancılaşma. *Eğitim Bilimleri Araştırmaları Dergisi*, 2(1), 53–72.

Thomas, R. K. (2003). *Society and Health Sociology for Health Professionals.* New Jersey: Academic Publishers.

Türkkaş Anasız, B., & Iliman Püsküllüoğlu, E. (2018). Algılanan örgütsel sapma davranışı ölçeği: Geçerlik ve güvenirlik çalışması. *Karadeniz Sosyal Bilimler Dergisi, 10*(19), 449–469.

Tütüncü, Ö., Küçükusta, D., Kiremitçi, İ., Dalmış, K.A., Tekin, F.A., Yazgan, M., Şen, A., Bozalan, E., (2008). Hastanelerde Örgütsel Sapma Davranışının Analizi, 5. Ulusal Sağlık Kuruluşları Yönetimi Kongresi, Muğla.

Uygun, S. (2008). Ortaöğretim Sosyal Alanlar Bölümünde Okuyan Öğretmen Adaylarının Mesleğe Yönelik Duyarlılıkları. *Ulusal Sosyal Bilimler Eğitimi Sempozyumu*. Çanakkale: Çanakkale Onsekiz Mart Üniversitesi Yayını, 187-192

Üngüren, E., Doğan, H., Özmen, M. Ö. ve Tekin, A. (2010). *"*Otel Çalışanlarının Tükenmişlik ve İş Tatmin Düzeyleri İlişkisi". *Journal of Yasar University,* 17, 2922-2937.

Wolff, A. C., Ratner, P. A., Robinson, S. L., Oliffe, J. L., & Hall, L. M. (2010). Beyond generational differences: A literature review of the impact of relational diversity on nurses' attitudes and work. *Journal of Nursing Management,* 18(8), 948-969.

Yalap, O. (2016). *Çalışanların örgütsel adalet algılamalarının sapma davranışları üzerinde etkisi: tekstil sektöründe bir araştırma*. (Yayınlanmamış Yüksek Lisans Tezi). Gaziosmanpaşa Üniversitesi, Tokat.

Yamuç, V.A. ve Türker, D. (2015). 'Örgütsel Stres Kaynaklarının Analizi: Bir Üretim İşletmesinde Kadın Ve Erkek Çalışanlar Üzerine İnceleme'. *Yönetim Bilimleri Dergisi. Cilt*: 13. Sayı: 25. 389-423.

Yıldız, S., & Alıcı, D. (2019). Akademisyenliğe Yabancılaşma Ölçeğinin Geliştirilmesi: Geçerlik ve Güvenirlik Çalışması. *Yükseköğretim Dergisi*, 9(1), 49–58. https://doi.org/10.2399/yod.18.028.

Yılmaz, S. & Sarpkaya, P. (2009). Eğitim örgütlerinde yabancılaşma ve yönetimi. *Uluslararası İnsan Bilimleri Dergisi*, 6 (2), 314- 333.

Yıldız, S., & Alıcı, D. (2019). Akademisyenliğe yabancılaşma ölçeğinin geliştirilmesi: Geçerlik ve güvenirlik çalışması. *Yükseköğretim Dergisi*, 9(1), 49-58.

Surgical Management of Cervical Cancer and The Role of Nursing Care

VIOLETA ZANAJ, JOANA BREGASI

Abstract: Cervical cancer is a significant public health issue affecting women worldwide, particularly in low- and middle-income countries. The cervix, located at the lower part of the uterus, plays a critical role in reproductive health but can be vulnerable to malignant changes, most commonly due to persistent infection with high-risk human papillomavirus (HPV). This article explores the anatomy and function of the cervix, the pathophysiology of cervical cancer, and the surgical interventions used in its treatment, such as hysterectomy and lymphadenectomy. It also examines the essential role of nursing care during the perioperative and postoperative periods, focusing on patient monitoring, education, and emotional support to ensure optimal recovery and quality of life.

Keywords: Cervical cancer, cervix, HPV, hysterectomy, surgery, nursing care, diagnosis, prevention, oncology, postoperative care, patient education.

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1. INTRODUCTION

Cervical cancer is a significant public health issue affecting women worldwide, particularly in low- and middle-income countries. The cervix, located at the lower part of the uterus, plays a critical role in reproductive health but can be vulnerable to malignant changes, most commonly due to persistent infection with high-risk human papillomavirus (HPV). This article explores the anatomy and function of the cervix, the pathophysiology of cervical cancer, and the surgical interventions used in its treatment, such as hysterectomy and lymphadenectomy. It also examines the essential role of nursing care during the perioperative and postoperative periods, focusing on patient monitoring, education, and emotional support to ensure optimal recovery and quality of life.

Purpose
The purpose of this study is to provide a comprehensive overview of cervical cancer, including its anatomical and pathological basis, the surgical treatment options available, and the essential role of nursing in the care of affected patients. By examining the key risk factors, diagnostic processes, and surgical techniques, the study aims to highlight the importance of early intervention and the contribution of nursing professionals in both physical and psychosocial aspects of patient recovery.

2. MATERIALS AND METHODS

This study is based on a literature review of the anatomy, pathology, and treatment of cervical cancer, with a specific focus on surgical intervention and nursing care.

Data on Cervical Cancer: This section reviews epidemiological data, risk factors (such as HPV infection, smoking, and immunosuppression), early symptoms, and stages of cervical cancer.

Diagnostic Methods and Evaluation: Diagnostic approaches such as Pap smear, HPV DNA testing, colposcopy, and biopsy were examined to understand their role in early detection and staging.

Surgical Treatment and Postoperative Care: An analysis of current surgical treatments including total hysterectomy, radical hysterectomy, and pelvic lymph node dissection was conducted, along with guidelines for postoperative care and complication prevention.

Health Education and Prevention: This part is based on cancer prevention strategies such as HPV vaccination, routine cervical screening, and public awareness programs.

Objective: To deepen understanding of cervical cancer surgery and to evaluate the nurse's role in supporting patients undergoing these procedures, especially in relation to education, monitoring, and psychological support.

2.1 Anatomy and physiology of the female internal genital organs

The internal female reproductive organs include the ovaries, uterine (Fallopian) tubes, uterus, cervix, and vagina. Together, they play a vital role in the reproductive cycle — from ovulation and fertilization to pregnancy and childbirth.

The ovaries are a pair of almond-shaped glands located in the pelvic cavity, one on each side of the uterus. Each ovary measures about 4 cm long and weighs around 6–8 grams. They serve a dual function: producing hormones like estrogen and progesterone, and generating egg cells through a process known as oogenesis. The outer part of the ovary (the cortex) contains follicles at different stages of development, while the central part (the medulla) houses blood vessels and connective tissue.

The uterine tubes are slender, flexible structures about 10 to 15 cm in length, connecting the ovaries to the uterus. Each tube has four sections — the uterine part, isthmus, ampulla, and infundibulum with its fimbriae. These tubes are responsible for capturing the released egg, providing a site for fertilization, and transporting the fertilized egg to the uterus.

The uterus is a muscular, hollow organ shaped like an inverted pear. It's located between the bladder and rectum and sits just above the vagina. In women who haven't given birth, the uterus typically measures 5 cm in length and weighs around 30–40 grams. It consists of three main parts: the body, the isthmus, and the cervix. Its wall is made up of three layers: the outer perimetrium, the thick muscular myometrium, and the inner mucosal endometrium — which thickens and sheds during the menstrual cycle.

The cervix is the lower, narrow end of the uterus, measuring about 2–3 cm. It connects the uterine cavity to the vagina and contains glands that produce mucus. The consistency of this mucus changes throughout the menstrual cycle to either hinder or facilitate the movement of sperm. The cervical opening (external os) is round in women who haven't given birth and slit-like in those who have.

Finally, the vagina is a muscular, elastic canal about 8–10 cm long that extends from the cervix to the external opening. It serves multiple functions: it's the passageway for menstrual flow, the organ for sexual intercourse, and the birth canal. In girls and women who have not yet had sexual intercourse, the vaginal opening may be partially covered by the hymen.[1]

2.2 What is cervical cancer?

Cervical cancer is a type of cancer that originates in the cervix — the lower part of the uterus that connects to the vagina. It develops when abnormal cells in the cervix begin to grow uncontrollably and can eventually invade surrounding tissues or spread to other parts of the body. The progression from the appearance of precancerous cells to invasive cervical cancer can take 10 to 20 years, which provides a valuable window for early detection and effective treatment.

Like other cancers, cervical cancer begins with a mutation in normal cells. Instead of following the natural cycle of growth, division, and cell death, these mutated cells multiply without regulation, forming a tumor. Over time, the tumor can invade nearby structures and metastasize to distant organs.

Cervical cancer is most commonly diagnosed in women under the age of 45, but any woman with a cervix is at risk. It often begins with pre-cancerous changes in the cervical tissue. If left undetected and untreated, these changes can evolve into full-blown cancer. The primary cause of these changes is persistent infection with human papillomavirus (HPV), a sexually transmitted virus. Because of this, regular cervical screening through Pap tests is strongly recommended, as it helps identify abnormal cells before they become cancerous.

Cervical cancer is the second most common cancer among women after breast cancer, but it carries a higher mortality rate. In Europe alone, around 60.000 women are diagnosed with cervical cancer each year, and nearly half of them die from the disease. One of the main reasons for this high death rate is late detection, often due to a lack of awareness or access to preventive care. Many women discover the disease only after it has advanced, making treatment more challenging and less effective.

The positive side is that invasive cervical cancer is largely preventable. It typically develops slowly and passes through a lengthy precancerous stage. One of its most important characteristics is that its primary cause is known: infection with high-risk types of HPV. While there are over 100 known HPV strains, only a few are linked to cervical cancer. The virus

[1]Anatomia e Njeriut – Dr.med.Ph.D. Nasir BEHXHETI,Dr.med. Selim ÇERKEZI, Dr.med. Argjent MUÇA - fq. 132-135 From: https://archive.org/details/AnatomiaENjeriut/mode/2up

can remain dormant in the body for years without causing symptoms, which is why routine screening and HPV vaccination are essential components of prevention. [2]

2.3 Early Warning signs of cervical cancer

Cervical cancer is often referred to as a **"silent cancer"** due to its lack of obvious early symptoms. However, routine screening — especially the **Pap test** — allows for the early detection of precancerous and cancerous changes, offering a chance for prevention, treatment, and even cure if caught early.

Early Symptoms
Irregular Vaginal Bleeding
After sexual intercourse
Between menstrual periods
After menopause
Unusual Vaginal Discharge
Dark-colored, foul-smelling, or blood-streaked
Pain During Sexual Intercourse (Dyspareunia)
May indicate tissue changes in the cervix
Pelvic or Lower Abdominal Pain
Especially if persistent and without a clear cause
Menstrual Cycle Changes
Longer, heavier, or more painful periods than usual[3]

2.4 Cervical cancer: common symptoms

Once abnormal cervical cells form a tumor and spread to nearby tissue, a range of symptoms may develop. While these can vary depending on cancer stage and extent, any of the following signs should prompt immediate medical evaluation.

Visual and Physical Signs
Vaginal bleeding:
After intercourse
Between periods
After pelvic exams or menopause
Heavier or prolonged menstruation
Unusual vaginal discharge:
Thick, watery, or blood-stained
May have a foul odor
On pelvic exam, the cervix may appear:
Raised, ulcerated, discolored (red/white), or easily bleeding
Advanced tumors may block the cervical canal or invade surrounding tissue
How Cervical Cancer May Feel
Normally, the cervix is smooth and firm. A warning sign: a lumpy or hardened cervix.
Though most lumps (e.g., cysts, polyps) are benign, only a health professional can determine the cause
Abdominal Bloating
In later stages, cancer spreading to the liver may lead to **abdominal swelling** due to **ascites**
Lower Back and Pelvic Pain
Early signs: mild pelvic pressure or lower back pain
As the cancer advances, pain may worsen, especially during urination or intercourse

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[2] **Strickler, H. D., Burk, R. D., Fazzari, M., Anastos, K., Minkoff, H., Massad, L. S., ... & Schlecht, N. F.** (2005). Natural history and possible reactivation of human papillomavirus in human immunodeficiency virus–positive women. *Journal of the National Cancer Institute*, 97(8), 577–586.

[3] Moffitt Cancer Center - Monica Avila, MD Gynecologic oncologist. From: https://www.moffitt.org/cancers/cervical-cancer/signs-symptoms/

Leg Pain or Swelling

Large tumors may compress pelvic nerves, causing **persistent leg pain or swelling**
Though these symptoms can have other causes, they warrant investigation if persistent

Foul-Smelling Vaginal Discharge

Strong, persistent odor may indicate **tissue breakdown or infection** within the tumor
Discharge may contain necrotic material and resemble the smell of decaying tissue[4]

2.5. Risk factors for cervical cancer

Cervical cancer is influenced by multiple risk factors — both behavioral and biological. Understanding these is crucial for prevention and early intervention.

Smoking

Tobacco contains carcinogens that damage cervical cells.
Smokers with HPV are more likely to develop persistent infections.
Smoking weakens immune response, facilitating HPV progression.

Multiple or Changing Sexual Partners

A higher number of sexual partners increases HPV exposure risk.
Partners with multiple previous partners raise infection likelihood.

Early Sexual Activity

Early onset of sexual activity increases vulnerability to HPV.
The immature cervix is more susceptible to persistent infection.

Other Sexually Transmitted Infections (STIs)

Infections like **herpes, chlamydia, gonorrhea, syphilis, and HIV/AIDS** can promote HPV persistence and cervical cell changes.
HIV, in particular, weakens immune surveillance against HPV.

Weakened Immune System

Immunocompromised individuals (e.g., HIV-positive patients) have a higher risk of chronic HPV infection and malignant transformation.

Exposure to Diethylstilbestrol (DES)

In utero exposure to **DES** (used in the 1950s to prevent miscarriage) has been linked to **clear cell adenocarcinoma** of the cervix in adulthood.[5]

2.6 Diagnosis of cervical cancer

Cervical cancer is one of the most preventable malignancies when detected early through regular screening. Early diagnosis significantly improves survival and treatment outcomes. The main diagnostic methods include:

Pelvic Examination

A routine gynecological procedure to assess the cervix's condition.
The physician manually examines the cervix and pelvic organs for abnormalities.
Non-invasive and typically painless; patients have the right to request a female physician or discontinue the exam at any time if uncomfortable.

Pap Smear (Papanicolaou Test)

The primary screening tool for detecting precancerous and cancerous cervical cells.
Cells are collected from the cervix (especially the transformation zone) and analyzed cytologically.
Recommended every 1–3 years for women aged 21–65.
Patients should avoid sexual activity, vaginal products, and menstruation before testing.

Colposcopy

Performed after abnormal Pap results.
Involves magnifying the cervix using a colposcope to detect tissue changes.
Application of acetic acid or iodine helps highlight abnormal areas.
Allows for detailed visualization of lesions not visible with the naked eye.

Cervical Biopsy

Often performed during colposcopy when abnormalities are detected.
A small sample of cervical tissue is taken and examined histologically.
Confirms the presence of precancerous or cancerous cells.

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[4] Denny, L. (2012). Cervical cancer: Prevention and treatment. Discovery Medicine, 14(75), 125–131. From: https://pubmed.ncbi.nlm.nih.gov/23061575/

[5] National Cancer Institute. (2023). Cervical Cancer: Causes and Risk Factors. From: https://www.cancer.gov/types/cervical/causes-risk-prevention

Considered the gold standard for definitive diagnosis.[6]

2.7. Stages of cervical cancer

Cervical cancer is classified into stages based on tumor size, depth of invasion, and spread to nearby or distant tissues. The staging follows the FIGO classification system:

Stage 0 – Carcinoma in situ

Pre-cancerous stage; abnormal cells are present but limited to the surface of the cervix.
Not officially included in the FIGO staging.

Stage I – Confined to the cervix

Cancer is limited to the cervix, with no spread beyond it.

Stage IA (Microinvasive cancer)

i. Detected only under a microscope.
ii. **IA1:** Invasion <3mm deep and <7mm wide.
iii. **IA2:** Invasion 3–5mm deep and <7mm wide.

Stage IB (Visible or larger lesions)

i. Cancer is clinically visible or deeper than IA.
ii. **IB1:** Lesion ≤4 cm.
iii. **IB2:** Lesion >4 cm.

Stage II – Beyond cervix but not to pelvic wall or lower vagina

Tumor invades the upper vagina or uterus.

Stage IIA: No parametrial invasion.
i. **IIA1:** Tumor ≤4 cm.
ii. **IIA2:** Tumor >4 cm.

Stage IIB: Invasion into parametrial tissue (tissue beside the cervix).

Stage III – Spread to pelvic wall, lower vagina, or causes kidney issues

i. Cancer affects pelvic structures or causes hydronephrosis.
ii. **Stage IIIA:** Tumor involves lower third of the vagina.
iii. **Stage IIIB:** Invasion into pelvic wall or causes kidney dysfunction due to ureter obstruction.

Stage IV – Distant spread

i. Cancer has metastasized beyond the pelvic region.
ii. **Stage IVA:** Invasion into nearby organs (bladder or rectum).
iii. **Stage IVB:** Distant metastasis to organs such as liver, lungs, bones, or brain.[7]
iv.

2.8 Types of cervical cancer

Cervical cancer is primarily classified into two main types, based on the cell origin:

Squamous Cell Carcinoma (SCC)

Accounts for **70–80%** of all cervical cancer cases.
Arises from the **squamous epithelial cells** covering the ectocervix.
Most common form of **invasive cervical cancer**.
Histological subtypes include:
Keratinizing large-cell SCC: Shows keratin pearl formation.
Non-keratinizing large-cell SCC: Minimal keratinization, lacks pearl formation.
Small-cell SCC: Poorly differentiated; may overlap with **neuroendocrine tumors**.
Less common variants:
Verrucous carcinoma: Wart-like, rarely metastasizes, but may locally invade.
Papillary SCC: Resembles transitional cell carcinoma; rare and aggressive.
Prognosis:
Keratinizing subtypes generally have a **better prognosis** than small-cell variants.

Adenocarcinoma

[6] Saslow, D., Solomon, D., Lawson, H. W., Killackey, M., Kulasingam, S. L., Cain, J., et al. (2012). American Cancer Society, American Society for Colposcopy and Cervical Pathology, and American Society for Clinical Pathology screening guidelines for the prevention and early detection of cervical cancer. CA: A Cancer Journal for Clinicians, 62(3), 147–172. From: https://doi.org/10.3322/caac.21139

[7] National Cancer Institute – NIH, October 13, 2022 From: https://www.cancer.gov/types/cervical/stages

Represents ~**20%** of cervical cancers.
Originates from the **glandular (mucus-secreting) cells** of the endocervix.
Key points:
Often associated with **adenocarcinoma in situ (AIS)**.
Can coexist with **squamous lesions** in up to 50% of cases.
Diagnosis often aided by **colposcopy**.
Histological subtypes:
Endocervical type (most common)
Endometrioid, **intestinal**, **clear cell**, or **mixed types**
Note:
Adenocarcinoma can be more difficult to diagnose and treat due to its histologic diversity.[8]

2.9 Surgical interventions in cervical cancer

Surgery involves removing the tumor along with some surrounding healthy tissue and is often the primary treatment for early-stage cervical cancer. The choice of surgery depends on tumor size, stage, potential complications, and the patient's fertility desires.

Common surgical options include:

Radical Trachelectomy:
Removes the cervix and upper vagina but preserves the uterus, allowing fertility preservation. Can be done vaginally, abdominally, or laparoscopically. Lymph nodes may also be removed. Pregnancy is possible post-surgery but with higher miscarriage risk.

Conization:
Removes a cone-shaped section of cervical tissue, used to diagnose and treat precancerous lesions or very early cancers. Techniques include cold knife biopsy, laser conization, or LEEP (Loop Electrosurgical Excision Procedure).

Simple Hysterectomy:
Removes the uterus and cervix without surrounding tissues. Used for severe precancerous lesions or early cervical cancer. Can be performed abdominally, vaginally, laparoscopically, or robotically.

Radical Hysterectomy:
Removes the uterus, cervix, upper vagina, and surrounding tissues (parametrium and uterosacral ligaments). Done abdominally or laparoscopically. Possible side effects include infertility, bleeding, infection, and urinary or bowel issues.

Pelvic Exenteration:
Reserved for recurrent cancer, this extensive surgery removes the uterus, vagina, bladder, rectum, and part of the colon. Urinary and fecal diversion may be required, often via surgically created stomas. Vaginal reconstruction may also be performed.

Lymph Node Sampling and Dissection:
Removal of pelvic and para-aortic lymph nodes during surgery to assess cancer spread and guide further treatment.

2.10. Radiotherapy in cervical cancer

Radiotherapy can be used before surgery to shrink tumors, after surgery to reduce recurrence risk, or as primary treatment. It is often combined with chemotherapy for better outcomes.

External Beam Radiotherapy (EBRT): High-energy rays target the tumor from outside the body to destroy cancer cells.

Brachytherapy (Internal Radiotherapy): Radioactive implants placed directly into the cervix deliver high radiation doses locally.

[8]The American Cancer Society medical and editorial content team, June 28, 2024 From: https://www.cancer.org/cancer/types/cervical-cancer/treating/surgery.html

Side effects of radiotherapy include:

Fatigue, emotional changes, skin irritation (external effects)

Infertility, abdominal pain, bowel obstruction, early menopause, vaginal stenosis (internal effects)

Nursing care involves skin and mucous membrane monitoring, symptom management, and radiation safety precautions, especially during brachytherapy.

2.11 Chemotherapy

Chemotherapy uses drugs such as cisplatin, carboplatin, and ifosfamide to kill cancer cells intravenously over several months. It can be used alone or combined with radiotherapy, especially in advanced stages.

Common side effects:

Infection risk, hair loss, fatigue, diarrhea, loss of appetite, nausea/vomiting

Rare side effects:

Kidney damage, hearing loss, anemia, cognitive issues

Nursing roles include monitoring fluid/electrolyte balance, infection risk, chemotherapy administration, and caregiver protection.

2.12 Immunotherapy

Also known as biological therapy, it enhances the body's immune response against cancer. Pembrolizumab is used for recurrent or metastatic cervical cancer.

Side effects may include: Skin reactions, diarrhea, weight changes, flu-like symptoms.

2.13 Palliative care in cervical cancer

Palliative care addresses physical, emotional, social, and financial challenges related to advanced cancer. It provides active support aimed at improving quality of life for patients and their families.

Should be offered to all patients regardless of cancer type, stage, age, or gender.

May include medications, nutritional support, relaxation techniques, emotional support, and other therapies.[9]

2.14 Pre-operative nursing care

Pre-operative nursing begins when the patient is admitted to the ward. The nurse ensures all required lab tests and imaging—such as cardiology consult with EKG, pulmonology consult with lung ultrasound, blood biochemistry, blood typing, and anesthesiology consult—are completed before surgery.

A thorough patient assessment, including medical history and comorbidities, is essential. Clear and professional communication with the patient and family helps manage expectations and address concerns.

Vital signs are closely monitored and recorded until the patient is transferred to the operating room. All medications, including daily treatments, must be documented.

IV access is established to administer pre- and post-operative therapies as ordered. Patients are advised to fast after midnight and avoid fluids about two hours before surgery.

Finally, patients are prepared with appropriate hospital attire and escorted to the OR.

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[9]Cohen, P. A., Jhingran, A., Oaknin, A., & Denny, L. (2019). Cervical cancer. The Lancet, 393(10167), 169–182. From: https://doi.org/10.1016/S0140-6736(18)32470-X

National Cancer Institute (NCI). (2023). Cervical Cancer—Radiation Therapy. From: https://www.cancer.gov/types/cervical/hp/cervical-treatment-pdq#section/_38

2.15 post-operative nursing care

Post-operative care starts when the patient returns from recovery to the surgical ward. The nurse ensures the patient is comfortable and assists with transferring to the bed. Pain management is critical, using epidural or IV analgesics, with regular pain assessments in the initial hours post-surgery.

Vital signs are continuously monitored and recorded. The nurse supports early mobilization to prevent complications such as muscle stiffness and impaired breathing, gradually encouraging independent activity.

Urinary catheter care is important; the nurse monitors output, color, and odor, keeps the catheter clean, and instructs the patient on its management if needed.

Wound care involves careful cleaning and dressing changes while watching for signs of infection. The nurse also coordinates required lab tests and imaging as per physician orders.

Emotional support plays a key role, especially for younger patients undergoing procedures like hysterectomy, as these surgeries can have profound psychological effects.

Hospital stay length varies by surgery type: 2-3 days after radical trachelectomy, 5-7 days after radical hysterectomy, and 14-21 days following pelvic exenteration.

Before discharge, the nurse completes documentation and educates the patient on post-op care, medications, activity restrictions, diet, and avoidance of alcohol and tobacco during recovery.

Rehabilitation may take 4-6 weeks, during which patients are encouraged to follow nursing guidance for physical and emotional well-being.[10]

2.16 Nursing diagnoses for patients with cervical cancer

Patients with cervical cancer face a range of physical, emotional, and spiritual challenges related to the disease and its treatments such as radiotherapy and chemotherapy. Common side effects include nausea, vomiting, pain, diarrhea, fatigue, and neutropenia. Key nursing diagnoses include:

Acute Pain related to tumor growth or metastasis, requiring prompt pain management.
Impaired Urinary Elimination due to surgery and catheter use, necessitating close monitoring.
Anxiety and Fear stemming from misinformation and uncertainty about life after treatment, calling for emotional support.
Spiritual and Emotional Distress especially in women post-hysterectomy due to loss of fertility, needing sensitive, ongoing support.
Risk for Infection linked to surgical wounds or cervical changes, requiring vigilant preventive care.
Risk for Impaired Skin Integrity from surgical wounds, emphasizing wound care to prevent infection and promote healing.
Risk for Deficient Fluid Volume due to decreased intake or losses, necessitating careful fluid balance monitoring.
Altered Sexual Function caused by disease and treatment side effects, an important concern needing compassionate intervention.

Each diagnosis should be personalized based on the patient's physical and psychological state, aiming to improve quality of life and support recovery.[11]

2.17 Statistics/reports on incidence and mortality rates in Albania

[10]Qendra Kombëtare e Cilësisë dhe Sigurisë / Institucioni i Shëndetit publik / Spitali Onkologjik, QSUT, Tiranë / Spitali Obstetrikë - Gjinekologjikë "Mbretëresha Gerlandinë" / Spitali Obstetrikë - Gjinekologjikë "Koço Glozheni
[11] National Cancer Institute (NCI). (2023). Cervical Cancer—Treatment From: https://www.cancer.gov/types/cervical American Cancer Society (ACS). (2022). Cervical Cancer Treatment Options by Stage From: https://www.cancer.org/cancer/cervical-cancer/treating/by-stage.html

According to the monitoring report data from the Ministry of Health for the period January–August 2023, the number of women screened for cervical cancer decreased by 32% compared to the same period last year. The actual number of screenings from January to August 2023 was 7,029, compared to a total of 10,400 women screened in 2022. The sharpest decline in screenings was recorded in 2020 during the Covid-19 pandemic due to restrictions and fear of infection. The downward trend in screenings during the pandemic was a global phenomenon.

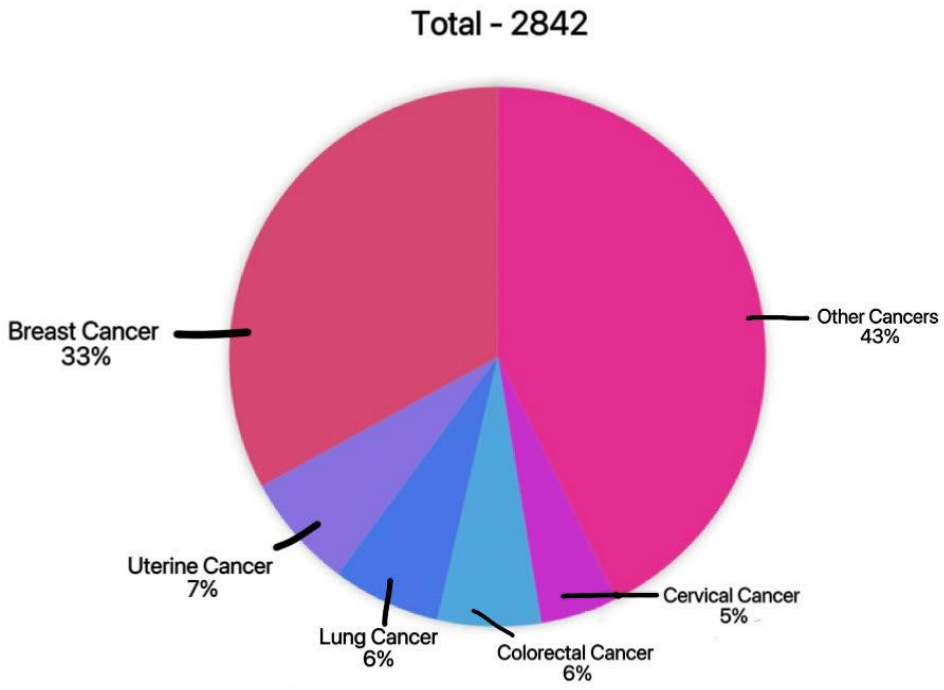

Figure 1. Cancers that affected women in Albania in 2021.

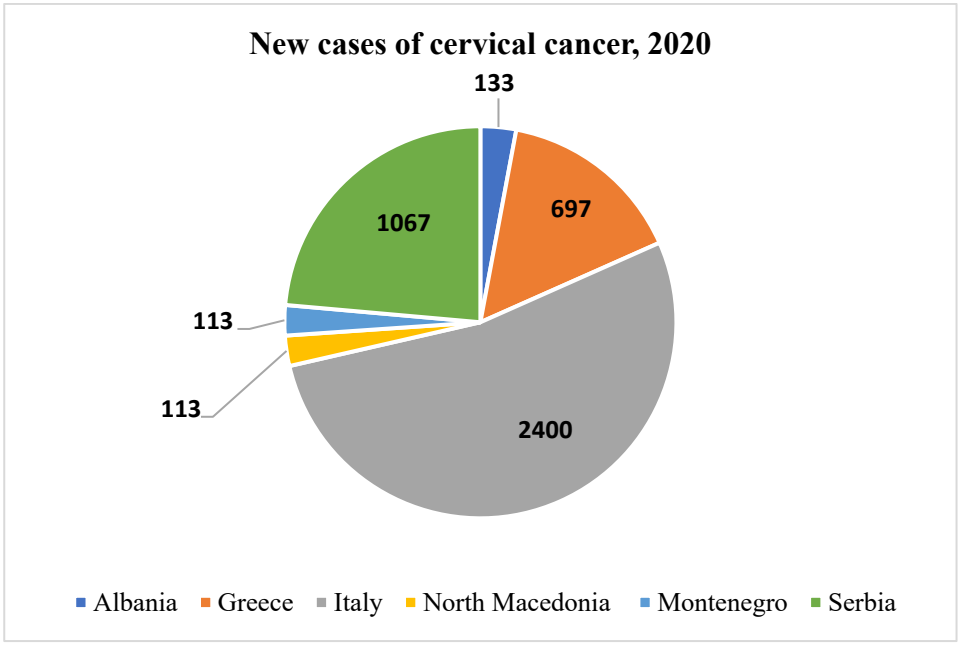

Figure 2. Comparative chart of new cervical cancer cases between Albania and neighboring countries for the year 2020.

In the chart presented above, a comparison is made between the number of newly reported cervical cancer cases in Albania and neighboring countries for the year 2020. The data shows:

- **Albania** – 133 new cases
- **Greece** – 697 new cases
- **Italy** – 2,400 new cases
- **North Macedonia** – 113 new cases

- **Montenegro** – 113 new cases
- **Serbia** – 1,067 new cases

In the chart below, we have a comparison of the number of deaths caused by cervical cancer in Albania and neighboring countries for the year 2020:

- **Albania** – 74 deaths
- **Greece** – 282 deaths
- **Italy** – 746 deaths
- **North Macedonia** – 62 deaths
- **Montenegro** – 54 deaths

Serbia – 634 deaths

Albania has a population of approximately **1.2 million women aged 15 and above**, who are considered at risk of developing cervical cancer. Current estimates show that each year, around **140 women are diagnosed** with cervical cancer, and about **74 die** from the disease.

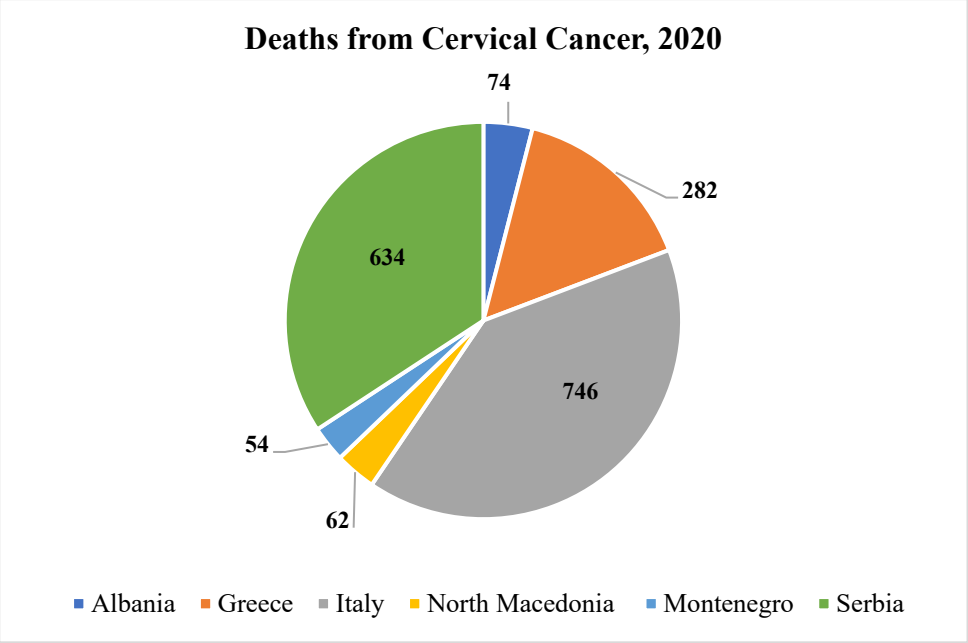

Figure 3. Comparative chart of cervical cancer-related deaths between Albania and neighboring countries, for the year 2020.

Cervical cancer ranks as the 5th most common cancer among women in Albania, and the 2nd most common cancer among women aged 15 to 44. Currently, there is no available data on the burden of HPV (Human Papilloma Virus) in the general population of Albania. However, in Southern Europe—the region Albania belongs to—approximately 3.8% of women in the general population are estimated to have a cervical HPV-16/18 infection at any given time. Furthermore, 68% of invasive cervical cancer cases are attributed to HPV types 16 or 18.[12]

3. CONCLUSIONS

Cervical cancer continues to pose a serious health challenge for women worldwide, affecting not only physical health but also emotional and reproductive well-being. While early diagnosis and treatment have improved, the disease remains prevalent, especially in regions with limited screening and healthcare access. This emphasizes the importance of comprehensive strategies that prioritize both prevention and treatment.

Surgical intervention remains a key treatment, particularly in early-stage cases. Tailored approaches—from conservative procedures like conization to radical surgeries such as hysterectomy or pelvic exenteration—should consider disease stage, fertility goals, comorbidities, and the patient's psychological state. Postoperative care presents ongoing challenges that require skilled nursing management.

[12]Shkurt 2021, https://www.togetherforlife.org.al/wp-content/uploads/2021/10/TB-3-ALB-Kanceri-i-gjirit-dhe-kanceri-i-qafes-se-mitres-gjate-periudhave-te-epidemive.pdf

Nurses play a central role throughout the treatment continuum—assessing, preparing, supporting, and educating patients. Beyond clinical duties, they are essential in promoting awareness, encouraging HPV vaccination, and guiding lifestyle changes to reduce risk.

Effective cervical cancer management must go beyond surgery and medication. It requires an integrated, patient-centered model combining medical expertise, evidence-based care, and compassionate support to improve both survival and quality of life.

REFERENCES

1. Anatomia e Njeriut – Dr.med.Ph.D. Nasir BEHXHETI,Dr.med. Selim ÇERKEZI, Dr.med. Argjent MUÇA - fq. 132-135 From: https://archive.org/details/AnatomiaENjeriut/mode/2up
2. **Strickler, H. D., Burk, R. D., Fazzari, M., Anastos, K., Minkoff, H., Massad, L. S., ... & Schlecht, N. F.** (2005). Natural history and possible reactivation of human papillomavirus in human immunodeficiency virus–positive women. *Journal of the National Cancer Institute*, 97(8), 577–586.
3. Moffitt Cancer Center - Monica Avila, MD Gynecologic oncologist. From: https://www.moffitt.org/cancers/cervical-cancer/signs-symptoms/
4. Denny, L. (2012). Cervical cancer: Prevention and treatment. *Discovery Medicine*, 14(75), 125–131. From: https://pubmed.ncbi.nlm.nih.gov/23061575/
5. **National Cancer Institute.** (2023). *Cervical Cancer: Causes and Risk Factors.* From: https://www.cancer.gov/types/cervical/causes-risk-prevention
6. **Saslow, D., Solomon, D., Lawson, H. W., Killackey, M., Kulasingam, S. L., Cain, J., et al.** (2012). American Cancer Society, American Society for Colposcopy and Cervical Pathology, and American Society for Clinical Pathology screening guidelines for the prevention and early detection of cervical cancer. *CA: A Cancer Journal for Clinicians*, 62(3), 147–172. From: https://doi.org/10.3322/caac.21139
7. National Cancer Institute – NIH, October 13, 2022 From: https://www.cancer.gov/types/cervical/stages
8. The American Cancer Society medical and editorial content team, June 28, 2024 From: https://www.cancer.org/cancer/types/cervical-cancer/treating/surgery.html
9. **Cohen, P. A., Jhingran, A., Oaknin, A., & Denny, L.** (2019). Cervical cancer. *The Lancet*, 393(10167), 169–182. From: https://doi.org/10.1016/S0140-6736(18)32470-X
National Cancer Institute (NCI). (2023). *Cervical Cancer—Radiation Therapy*. From: https://www.cancer.gov/types/cervical/hp/cervical-treatment-pdq#section/_38
10. Qendra Kombëtare e Cilësisë dhe Sigurisë / Institucioni i Shëndetit publik / Spitali Onkologjik, QSUT, Tiranë / Spitali Obstetrikë - Gjinekologjikë "Mbretëresha Gerlandinë" / Spitali Obstetrikë - Gjinekologjikë "Koço Glozheni
11. **National Cancer Institute (NCI).** (2023). *Cervical Cancer—Treatment* Marrë nga: https://www.cancer.gov/types/cervical
American Cancer Society (ACS). (2022). *Cervical Cancer Treatment Options by Stage* From: https://www.cancer.org/cancer/cervical-cancer/treating/by-stage.html
12. Shkurt 2021, https://www.togetherforlife.org.al/wp-content/uploads/2021/10/TB-3-ALB-Kanceri-i-gjirit-dhe-kanceri-i-qafes-se-mitres-gjate-periudhave-te-epidemive.pdf

Behaviour Of Rubberized Asphalt Mixture Subjected To Thermal Loading

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Abstract: This study investigated the behavior of dry mixed rubberized asphalt mixture subjected to permanent deformation under high temperature variation. Crumb rubber, obtained from recycled scrap tires was used as an aggregate replacement within the asphalt mixture as it could potentially provide greater elastic recovery to the mixture. The elements of natural and synthetic rubber within the scrap tires have been identified to improve the thermal stability of the tire compound and provide wider working temperature range. Therefore, to use the crumb rubber as a modifier in asphalt mixture could possibly improve the properties of asphalt mixture at various service temperatures and consequently, improve the resistance against permanent deformation. Additionally, this could provide an alternative in recycling the scrap tires as non-decaying waste material. In this study, a mixture of Asphaltic Concrete of AC14 (dense graded with nominal maximum aggregate size 14 mm) was modified with 1, 2 and 3% of crumb rubber (coarse size, 5 mm) from the total weight of aggregate using dry process method. The properties of the rubberized mixtures were compared to the control mixture (with no rubber). Samples were prepared using Marshall Compactor and tested under Resilient Modulus at 25 and 40ºC to measure the material stiffness. In addition, Dynamic Creep Test was conducted to determine the permanent deformation at four temperature conditions; 25, 40, 50, and 60°C. The analysis was focused on the effect of adding crumb rubber in asphalt mixture in terms of accumulated permanent strain under the influence of temperature variation. Based on this study, it was observed that the susceptibility of asphalt mixture to high temperature was reduced by the crumb rubber modification.

Keywords: Rubberized Asphalt, Sustainable pavement, Thermal loading, Crumb rubber

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1. INTRODUCTION

Asphalt mixtures are complex and heterogeneous composite materials composed of bitumen, aggregates, and air voids. The interactions among these components enable the mixture to resist traffic-induced loads transmitted to the underlying layers, and their properties largely determine the pavement's ability to endure these stresses and prevent structural failure (Abdul Hassan & Rosli, 2012). At elevated temperatures, bitumen tends to soften and behave as a viscous liquid, leading to a reduction in internal friction between aggregate particles. Consequently, the repetitive loading is primarily borne by the asphalt binder rather than the aggregate skeleton, resulting in the permanent deformation of the asphalt mixture (Huang et al., 2012).Furthermore, asphalt mixtures are temperature-sensitive materials due to the nature of their constituents. At lower temperatures, they exhibit properties closer to those of elastic materials, while at higher temperatures, their behavior becomes more viscous. The viscoelastic characteristics of asphalt binders are closely associated with pavement distresses such as rutting, cracking, and fatigue (Peilong Li et al., 2013). Therefore, identifying effective methods to slow down the deterioration of conventional asphalt pavements is essential for extending pavement service life.Numerous studies have indicated that the incorporation of additives, including various types of polymers and fibers, can effectively improve asphalt mixture performance and delay pavement deterioration (Moghaddam et al., 2011). Among these additives, crumb rubber modifier (CRM), derived from recycled waste tires, and has gained considerable attention globally, particularly in the United States. Field observations have shown that CRM-modified pavements remain in good condition for several years compared to conventional mixtures (Wong & Wong, 2007). Previous research has demonstrated that CRM binders enhance the mechanical performance of pavements by providing superior rutting resistance, better low-temperature cracking resistance, reduced fatigue and thermal susceptibility, lower noise and maintenance costs, and extended pavement lifespan. Moreover, the use of crumb rubber contributes to environmental sustainability by utilizing waste materials and conserving natural resources. Due to these benefits, CRM-modified asphalt mixtures are increasingly adopted as eco-friendly materials in highway construction projects worldwide (Rodríguez et al., 2014).

Crumb rubber can be incorporated into asphalt mixtures through two primary methods: the wet process and the dry process. In the wet process, crumb rubber is blended with bitumen to form a modified binder, whereas in the dry process, ground rubber particles are directly mixed with aggregates before adding the bitumen. Although the wet process generally provides better performance, the dry process offers distinct advantages, such as simpler production and the potential for higher utilization of recycled rubber. In this study, the performance of rubberized asphalt mixtures produced via the dry process was evaluated under conditions of high temperature, focusing on their susceptibility to permanent deformation. Various proportions of CRM-modified mixtures were analyzed and compared with conventional asphalt mixtures to assess their mechanical behavior and resistance to rutting.

2.1. PROBLEM STATEMENT

The design life and service quality of any highway construction project largely depend on the characteristics of the asphalt mixture, which comprises bitumen, aggregates, and air voids. However, with the continuous growth in traffic volume, the increase in axle loads, and the substantial fluctuations in daily and seasonal temperatures, asphalt mixtures—being viscoelastic in nature—become susceptible to damage under varying environmental conditions, particularly at elevated temperatures. Under such conditions, the viscosity of the asphalt binder decreases significantly, resulting in a reduction of internal friction among aggregate particles and ultimately leading to permanent deformation within the pavement structure.

Permanent deformation, or rutting, has a substantial impact on the overall performance and lifespan of asphalt pavements. It not only shortens the service life of the pavement but also affects vehicle handling and stability, posing potential safety risks for road users. Hence, there is a critical need to enhance the properties of conventional asphalt mixtures through modification techniques aimed at improving their resistance to deformation. One promising approach involves the incorporation of recycled materials, such as crumb rubber obtained from waste tires, as a partial replacement for aggregate using the dry process. Prior studies have demonstrated that the inclusion of crumb rubber modifiers (CRM) can significantly enhance the mixture's resistance to permanent deformation and fatigue cracking (Hamed, 2010; Peilong Li et al., 2013; Moghaddam et al., 2011).

Moreover, modifying asphalt mixtures with CRM through the dry process has been found to improve their performance under both high and low temperature conditions (Cao, 2007). Therefore, this study aims to examine the influence of crumb rubber modification on the mechanical properties of asphalt mixtures, particularly their resistance to permanent deformation under varying temperature conditions. It is important to note that the rubber composition in tires contains both natural and synthetic rubber, which contributes to enhanced thermal stability of the compound—making it suitable for anti-vibration and high-heat applications such as large vehicle tires. For instance, natural rubber exhibits a working temperature range of approximately –50°C to 100°C. Additionally, the inherent characteristics of these rubber compounds, such as excellent elasticity, high physical strength, resilience, and strong resistance to tearing and abrasion, suggest that incorporating crumb rubber into asphalt mixtures could significantly improve pavement durability and long-term performance.

1.3 AIM AND OBJECTIVES OF THE STUDY

The primary aim of this study is to evaluate the mechanical behavior of dry-mixed rubberized asphalt mixtures when subjected to temperature variations. To achieve this aim, the following specific objectives have been established:

i) To assess the influence of varying crumb rubber modifier (CRM) contents on the resilient modulus of asphalt mixtures.
ii) To evaluate the performance of rubberized asphalt mixtures in terms of their resistance to permanent deformation under different temperature conditions.

1.4 SCOPE OF THE STUDY

In this study, four types of asphalt mixtures were prepared for evaluation. The first was a control mixture—an asphalt concrete with a nominal maximum aggregate size (NMAS) of 14 mm (designated as AC14) without the inclusion of crumb rubber. The other three were rubberized asphalt mixtures containing 1%, 2%, and 3% crumb rubber (with a particle size of 5 mm) by total aggregate weight. The AC14 mixture represents a dense-graded asphalt mixture in accordance with the JKR/SPJ/2008-S4 specification.

The Marshall Mix Design method was employed to prepare the compacted samples and to determine the optimum bitumen content. The Resilient Modulus Test was performed at temperatures of 25°C and 40°C to assess the stiffness characteristics of the mixtures. Furthermore, the samples were subjected to the Dynamic Creep Test under different temperature conditions to evaluate their susceptibility to permanent deformation at elevated temperatures.

The tests were conducted at four temperature levels: 25°C, 40°C, 50°C, and 60°C. This temperature range was selected to simulate the variations experienced during the hot season and to represent realistic in-service pavement conditions. It is important to note that the temperature within asphalt pavement layers typically exceeds the ambient air temperature. Therefore, the testing temperatures adopted in this study correspond to actual pavement temperatures rather than the surrounding atmospheric conditions.

1.5 SIGNIFICANCE TO KNOWLEDGE

Significant temperature variations in many regions have a considerable impact on the performance of asphalt mixtures, leading to various forms of pavement distress. Among these, permanent deformation (rutting) is one of the most common and critical distresses, particularly in hot climatic zones where pavements are frequently subjected to heavy and repetitive axle loads. The resistance of asphalt mixtures to such deformation is strongly affected by temperature fluctuations due to the thermal susceptibility of asphalt binders, which tend to soften and flow under high temperatures. Consequently, substantial financial resources—amounting to millions of dollars annually—are allocated to road construction, rehabilitation, and maintenance activities.

Incorporating elastomeric polymers such as crumb rubber into asphalt mixtures presents a promising solution to enhance their stability and performance across varying temperature conditions. The beneficial chemical constituents present in crumb rubber can improve the rheological and mechanical properties of bitumen, thereby enhancing the overall durability and thermal stability of asphalt mixtures. Moreover, this approach offers an environmentally sustainable method for recycling waste tires, which are otherwise non-biodegradable and pose serious environmental concerns.

Previous studies on crumb rubber–modified asphalt, particularly those utilizing the wet process, have demonstrated that rubber inclusion reduces temperature susceptibility and improves resistance to thermal cracking (Rodríguez et al., 2014). However, there is a notable lack of research focusing on the dry-mixed rubberized asphalt mixtures and their performance under varying temperature conditions. Hence, this study provides valuable insights and experimental data regarding the influence of temperature on the permanent deformation behavior of dry-mixed rubberized asphalt mixtures. The findings are expected to contribute to the advancement of knowledge in asphalt technology and to promote the use of sustainable, high-performance pavement materials

2. LITERATURE REVIEW

2.1 Introduction

This chapter presents a concise discussion of the key issues associated with the effects of thermal loading on asphalt pavements, particularly under elevated temperatures during hot seasons. The impact becomes more critical in areas with high traffic volumes and heavy axle loads, which often lead to significant pavement deformation. Various factors influencing the permanent deformation behavior of asphalt mixtures are discussed, including the influence of the mixture's heterogeneous composition and the incorporation of performance-enhancing modifiers such as crumb rubber.

Additionally, the chapter provides an overview of crumb rubber production, its physical characteristics (composition, size, and type), and its application as a modifier in asphalt mixtures. A detailed explanation of the rubberized asphalt mixture concept, with special emphasis on the dry process, is also presented to establish the theoretical background for this research.

2.2 THERMAL EFFECTS ON ASPHALT PAVEMENT

Asphalt mixtures exhibit strong temperature sensitivity, and variations in temperature directly affect their viscoelastic behavior. Generally, asphalt behaves more elastically at low temperatures and more viscously at elevated temperatures (Peilong Li et al., 2013). During summer, pavement surface temperatures often exceed the ambient air temperature because of the high solar absorption capacity of asphalt materials. Conventional asphalt surfaces are dark in color, possessing a very low solar reflectance index (SRI)—typically close to 0—with a solar reflectance (albedo) ranging between 0.04 and 0.06. Consequently, the surface temperature of asphalt pavements during hot days is significantly higher than both the air temperature and the surface temperature of lighter-colored materials such as cement concrete pavements. Empirical studies have reported that the surface temperature of asphalt pavements can reach up to 70°C during periods of intense solar radiation (Chen et al., 2012). Similarly, more recent investigations indicate that when the ambient air temperature exceeds 30°C, the pavement surface temperature may rise above 50°C, often approaching or surpassing the softening point of the asphalt binder (Ping Li et al., 2012).GU et al. (2012) developed and validated a pavement temperature prediction model through field measurements to estimate the temperature distribution across different pavement depths (Figure 2.1). The results demonstrated that the surface layer consistently exhibits higher temperatures than the surrounding air, and the magnitude of this difference increases with rising ambient temperature. However, this temperature effect diminishes progressively with depth, resulting in lower temperatures in the bottom layers of the pavement structure.

3. MATERIAL AND METHOD

3.1 Introduction

The primary objective of this study is to evaluate the laboratory performance of rubberized asphalt mixtures under varying elevated temperature conditions. This chapter presents comprehensive details on the materials, equipment, and laboratory procedures employed throughout the experimental program.

In this research, four types of asphalt mixtures were prepared:

- A control mixture, which is a conventional asphalt concrete (AC14) with a nominal maximum aggregate size (NMAS) of 14 mm and no crumb rubber addition; and

- Three rubberized asphalt mixtures, modified with 1%, 2%, and 3% crumb rubber (of single particle size 5 mm) by total aggregate weight.

The AC14 mixture represents a dense-graded asphalt type designed in accordance with the JKR/SPJ/2008 specification.

All laboratory works were carried out in the Transportation Laboratory of Universiti Teknologi Malaysia (UTM) and were organized into three main stages, as summarized below:

1. Stage One – Sample Preparation:
Preparation of both control and rubberized asphalt mixtures was carried out using the Marshall Mix Design method. This stage included determining the Optimum Bitumen Content (OBC) for each mixture type through standard Marshall tests.

2. Stage Two – Resilient Modulus Testing:
After preparing the specimens at their respective OBCs, Resilient Modulus Tests were conducted at 25°C and 40°C to evaluate the stiffness characteristics of all mixtures.

3. Stage Three – Dynamic Creep Testing:
In the final stage, Dynamic Creep Tests were performed on the Marshall-compacted samples at four temperature levels (25°C, 40°C, 50°C, and 60°C) to assess the mixtures' resistance to permanent deformation.

3.2 Materials

Asphalt mixture is a composite material primarily composed of two fundamental constituents: aggregates and bitumen. This section provides detailed information on the characteristics of the aggregates, bitumen, and crumb rubber, the latter being utilized as a modifier in the production of rubberized asphalt mixtures.

3.2.1 Aggregate

In accordance with the AJK/SPJ/2008-S4 specification, the aggregates used in asphalt mixture wearing courses (AC14) must consist of a combination of coarse and fine aggregates, along with a mineral filler. In this study, granite coarse aggregate (particle size > 5 mm), fine aggregate (particle size ≤ 5 mm), and hydrated limestone (used as a mineral filler with a particle size ≤ 75 μm) were employed. The mineral filler constituted 2% of the total aggregate weight, as illustrated in Figure 3.2.

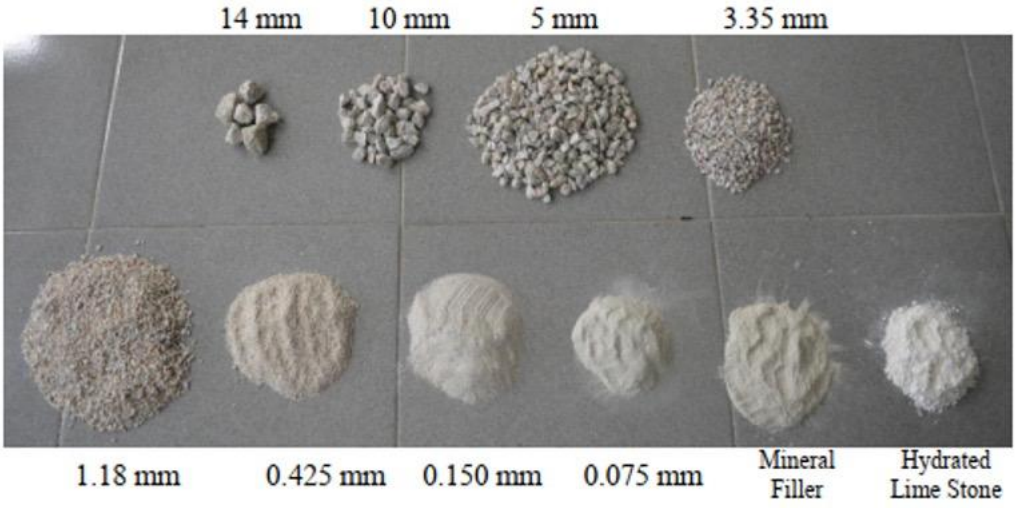

Figure.1 (AC 14 Aggregate Mix, Retaining on Various Sieve Sizes (1200 g)

3.2.2 Bitumen

Bitumen with a 60/70 penetration grade was employed as the binding material, as illustrated in Figure 3.3. The physical properties of the bitumen, including penetration and softening point, were determined in accordance with the standards ASTM D5 and ASTM D36, respectively.



Figure 2. (Bitumen Pen 60/70 sample)

3.2.3 Crumb Rubber

The recycled crumb rubber utilized in this study was obtained from Yong Fong Rubber, Malaysia, and produced through a mechanical shredding process. The resulting material was in granular coarse form, passing the 5 mm sieve and retained on the 3.35 mm sieve, as illustrated in Figure 3.4. It was used as a partial replacement for coarse aggregates of the same size.



Figure.3 (Crumb Rubber Modifier (CRM)

4. RESULTS

This chapter presents the analysis and discussion of the laboratory test results conducted to achieve the objectives of this study. The first stage of the experimental work involved the design of asphalt mixtures, including the control mixture (AC14) graded according to the JKR/SPJ 2008-S4 specification, and the rubberized asphalt mixtures modified with crumb rubber modifier (CRM) at 1%, 2%, and 3% of the total aggregate weight. This chapter provides a detailed explanation of the mixture components, gradation, Marshall Mix design results, and the determination of the optimum bitumen content. Subsequently, the findings from the second and third stages of the laboratory investigation are discussed. These include the results of the Resilient Modulus test conducted at 25°C and 40°C, as well as the Dynamic Creep test performed on both control and modified mixtures at 25°C, 40°C, 50°C, and 60°C, simulating hot climatic conditions.

4.1 ASPHALT MIX DESIGN

4.1.1 MATERİAL PROPERTİES

The properties of the materials utilized in this study—namely bitumen, aggregates, and crumb rubber—are described and discussed in the following sections.

4.1.2 BİTUMEN PROPERTİES

Bitumen with a 60/70 penetration grade was utilized as the binder for the Marshall test specimens. The outcomes of the tests performed on the bitumen samples, in accordance with the relevant standard specifications, are presented in Table 4.1.

Table.4.1 Bitumen Properties

Property	Unit	Used Standard	Value
Penetration at 25ºC	0.1mm	ASTM: D5	65
Softening point	ºC	ASTM: D36	52
Specific gravity	---	ASTM: D70	1.03

4.1.3 AGGREGATE PROPERİTES

Crushed granite aggregate was employed in this study, comprising both coarse and fine aggregates along with mineral filler. In accordance with the JKR/SPJ 2008-S4 specification, a small quantity of hydrated lime—approximately 2% of the total aggregate weight—was incorporated as an anti-stripping agent. The results of the specific gravity test for the aggregates are presented in Table 4.2.

Table.4.2 Aggregate Properties

Property	Unit	Used Standard	Value
Bulk Specific gravity	---	BS EN 1097-6	2.595
Apparent Specific gravity	---	BS EN 1097-6	2.648
Water absorption	%	BS EN 1097-6	0.

4.1.4 Crumb Rubber.

A granular coarse-sized crumb rubber was utilized in this study, passing the 5 mm sieve and retained on the 3.35 mm sieve, as a partial replacement for coarse aggregates of equivalent size. The crumb rubber was supplied by Yong Fong Rubber, Malaysia, and produced through a mechanical shredding process carried out at ambient temperature. A specific gravity of 1.15 was adopted for the crumb rubber, as determined using the gas pycnometry method.

4. DISCUSSION AND CONCLUSIONS / TARTIŞMA VE SONUÇLAR

5.1 Conclusions

Asphalt pavements are subjected to various forms of distress throughout their service life, primarily due to extreme environmental conditions, increasing traffic volumes, and the use of heavier axle loads and higher tire pressures in modern vehicles. These factors have imposed significant challenges on the performance and durability of highway systems. Among the major forms of pavement distress, permanent deformation (rutting) is one of the most critical. Previous research has demonstrated that seasonal temperature variations significantly influence the mechanical properties of asphalt materials. Experimental findings have revealed that the strain response of asphalt mixtures is far more sensitive to changes in temperature than to variations in load magnitude. In light of this, the present study was undertaken to evaluate the permanent deformation behavior of dry-mixed rubberized asphalt mixtures under varying temperature conditions. The findings of this research indicate that the temperature susceptibility of asphalt mixtures is influenced by the incorporation of crumb rubber particles through the dry process method. The design approach for rubberized asphalt mixtures (RAM) involved replacing a portion of the coarse aggregate with an equivalent volume of crumb rubber. This method produced consistent Marshall Mix design parameters, particularly in terms of voids in total mix (VTM), and effectively reduced the rubber swelling effect within compacted specimens—a common issue in rubberized asphalt mixtures.

The resilient modulus values were observed to decrease with increasing crumb rubber content compared to the conventional mixture, indicating enhanced elasticity and improved strain recovery under loading conditions.In terms of permanent deformation resistance, the mixture containing 1% crumb rubber modifier (CRM) exhibited superior performance compared to the control mixture, particularly at elevated temperatures. At 50°C, the 1% CRM mixture reached the terminal strain limit of 5% after 6,700 loading cycles, whereas the control mixture failed at 5,745 cycles, representing an improvement of over 15%. Similarly, at 60°C, the 1% CRM mixture reached 5% strain at 2,325 cycles, compared to only 1,560 cycles for the control mixture—demonstrating approximately 50% better performance.At lower temperatures (25°C and 40°C), both the control and 1% CRM mixtures exhibited similar deformation behavior due to the test's limited cycle count (10,000 cycles). The total deformation was approximately 1 mm at 25°C and 2.7 mm at 40°C, with the 1% CRM mixture deforming 6% less than the control. However, mixtures containing 2% and 3% CRM demonstrated lower resistance to strain, especially in the primary creep zone across all temperatures, due to excessive flexibility introduced by the higher rubber content. The creep test results further revealed that rubberized asphalt mixtures showed lower susceptibility to temperature variations compared to the control mixture. Although the increased elasticity of rubberized mixtures sometimes led to greater permanent deformation, the 1% CRM mixture maintained superior performance at 50°C and 60°C, demonstrating an optimal balance between elastic recovery and resistance to deformation.

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Ethics Committee Approval

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Peer-review

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Author Contributions / Yazar Katkıları

Conceptualization: H.S.; Investigation: H.S.; Material and Methodology: H.S., S.Ö.; Supervision: H.S., E.T.E.; Visualization: S.Ö.; Writing-Original Draft: H.S., D.A.; Writing-review & Editing: D.A., S.Ö.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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REFERENCES

Abdul Hassan, N. (2012). *Microstructural Characterisation of Rubber Modified Asphalt Mixture.* (Doctor of Philosophy), University of Nottingham.

Abdul Hassan, N., & Rosli, H. M. (2012). Application of X-ray Computed Tomography for Air Voids and Damage Characterisation in Asphalt Mixtures. *JURUTERA*, 20-23.

Ahari, A. S., Forough, S. A., Khodaii, A., & Nejad, F. M. (2013). Modeling the Primary and Secondary Regions of Creep Curves for SBS-Modified Asphalt Mixtures under Dry and Wet Conditions. *Journal of Materials in Civil Engineering, 26*(5), 904-911.

Aloysius, T., & Napitupulu, R. (2013). *Verification of Resilient Modulus Prediction of Asphalt Mixtures.* Paper presented at the Proceedings of the Eastern Asia Society for Transportation Studies.

American Society for Testing and Materials (2005). Standard Test Method for Penetration of Bituminous Materials, ASTM D 5. Philadelphia, USA.

American Society for Testing and Materials (2014). Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), ASTM D 36. West Conshohocken, PA.

American Society for Testing and Materials (2003). Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method), ASTM D 70. West Conshohocken, PA.

American Society for Testing and Materials (2006). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C 136. West Conshohocken, PA.

American Society for Testing and Materials (2000). Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures, ASTM D 2041. West Conshohocken, PA.

American Society for Testing and Materials (1995). Standard Test Method for Indirect Tension test for Resilient Modulus of Bituminous Mixtures, ASTM D 4123. West Conshohocken, PA.

Design and analysis of a sustainable scheme based on geothermal energy and a CO_2 power cycle: A thermodynamic assessment

FATIH YILMAZ*[1]

Abstract: Renewable energy sources are among the most significant contributors to environmental problems. These energy sources are important for sustainable system design for the net-zero emissions goal in 2025. In this study, a comprehensive thermodynamic analysis of electricity, heating, and hot water production with a combined system supported by geothermal energy is performed and proposed. The suggested system includes a geothermal energy cycle, a supercritical CO_2 power cycle, a heating process, and hot water production for fish farming. The developed system includes energy and exergy efficiencies of each system according to a 180 °C geothermal source output, as well as exergy destruction analysis. In addition, the effects of variables such as environmental temperature, geothermal source temperature, and geothermal mass flow rate, which affect the system performance, on the system efficiency are analyzed parametrically. The average hot water supply of 28 °C for the fish farm was also analyzed, and its effect on system efficiency was examined. Changes in system efficiency are examined by increasing these variables. As a result of the obtained analyses, 1406 kW of electricity could be produced with this system. In addition, the energy efficiency of the developed system is calculated as 48.47% and the exergy efficiency as 24.72%.

Keywords: Energy, exergy, geothermal, heating, fish farming

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1. INTRODUCTION

Energy demand continues to grow rapidly worldwide. Carbon-based fossil fuels play a crucial role in meeting this growing energy demand. The release of these fossil fuels causes serious health and human harm. Chief among these harms is global warming, acid rain, ozone depletion, and other factors that pose a significant threat to humanity's future. Therefore, the active and effective use of alternative energy sources is vital to overcoming these challenges. Renewable energy sources include solar, wind, geothermal, hydro, biomass, and wave energy. Among all renewable energy sources used as the primary drivers for power plants, geothermal energy offers a more reliable and sustainable solution in locations where its availability is promising. Geothermal energy is primarily stored as heat in underground fluids and rocks within the Earth's surface (Gholizadeh et al. 2020).

Generally, geothermal resources can be divided into three categories: low-temperature resources (below 90°C), medium-temperature resources (between 90°C and 150°C), and high-temperature resources (above 150°C). Low-temperature geothermal resources are more suitable for direct heating, medium-temperature geothermal resources are well-suited for small-scale applications for the production of various commodities (e.g., power, heating, cooling, etc.), and high-temperature geothermal resources are highly attractive for large-scale power grids. Considering three different types of geothermal processing for power generation: dry steam, flash steam, and binary steam, previous studies have found that the use of single- or double-flash binary geothermal may be the best scenario for high-temperature resources (Kanoglu and Bolatturk, 2008; Ratlamwala and Dincer, 2014).

The literature survey has included many papers on geothermal-driven combined systems that generate different beneficial products. Akrami et al. (2017) developed an energy and exergy assessment of the geothermal energy-based trigeneration plant. Their results indicated that overall system energy and exergy efficiency are determined as 26.14% and 44.45%, respectively. The thermodynamic performance investigation of the geothermal energy-based combined plant is examined by Siddiqui and Dincer (2018). The study covers the energy and exergy analyses of a geothermal power plant for trigeneration applications. The energy efficiency of the developed paper is to be 32.4% for the entire model. In 2025, Ramachandran et al. (2025) examined a thermodynamic and economic assessment of the geothermal-assisted trigeneration plant. Also, the authors have conducted a multi-objective optimization in this paper. According to the results, their developed plant can generate 1.1 MW of net power. Li et al. (2025) studied a thermoeconomic and exergy-environmental analysis of a trigeneration system based on geothermal energy with waste heat recovery and post-combustion CO_2 capture.

In summary, the literature review shows that combined power plants operating with geothermal energy are gaining more and more importance with each passing year. This study covers the thermodynamic analysis of a geothermal energy-supported trigeneration system. The thermodynamic analysis examines the system's energy and exergy efficiencies. Furthermore, a comprehensive analysis of the heating, hot water, and net electricity capacities that can be generated by

applying this analysis to the system is provided, and the effects of varying these variables are then parametrically examined.

2. MATERIAL AND METHOD

Geothermal energy-supported systems are important for a sustainable future. Figure 1 shows the flowchart of a designed geothermal system power plant. At point 1, the geothermal fluid, emerging at approximately 180°C, enters the valve, where it decreases in pressure and temperature and enters the separator (S) as a liquid-vapor mixture. It then continues as a saturated vapor at point 3 and as a saturated liquid at point 6. Electricity is generated between points 3 and 4 through expansion in the turbine. Heat exchanger 3 (HEX-3) heats pure water from point 17, which can be used for hot water in fish farms. Subsequently, the geothermal fluid heat at approximately 132°C at point 6 transfers to the subcycle, the supercritical CO_2 (sCO_2) cycle. This cycle also generates electricity. Since it is more suitable to send it underground at 50-60°C, the geothermal fluid returns to the underground by heating the area with HEX-2.

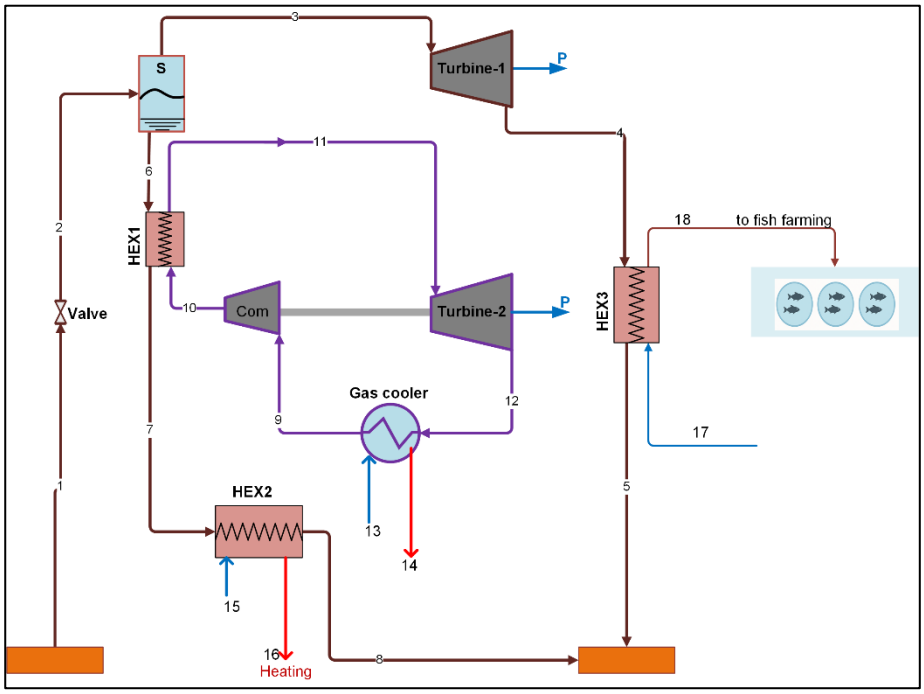

Figure 1. The developed geothermal energy-based combined plant diagram

2.1. Thermodynamic analysis

In this part of the study, a comprehensive thermodynamic analysis is conducted to examine the efficiency of the developed system and investigate its changes. Thermodynamic analysis is applied to each system to investigate energy and exergy efficiencies. Thermodynamic analysis is generally performed by considering the four equilibrium equations of a system's components: mass, energy, entropy, and exergy (Cengel et al. 2011; Dincer 2020)

The mass, energy, entropy, and exergy balances are;

$$\dot{m}_{in} = \dot{m}_{out} \tag{1}$$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m}_{in} h_{in} = \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m}_{out} h_{out} \tag{2}$$

$$\sum \dot{m}_{in}\, s_{in} \sum \left(\frac{\dot{Q}}{T}\right) + \dot{S}_{gen} = \sum \dot{m}_{out}\, s_{out} \tag{3}$$

$$\dot{E}x^{Q_{in}} + \dot{E}x^{W_{in}} + \sum \dot{m}_{in} ex_{in} = \dot{E}x^{Q_{out}} + \dot{E}x^{W_{out}} + \sum \dot{m}_{out} ex_{out} + \dot{E}x_D \tag{4}$$

Overall energy and exergy efficiency can be given as;

$$\eta_{sys} = \frac{\dot{W}_{net} + \dot{W}_{heating} + \dot{W}_{hw}}{\dot{Q}_{in,geothermal}} \tag{5}$$

$$\psi_{sys} = \frac{W_{net} + Ex_{Q,heating} + Ex_{Q,hw}}{Ex_{Q,in,geothermal}} \quad (6)$$

3. RESULTS AND DISCUSSION

In this study, a comprehensive thermodynamic analysis was conducted to determine system efficiency and the amount of useful products obtained. Figure 2 shows the system efficiency and the outputs obtained at a geothermal resource temperature of 180°C. Figure 2(a) shows the sCO_2 and the energy and exergy efficiencies of the entire cycle. Here, the sCO_2 energy efficiency was calculated as 8.61%, while the overall system energy efficiency was 48.69%. The resulting useful products (power, heat, and hot water) are depicted in Figure 2(b). Accordingly, the net electricity production of this system was calculated as 877.4 kW.

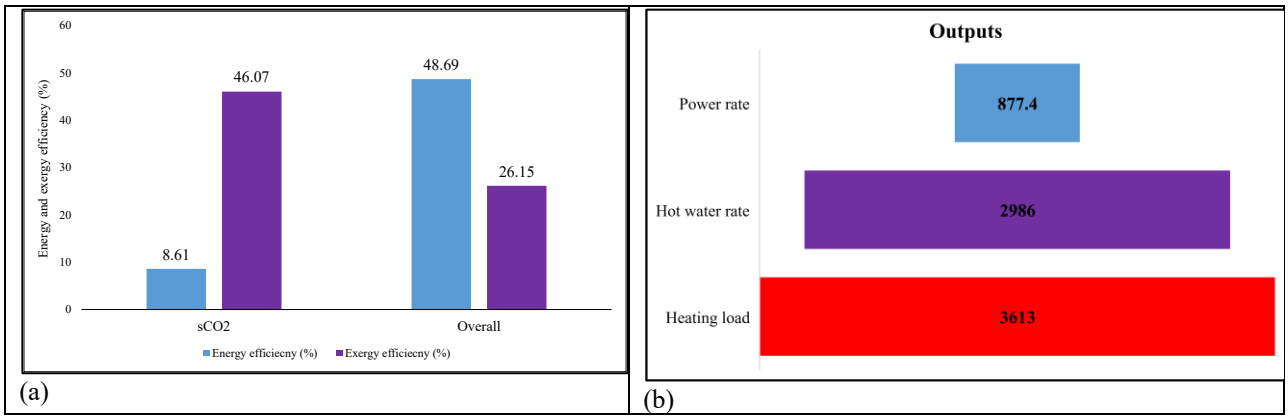

Figure 2. The main results of the thermodynamic analysis for the developed combined plant

In parametric studies, geothermal resource temperature is an important indicator, as it is one of the players that directly influences system efficiency. Figure 3 illustrates the useful outputs generated by the system as the geothermal resource temperature increases from 160°C to 200°C (Figure 3(a)), along with the sCO_2 and overall system efficiency (Figure 3(b)). As the resource temperature increases, both the beneficial useful outputs and the overall system efficiency increase linearly. The main reason for this is that as the resource temperature increases, the system operates at a higher enthalpy, resulting in increased output.

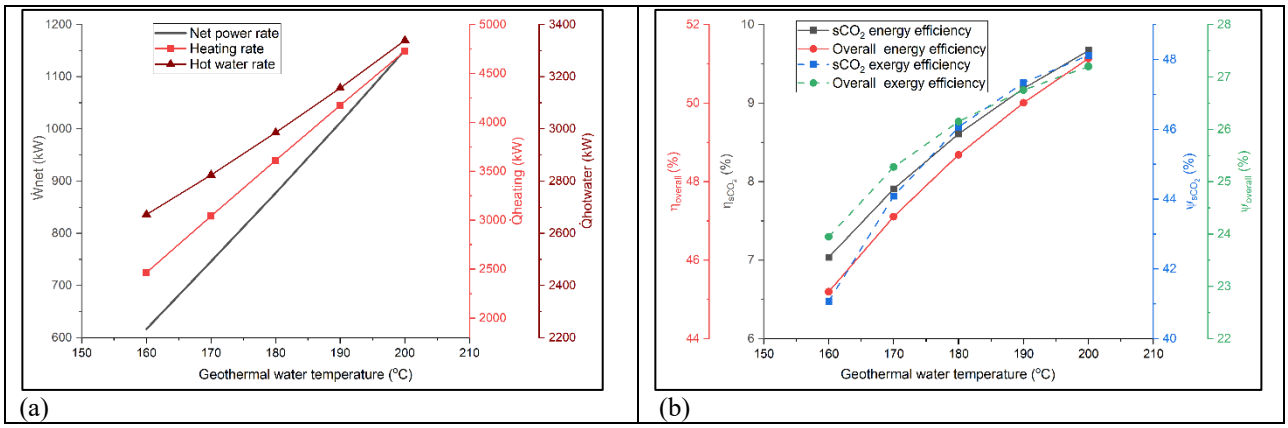

Figure 3. Relationship between geothermal source temperature and system outputs

Figure 4 presents and considers the effect of the geothermal resource mass flow rate on system outputs. As a result of a 40 kg/s increase in mass flow rate, the net electricity generated (from 500 kW to 1700 kW), hot water (from 200 kW to 6000 kW), and heating load (from 2500 kW to 7500 kW) increase linearly. Furthermore, this increase is parallel to the increase in both sCO_2 and the energy and exergy efficiencies of the entire system (see Figure 3(b)).

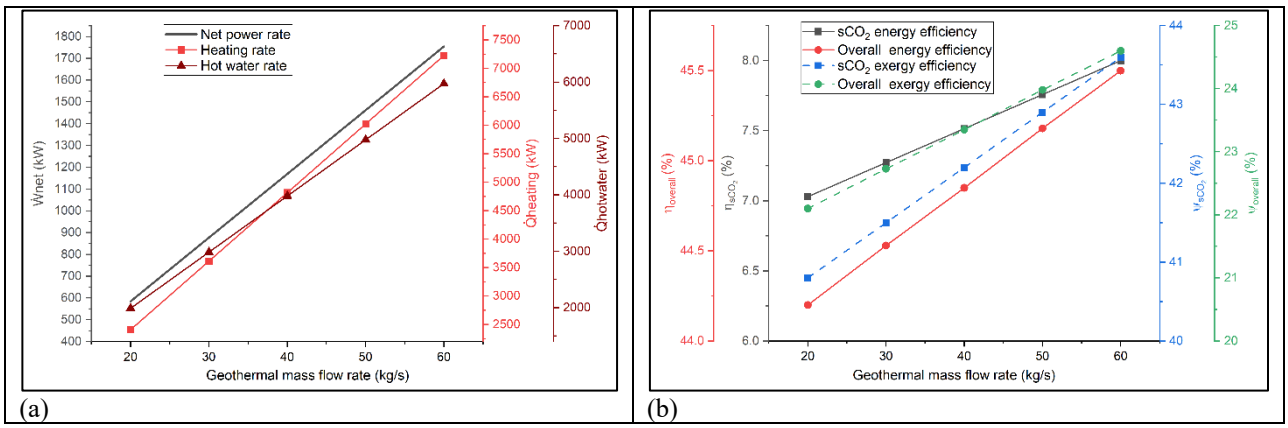

Figure 4. Relationship between geothermal source mass flow rate and system outputs

Finally, the changes in system efficiency and the beneficial products produced by increasing the heat exchanger contact point (PPT-HEX) are examined and illustrated in Figure 5. The lack of change in heating and hot water output is due to the lack of correlation with HEX-1. Conversely, the efficiency of the systems, both for electricity generation and for electricity generation, decreases inversely with increasing PPT-HEX-1.

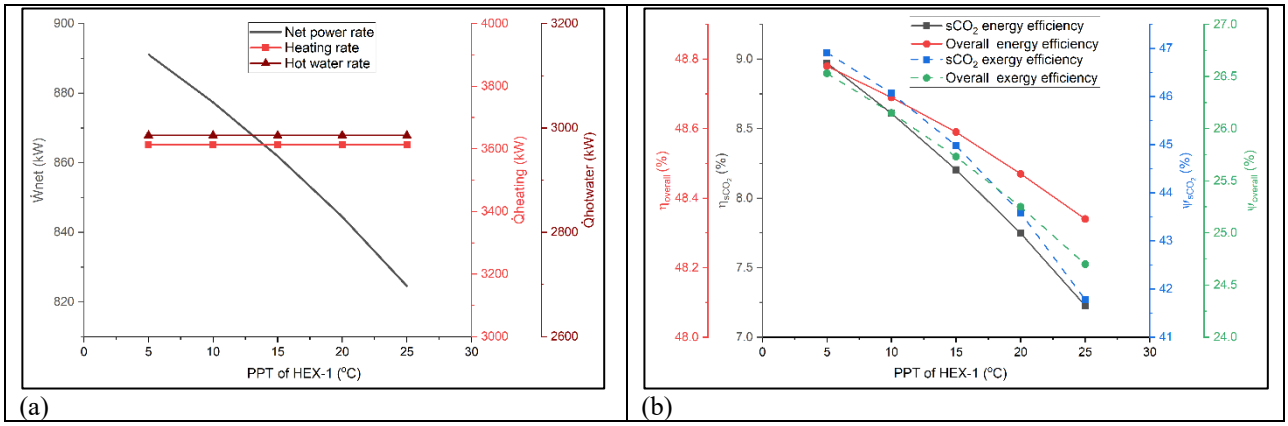

Figure 5. Effect of the pinch point temperature of HEX on the beneficial products(a) and efficiency(b)

4. CONCLUSIONS

Geothermal energy-supported integrated systems are a key player in combating environmental problems, and their use is increasing daily. This study presents an analysis of the beneficial outputs and efficiencies of a 180°C geothermal resource system used as trigeneration. This system primarily comprises the SCO_2 power generation cycle and hot water production units. A detailed thermodynamic performance analysis was conducted using an energy and exergy efficiency approach. The most fundamental results obtained can be briefly summarized as follows:

1. This developed system generates 877.4 kW of net electricity. Furthermore, this system generates 3613 kW of heating load, which can be used in grain farms.

2. The energy and exergy efficiencies of the lower cycle and SCO_2 are calculated as 8.61% and 46.07%, respectively.

3. The overall system has an energy efficiency of 49.69% and an exergy efficiency of 26.15%.

4. It has been observed that the increase in welding temperature and welding global flow rate has positive effects on the system.

Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Akrami, E., Chitsaz, A., Ghamari, P., & Mahmoudi, S. M. S. (2017). Energy and exergy evaluation of a tri-generation system driven by the geothermal energy. *Journal of mechanical science and technology*, *31*(1), 401-408.

Cengel, Y. A., Boles, M. A., & Kanoğlu, M. (2011). Thermodynamics: an engineering approach (Vol. 5, p. 445). New York: McGraw-hill.

Dincer, İ. (2020). Thermodynamics: a smart approach. John Wiley & Sons

Gholizadeh, T., Vajdi, M., & Rostamzadeh, H. (2020). A new trigeneration system for power, cooling, and freshwater production driven by a flash-binary geothermal heat source. *Renewable Energy*, *148*, 31-43.

Kanoglu, M., & Bolatturk, A. (2008). Performance and parametric investigation of a binary geothermal power plant by exergy. *Renewable Energy*, *33*(11), 2366-2374.

Li, L., Alsenani, T. R., Luo, J., Ahmad, S. F., Muhammad, T., & Huang, L. (2025). Thermoeconomic and exergo-environmental analysis trigeneration system based on Waste heat recovery and geothermal energy with post-combustion CO2 Capture. *Renewable Energy*, 123317.

Ramachandran, S., Bhogilla, S. S., & Vijayan, P. K. (2025). Geothermal Sourced Trigeneration Plant for Puga Valley: Techno-Economic Analysis and Multi-Objective Optimization. *Thermal Science and Engineering Progress*, *60*, 103487.

Ratlamwala, T. A. H., & Dincer, I. (2014). Energetic and exergetic investigation of novel multi-flash geothermal systems integrated with electrolyzers. *Journal of Power Sources*, *254*, 306-315.

Siddiqui, O., & Dincer, I. (2018). Energy and exergy analyses of a geothermal-based integrated system for trigeneration. In *Exergetic, energetic and environmental dimensions* (pp. 213-231). Academic Press.

A study on energetic and exergetic performance analysis of the recompression supercritical Brayton cycle based on waste heat recovery for the production of clean power

FATIH YILMAZ*[1]

Abstract: Recovering and reusing waste heat in cement factories offers significant environmental benefits. By capturing thermal energy from exhaust gases and redirecting it to generate electricity or support production processes, these systems reduce fossil fuel consumption and lower greenhouse gas emissions. This leads to a substantial decrease in the factory's overall carbon footprint. The newly configured research undertakes a comprehensive investigation into the thermodynamic performance of the recompression supercritical Brayton cycle for power generation. The system comprises a waste heat cycle and a recompression supercritical Brayton cycle (sCO_2). The study mainly investigated the use of waste heat thermal energy in a power generation plant. For this reason, energy and exergy efficiency are conducted and investigated parametrically. Additionally, the exergy destruction rate of each system's component is examined. Furthermore, the various design parameter changes are examined to determine their effect on the system performance. Based on the analysis, the developed system's net power generation rate is determined to be 1423 kW under the 380°C waste heat temperature. The energy and exergy efficiencies are determined to be 19.86% and 44.16%, respectively. With this system, it can be stated that the developed system is applicable and effective both in terms of environment and efficiency by reusing the waste heat that is expected to be discharged to the environment at 380°C.

Keywords: CO_2, Energy, Exergy, Waste heat, Power

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1. INTRODUCTION

Waste heat utilization is becoming increasingly important for a sustainable future in energy efficiency. Along with the active use of renewable energy sources, energy efficiency methods are also important indicators of overcoming global warming and environmental problems. In this regard, waste heat recovery methods are of paramount importance. Waste heat comes in various forms and can vary depending on the production and operations of various industries. Among these forms, high-quality waste heat has significant potential and extensive resources, accounting for approximately half of the total waste heat sources from heating equipment, boilers, and internal combustion engines in various fields. In the chemical industry, waste heat generated by chemical reactions and waste slag accounts for a small portion of total energy, but its remarkable waste heat potential proves that it remains indispensable for the WHR field (Su et al. 2021).

In recent years, waste heat recovery, renewable energy sources, cogeneration, and combined cycle power generation systems have received significant attention (Nag and De, 1997). There is extensive scope for recovering waste heat from various industries and generating power or process heat using a heat recovery steam generator. These are also used in gas turbine and steam turbine-based power plants to recover waste heat from gas turbine exhaust gas and generate steam. From an economic perspective, HRSG performance is crucial for the operation of these advanced energy systems because each additional steam unit generated translates into additional power generation or process heat for the application (Butcher and Reddy, 2007). When looking at the literature, there are many studies on waste heat-supported combined systems.

Biondi et al. (2020) developed a waste heat-based supercritical CO_2 power (sCO_2) plant for the steel industry. They conducted a comprehensive thermodynamic and economic analysis and found that overall system efficiency can be achieved at 30.4%. Wright et al. (2016) conducted a Thermo-Economic Analysis of four sCO_2 waste heat recovery power systems. All produce at least 1.2-1.6 MWe more power/or up to 22% more electrical power than the SRBC. In 2024, Vesely et al. examined a performance evaluation and optimization of the sCO_2 power plant for aircraft. Their analysis findings show that the efficiency of sCO_2 can reach 39% from 25%. Reale and Massoli (2025). WHR systems based on sCO2 gas turbines for marine applications: Detailed study and analysis of the impact of route environmental conditions on performance. Based on their analysis, it was concluded that WHR efficiency is 47% lower in summer than in winter. Kim et al. (2025) investigated the design and testing of a compressor and turbine for a 2 MW sCO_2 power system in waste heat recovery applications.

According to a brief literature review, waste heat-assisted sCO_2 power generation systems, in particular, remain important and are a key player in the sustainable future. Therefore, in this proposed study, the energy and exergy efficiencies of the

waste heat-assisted sCO_2 cycle for electricity generation are comprehensively investigated. Furthermore, the parametric variables affecting system efficiency are presented graphically.

2. MATERIAL AND METHOD

In this study, the aim is to produce electricity by integrating factory waste heat into the sCO_2 cycle (see Figure 1). The system consists of two main cycles: the first is the waste heat cycle, and the second is the sCO_2 power generation cycle. The waste heat, at approximately 350°C, transfers its thermal energy to the incoming CO_2 fluid at point 8 through heat exchanger 1, which enters the turbine at point 9 as superheated steam and at supercritical pressure. The expansion results in electricity generation. A key feature of this system is the use of a recuperator to increase system efficiency. The cycle consists of two compressors (main compressor (MC) and recompression compressor (RC)), a HEX, a recuperator, a pre-condenser, and a turbine, operating simultaneously.

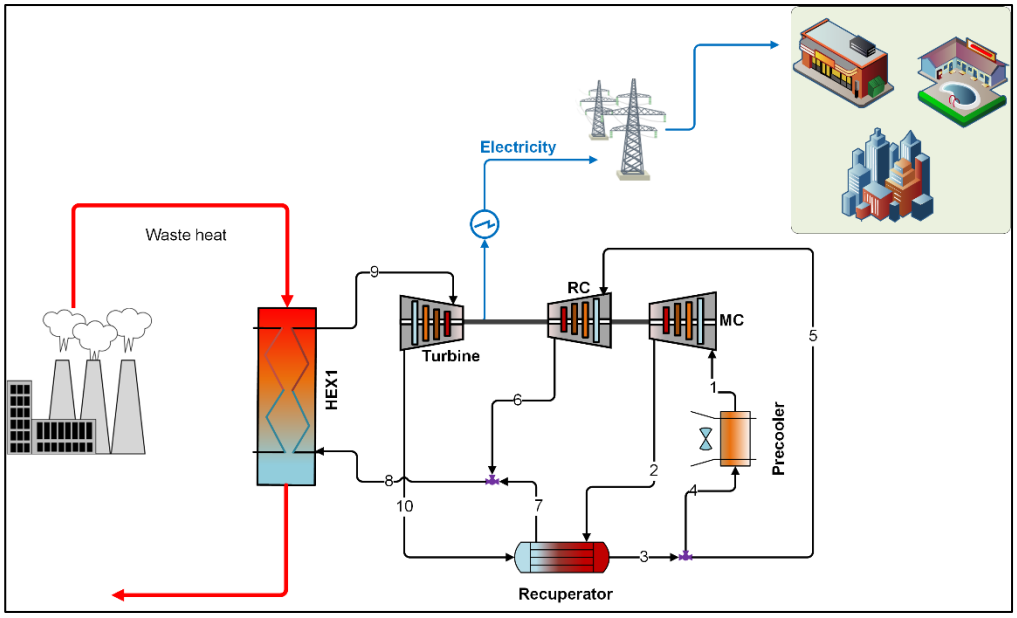

Figure 1. The developed system schematic view

2.1. Thermodynamic analysis

Thermodynamic analysis is generally performed by considering the four equilibrium equations of a system's components: mass, energy, entropy, and exergy (Cengel et al. 2011; Dincer 2020).

Mass balance:

$$\dot{m}_i = \dot{m}_e \tag{1}$$

Energy balance:

$$\dot{Q}_i + \dot{W}_i + \sum \dot{m}_i h_i = \dot{Q}_e + \dot{W}_e + \sum \dot{m}_e h_e \tag{2}$$

Entropy balance:

$$\sum \dot{m}_i s_i \sum \left(\frac{\dot{Q}}{T}\right) + \dot{S}_{gen} = \sum \dot{m}_e s_e \tag{3}$$

Exergy balance:

$$\dot{E}x^{\dot{Q}_i} + \dot{E}x^{\dot{W}_i} + \sum \dot{m}_i ex_i = \dot{E}x^{\dot{Q}_e} + \dot{E}x^{\dot{W}_e} + \sum \dot{m}_e ex_e + \dot{E}x_D \tag{4}$$

After these balance equations, the system efficiency can be written as follows:

$$\eta_{sys} = \frac{\dot{W}_{net}}{\dot{Q}_{waste,in}} \tag{5}$$

$$\psi_{sys} = \frac{\dot{W}_{net}}{\dot{E}x_{Q,waste,in}} \tag{6}$$

The net power generation rate is;

$$\dot{W}_{net} = \dot{W}_{turbine} - (\dot{W}_{MC} + \dot{W}_{RC}) \quad (7)$$

3. RESULTS AND DISCUSSION

This study presents a comprehensive thermodynamic analysis of a waste heat-assisted sCO_2 power generation cycle for electricity generation. The assumptions made here are as follows:

- The system is assumed to be steady-state flow.
- The compressor and turbines have isentropic efficiencies.
- The waste heat temperature and pressure are modeled as 350°C and 101.325 kPa.
- The waste heat is modeled as air.
- Kinetic and potential energy changes are neglected.
- The heat exchanger efficiency coefficient is assumed to be 80%.
- The ambient temperature and pressure are calculated as 25°C and 101.325 kPa.
- The CO_2 fluid pressure at the turbine inlet is calculated as 21210 kPa.

The main results of the developed system are given in the following Table 1. This analysis is performed at a constant waste heat value of 380°C, and the electricity consumption of the MC and RC compressors was calculated as 484 kW and 803 kW, respectively. Furthermore, the net electricity production obtained by the system was found to be 1423 kW. Under these conditions, the developed system achieved energy and exergy efficiencies of 19.86% and 44.16%, respectively.,

Table 1. Thermodynamic analysis results of the developed system

Parameters	Results/Unit
$\dot{W}_{MC}$	484 kW
$\dot{W}_{RC}$	803 kW
$\dot{W}_{turbine}$	2710 kW
$\dot{W}_{net}$	1423 kW
Efficiency	
η_{sys}	19.86 %
ψ_{sys}	44.16 %
$T_{waste,in}$=380 ℃	

In the following, parametric modeling was carried out to investigate the effects of changes in parameters such as waste heat temperature, isentropic efficiency of the MC compressor, Recuperator efficiency coefficient on the system efficiency and the electricity produced Engineering Equation Solver (EES) program is preferred in all of these calculations. The changes in net power rate and system's efficiency as the waste heat temperature changes parametrically are investigated and are shown in Figure 2. As the waste heat temperature increases from 300°C to 600°C, the system not only generates more electricity but also becomes more efficient. The primary reason for this is that the system reaches higher temperatures with increasing temperature, namely the increase in turbine inlet temperature.

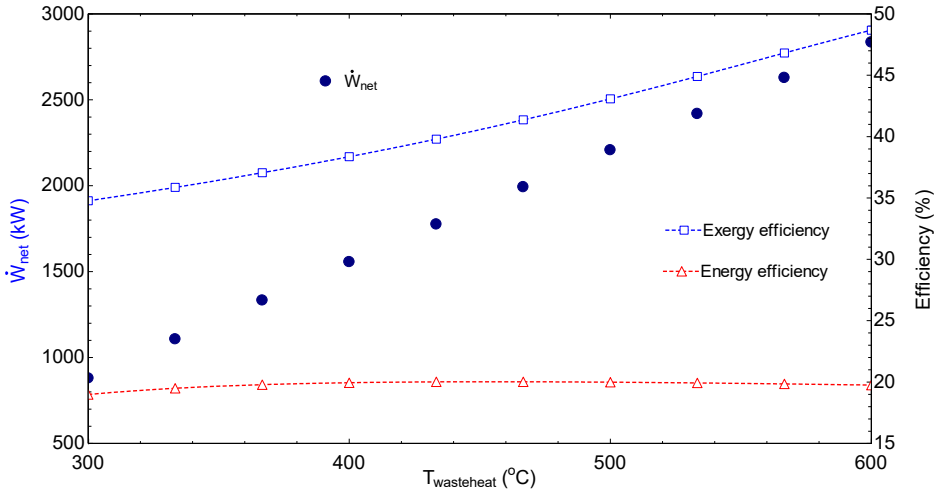

Figure 2. Effect of the waste heat temperature on the system power generation and efficiency indicators

Figure 3 examines the effect of changes in waste heat mass flow rate on the amount of electricity generated by the system. Increasing the waste heat mass by approximately 60 kg/s results in a linear increase in net electricity output from 850 kW to 3000 kW. With the addition of mass input, the system can reach even higher values.

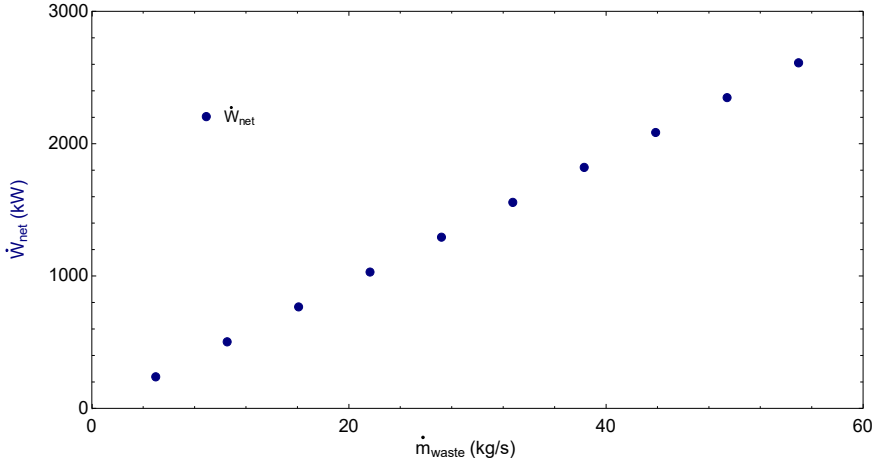

Figure 3. The impact of the mass flow rate of the waste heat on the developed system power rate

The effects of isentropic efficiency on net electricity generation, system efficiency, and compressor electricity consumption are illustrated in Figures 4 and 5. According to Figure 4, increasing isentropic efficiency increases the net electricity generated in the system, resulting in increased energy and exergy efficiencies for the entire system. Conversely, in Figure 5, increasing isentropic efficiency decreases the power consumed by the MC compressor while increasing net electricity production. Consequently, the increase in the compressors' isentropic efficiency can be interpreted as having a positive impact on the system.

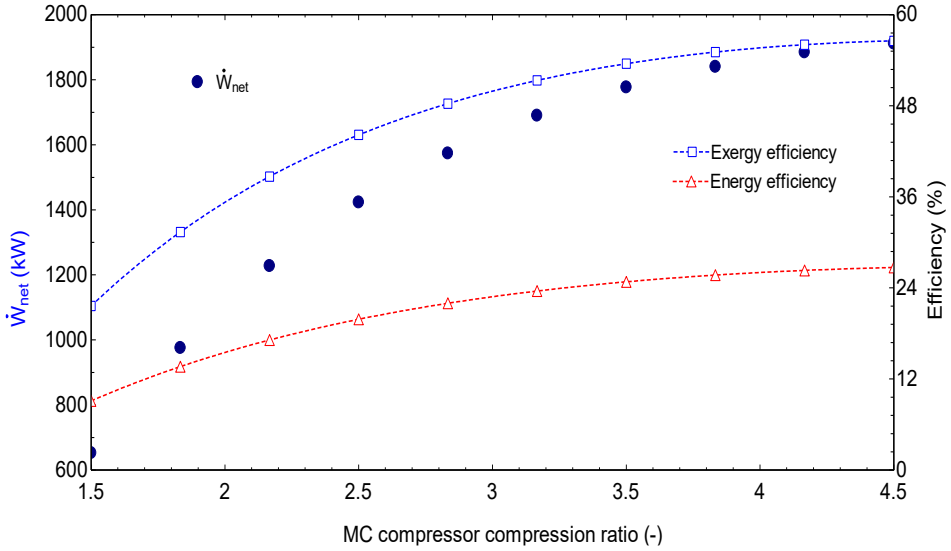

Figure 4. Net power production changes according to the MC isentropic efficiency

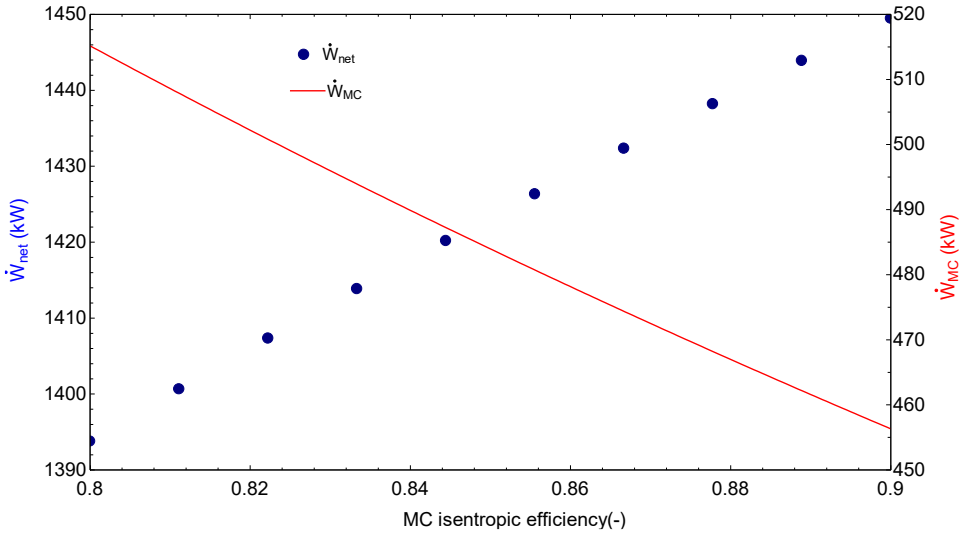

Figure 5. Efficiency changes according to the MC isentropic efficiency

Figure 6 examines the effect of changing the recuperator effectiveness coefficient on system efficiency and net electricity production. Increasing the recuperator effectiveness from 0.6 to 0.9 directly increased the amount of electricity generated in the system. This increase parallels both energy efficiency and exergy efficiency. This is because increasing recuperator efficiency reduces the MC compressor's electricity consumption.

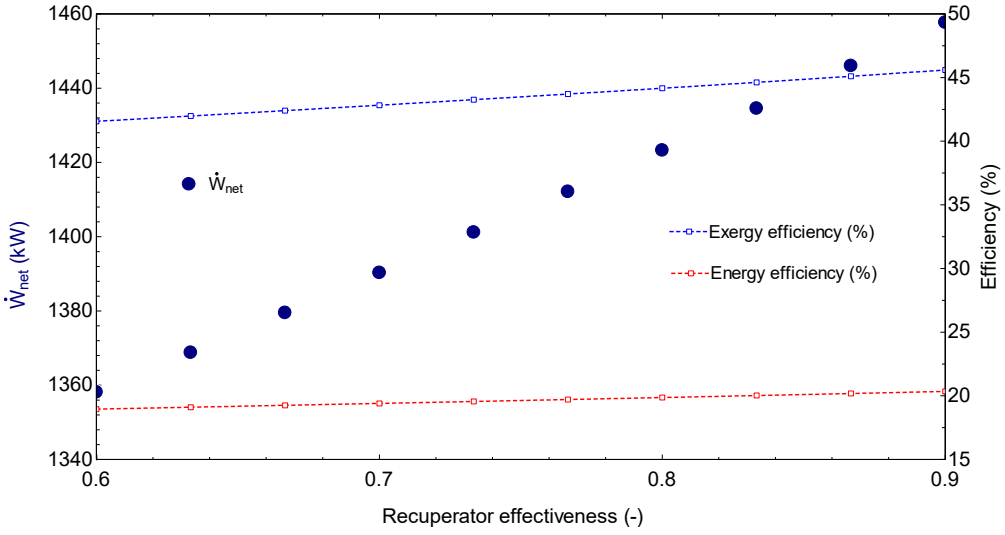

Figure 6. Efficiency and power rate change according to the recuperator's effectiveness

4. CONCLUSIONS

The proposed paper covers the examination of the comprehensive thermodynamic analysis of the waste heat-based SCO_2 power plant for power generation. To determine the system performance and electricity capacity, detailed energy and exergy approaches are applied. Furthermore, a parametric investigation is conducted, and then the case study results are as follows;

- The proposed system can generate 1.4 MW of net power. The MC and RC compressor power consumption rates are determined to be 484 kW and 803 kW, respectively.
- The developed plant energy and exergy efficiency are computed as 19.86% and 44.16%, respectively.
- According to the parametric analysis results, increases in waste heat temperature and mass flow rate have a positive impact on system performance. Furthermore, using a more effective recuperator would be advantageous for the system.

For a sustainable future, waste heat management is an important and indispensable issue. This study addresses waste heat management and presents integrated system performance. It is believed that it can guide future experimental studies.

Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Biondi, M., Giovannelli, A., Di Lorenzo, G., & Salvini, C. (2020). Techno-economic analysis of a sCO2 power plant for waste heat recovery in steel industry. Energy Reports, 6, 298-304.

Butcher, C. J., & Reddy, B. V. (2007). Second law analysis of a waste heat recovery based power generation system. International Journal of heat and mass transfer, 50(11-12), 2355-2363.

Cengel, Y. A., Boles, M. A., & Kanoğlu, M. (2011). Thermodynamics: an engineering approach (Vol. 5, p. 445). New York: McGraw-hill.

Dincer, İ. (2020). Thermodynamics: a smart approach. John Wiley & Sons

Kim, B., Lee, C., Bae, J., Schmitz, U., & Muhamad, H. A. (2025). Design and Testing of a Compressor and Turbine for a 2MW sCO2 Power System in Waste Heat Recovery Applications. In The 6th European sCO2 Conference for Energy Systems (2025-sCO2. eu-231).

Klein, S., 2021, Engineering equation solver (EES), AcademicCommercial, V11.199. 2021. Madison, USA, F-chart software.

Nag, P. K., & De, S. (1997). Design and operation of a heat recovery steam generator with minimum irreversibility. Applied Thermal Engineering, 17(4), 385-391.

Reale, F., & Massoli, P. (2025). WHR systems based on sCO2 gas turbines for marine applications: The effect of route environmental conditions on performance. Energy Conversion and Management: X, 26, 100915.

Su, Z., Zhang, M., Xu, P., Zhao, Z., Wang, Z., Huang, H., & Ouyang, T. (2021). Opportunities and strategies for multigrade waste heat utilization in various industries: A recent review. Energy Conversion and Management, 229, 113769.

Vesely, L., Bringhenti, C., Kapat, J., Tomita, J. T., & Stoia, M. (2024). Performance and optimization evaluation for integration of sCO2 power system into the aircraft propulsion system. International Journal of Thermofluids, 24, 100798.

Wright, S. A., Davidson, C. S., & Scammell, W. O. (2016, March). Thermo-economic analysis of four sCO2 waste heat recovery power systems. In Fifth International SCO2 Symposium, San Antonio, TX, Mar (pp. 28-31).

Soil–Plant Interactions and Ecosystem Resilience to Desertification and Land Degradation

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Abstract: This review synthesizes current knowledge on how soil–plant interactions determine ecosystem resistance to, and recovery from, desertification and land degradation in drylands, with emphasis on Mediterranean, Middle Eastern and Central Asian contexts relevant to Türkiye. We conducted a structured narrative review of observational, experimental and modeling studies published between 2005 and 2025, screening multidisciplinary databases with bilingual search strings and applying explicit inclusion criteria for biophysical indicators. Evidence converges on a core set of soil attributes higher soil organic carbon, stable aggregates, adequate infiltration and water-holding capacity, moderate salinity/sodicity, and balanced nutrient availability that underpin resistance to drought, grazing pressure and erosive events. Complementary plant traits and community properties deep and diverse rooting strategies, high functional diversity, greater perennial cover, resprouting capacity and persistent seed banks enhance both short-term resistance and longer-term recovery trajectories. Feedback between soil and vegetation can be strongly nonlinear: once thresholds in bare ground or soil crusting are exceeded, hydrological connectivity and erosion accelerate, pushing systems toward alternative degraded states with slow or uncertain recovery. Remote sensing indicators (e.g., NDVI/LAI trends, bare soil fraction) align with field metrics and enable spatially explicit tracking of resistance and recovery, especially when calibrated against soil moisture and carbon proxies. Management options that consistently bolster resilience include tailored grazing regimes, organic matter additions and residue retention, reduced or conservation tillage on agro drylands, the protection of biological soil crusts, and restoration plantings that combine native species with complementary rooting depths and phenologies. We identify key gaps in long-term root and soil biodiversity datasets, cross-scale modeling of feedback, and harmonized indicator frameworks for Land Degradation Neutrality (LDN). We conclude that integrating a concise indicator suite, soil organic carbon, infiltration capacity, aggregate stability, functional diversity and NDVI trend, offers a practical early-warning and performance-tracking approach for resilience-oriented dryland management.

Keywords: Ecosystem resilience; Dryland aridity gradients; Functional trait diversity; Organic carbon stocks; Hydrological connectivity

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1. INTRODUCTION

Desertification and land degradation constitute pervasive challenges that undermine ecosystem services, jeopardize livelihoods, and impede sustainable development in dryland regions. Globally, drylands encompass approximately 41% of the Earth's terrestrial surface and support a substantial proportion of the human population. The processes of desertification and land degradation result in diminished soil fertility, loss of biodiversity, and a reduction in productive capacity (Burrell et al., 2020; Vieira et al., 2015; Vogt et al., 2011). Empirical evidence demonstrates that desertification is driven by a complex interplay between climatic variability and anthropogenic pressures, such as overgrazing, unsustainable land management practices, and land-use change. These drivers collectively contribute to the decline of vegetation cover, soil organic matter, and hydrological functioning (Lin et al., 2009; Vogt et al., 2011; Petrosillo et al., 2021). Contemporary conceptual frameworks characterize desertification as the outcome of protracted imbalances between the demand for and supply of ecosystem services in drylands, thereby linking biophysical processes to governance, equity, and resilience concerns (Petrosillo et al., 2021; Assennato et al., 2020). These conceptualizations underpin measurement approaches that integrate biophysical indicators (e.g., vegetation indices, soil properties) with socio-economic data to elucidate scale- and driver-specific patterns of degradation (Higginbottom & Symeonakis, 2014; Rastgoo & Hasanfard, 2022).

Turkey exhibits pronounced spatial heterogeneity in climate, land cover, and management practices, with arid and semi-arid interior regions particularly susceptible to land degradation and desertification. Empirical research demonstrates that land-use intensification, excessive grazing pressure, and climatic variability exacerbate degradation processes in drylands, whereas adaptive, participatory, and integrated land-management interventions can enhance resilience and promote ecological recovery (Minaei et al., 2018; Zwain et al., 2021). Recent assessments have underscored that degradation is not solely a biophysical phenomenon but also encompasses governance and livelihood dimensions, thus necessitating integrated land management, robust stakeholder engagement, and adaptive policy responses tailored to Türkiye's diverse biophysical zones and socio-economic contexts (Higginbottom & Symeonakis, 2014; Fraser et al., 2011). Consistent with UNCCD frameworks, Turkish assessments benefit from the integration of remote sensing, ground-based observations, and resilience-based approaches to map susceptibility, monitor trends, and inform policy and practice aimed at mitigating

desertification pressures and advancing sustainable land management (Burrell et al., 2020; Vogt et al., 2011; Assennato et al., 2020).

A key conceptual distinction in dryland research is that between resilience and recovery. Resilience refers to the capacity of a social-ecological system to absorb disturbances while maintaining its essential structures and functions, whereas recovery describes the process by which a system returns to its pre-disturbance state, with or without direct human intervention. In degraded or stressed dryland systems, reductions in soil health, vegetation cover, and hydrological integrity can undermine resilience by diminishing the system's ability to withstand shocks such as droughts and grazing pressure (Enfors & Gordon, 2007; Keane et al., 2018; Zwain et al., 2021). Restoration and adaptive land-management practices—including afforestation, improved pasture management, and erosion control—can foster resilience by enhancing vegetation cover, soil organic matter, and hydrological stability, thereby increasing a system's disturbance-absorbing capacity and enabling more favorable recovery trajectories (Frutos et al., 2015; Zwain et al., 2021; Rastgoo & Hasanfard, 2022). Empirical evidence indicates that resilience and recovery are related yet distinct: resilience centers on functional persistence under disturbance, while recovery emphasizes the return to pre-disturbance conditions, potentially shaped by ongoing management and policy interventions (Enfors & Gordon, 2007; Keane et al., 2018; Lucash et al., 2017). Within the Turkish context, integrating resilience thinking into land management supports the identification of practical strategies to mitigate vulnerability, sustain ecosystem services, and guide post-disturbance recovery (Fleskens & Stringer, 2014; Riva et al., 2018; Jafari & Bakhshandehmehr, 2013).

This review synthesizes the extent and drivers of desertification and land degradation from a Turkish perspective, elucidates the conceptual distinction between resilience and recovery, and articulates the aims of the study. The objective is to integrate theoretical and empirical insights pertaining to desertification and land degradation, with particular emphasis on resilience and recovery dynamics in drylands, and to situate these insights within Türkiye's distinctive biophysical and socio-economic contexts. On this basis, the study seeks to address the following research questions:

- RQ1: What is the current extent and trajectory of desertification and land degradation in Türkiye's drylands, and what are the principal drivers and indicators employed in their assessment? Justification: International and regional assessments underscore the pervasive nature of desertification and the necessity for indicators that capture spatial and temporal dynamics, encompassing biophysical and socio-economic dimensions pertinent to Türkiye (Burrell et al., 2020; Vieira et al., 2015; Vogt et al., 2011).

- RQ2: How do the concepts of resilience and recovery diverge in the context of desertification, and what empirical evidence substantiates the erosion or enhancement of resilience under varying Turkish land-management practices? Justification: Conceptual distinctions between disturbance absorption (resilience) and reversion to pre-disturbance states (recovery) are well established in dryland research, with empirical studies linking degradation to reduced resilience and restoration practices to increased resilience (Enfors & Gordon, 2007; Keane et al., 2018; Zwain et al., 2021).

- RQ3: What is the policy, governance, and land-management implications for Türkiye in strengthening resilience and facilitating recovery following disturbances? Justification: International and regional syntheses emphasize the significance of adaptive governance, stakeholder participation, and integrated land-management strategies in mitigating desertification and promoting resilience, which are highly pertinent to Türkiye's governance context (Fleskens & Stringer, 2014; Riva et al., 2018; Bisaro et al., 2013).

- RQ4: How can methodological frameworks derive from the desertification literature (e.g., remote-sensing indicators, vulnerability indices, and resilience assessments) be integrated to inform Turkish land management and resilience-building initiatives? Justification: A range of transferable approaches including vegetation indices, vulnerability and desertification indices, and resilience metrics enable effective assessment and policy formulation within Türkiye's dryland environments (Higginbottom & Symeonakis, 2014; Vogt et al., 2011; Verstraete & Schwartz, 1991).

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Collectively, these research questions aim to (a) quantify the magnitude and drivers of desertification and land degradation in Türkiye's drylands; (b) elucidate the operation of resilience and recovery within Türkiye's socio-ecological systems; and (c) translate these insights into policy-relevant guidance to enhance land management, strengthen resilience, and facilitate recovery pathways across Türkiye's diverse landscapes. The review draws on a breadth of sources that define desertification and land degradation, document context-specific challenges in Türkiye, and articulate resilience and recovery concepts, thereby providing a coherent, evidence-based framework for the study.

2. Conceptual Framework

This section presents a conceptual framework for soil–plant feedback in dryland systems, emphasizing positive and negative feedback, ecological thresholds, regime dynamics (including alternating equilibria and hysteresis), and the primary drivers influencing ecosystem states. The framework synthesizes key principles from resilience theory, feedback-

control paradigms, and disturbance ecology to elucidate the mechanisms underpinning desertification and land degradation in Türkiye's drylands.

2.1. Soil–plant feedback and regime dynamics

- Positive and negative feedback: Within dryland ecosystems, soil–plant feedback may function as reinforcing (positive) loops that intensify degradation, or as stabilizing (negative) loops that promote ecosystem stability. Positive feedback arises when diminished vegetation cover increases bare soil exposure, resulting in soil moisture loss and erosion, which subsequently inhibits vegetation recruitment and soil fertility. Conversely, negative feedback is observed when vegetation recovery improves soil structure, augments organic matter, and enhances moisture retention, collectively facilitating further vegetation establishment. Thorough understanding of these feedback mechanisms is essential for analyzing regime shifts and the emergence of hysteresis in desertification processes (Ingrisch & Bahn, 2018; Runge et al., 2025).

- Thresholds and hysteresis: Ecosystems may exhibit critical thresholds, beyond which alternative stable states emerge. Exceeding these thresholds due to drivers such as drought, heat waves, or intensified grazing can shift a system from a resilient, vegetated state to a degraded, desertified state. Reversing such transitions often necessitates substantial restoration or management efforts, exemplifying hysteresis in ecosystem responses to disturbance. Ecological models and empirical research document this hysteresis-like behavior, highlighting the influence of feedback strength and system inertia on recovery trajectories (Ingrisch & Bahn, 2018; Runge et al., 2025).

- Alternating equilibria: Under persistent drivers (e.g., recurrent droughts, altered fire regimes, or chronic overgrazing), dryland systems may alternate between distinct equilibria such as a productive, shrub-dominated state and a sparsely vegetated, degraded state. The existence of multiple equilibria suggests that minor changes in driving variables can precipitate substantial shifts in ecosystem state, each characterized by unique resilience properties and recovery trajectories (Ingrisch & Bahn, 2018; Runge et al., 2025).

- Hysteresis and irreversibility: The magnitude and duration of disturbances, in conjunction with the strength of feedback mechanisms, may render state transitions irreversible. For example, when vegetation loss and soil degradation exceed a critical threshold, restoration of pre-disturbance productivity may demand disproportionately extensive management interventions, soil restoration, or favorable climatic conditions, thereby underscoring the role of hysteresis within the desertification process (Wang et al., 2025; Abbott et al., 2023).

2.2. Drivers and drivers–feedback coupling

- Drought and heat waves (SPEI/PDSI): Severe drought and heat anomalies exert direct impacts on soil moisture availability, plant physiological stress, and carbon allocation, thereby intensifying negative soil–plant feedbacks (e.g., reduced root biomass, soil crusting) and elevating vulnerability to erosion and desertification. These hydrological stressors interact with feedback mechanisms, propelling systems toward degraded equilibria, with recovery trajectories highly dependent on moisture dynamics and the duration of recovery periods (Wang et al., 2025; Runge et al., 2025).

- Precipitation variability: Interannual and decadal rainfall variability can influence regeneration opportunities, seedling establishment, and the cover of grasses and shrubs. Variability can intermittently strengthen negative feedbacks (through vegetation loss) or, during wetter periods, facilitate a return to more resilient states via soil stabilization and organic matter accrual (Ingrisch & Bahn, 2018; , Runge et al., 2025).

- Land use and grazing pressure: Grazing intensity, trampling, and selective herbivory alter plant community composition, diminish surface litter, and expose soil, thereby reinforcing erosion and crust formation. Such land-use practices modulate feedback strength and may induce path-dependent trajectories toward degraded states unless managed through adaptive strategies (Minaei et al., 2018; Ingrisch & Bahn, 2018).

- Tillage and disturbance regimes: Tillage activities augment soil disturbance, deplete soil organic matter, and disrupt soil–plant interactions, frequently strengthening negative feedbacks that accelerate degradation, especially in fragile dryland environments. Fire regimes interact with vegetation structure and soil properties, contributing either to the stabilization or destabilization of system states, contingent upon their frequency and intensity (Minaei et al., 2018; Ingrisch & Bahn, 2018).
- Fire: Fire serves as a disturbance that resets successional trajectories and alters soil properties. The influence of fire on resilience and hysteresis is mediated by the capacity for post-fire regeneration and the efficacy of subsequent management interventions; repeated fires may drive systems toward alternative degraded equilibria if recovery processes are impeded (Ingrisch & Bahn, 2018).
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2.3. Measurement constructs and indicators (linking theory to data)

- Resilience metrics: Resilience is defined as the capacity of the soil–vegetation–microbial system to absorb disturbances and maintain critical ecosystem functions (e.g., productivity, soil moisture retention, erosion resistance). Various quantitative methodologies such as recovery time, resistance, and resilience indices are available, and the selection of a particular approach shapes the interpretation and comparison of resilience trajectories across landscapes (Ingrisch & Bahn, 2018; Runge et al., 2025).

- Early-warning signals and thresholds: Temporal series of vegetation indices, soil moisture measurements, and productivity proxies can offer insights into decelerating recovery or heightened variability preceding regime shifts, thereby signaling proximity to ecological thresholds. Analytical approaches employing remote sensing and in situ observations enable the detection of critical slowing down and alterations in system stability, thereby informing proactive management strategies (Runge et al., 2025).

- Earth observation and data fusion: Contemporary frameworks integrate remote-sensing vegetation indices, soil property proxies, and land-use data to quantify feedback strength, state variables, and resilience, facilitating cross-site comparisons and application to Türkiye's heterogeneous drylands (Runge et al., 2025).

2.4. Drivers in Türkiye's context

- Türkiye-specific drivers include drought and heat events, interannual precipitation variability, grazing pressure, and diverse management practices across distinct biophysical zones. Integrating this conceptual framework with Türkiye's data sources (such as remote sensing, climate proxies, and land-use records) enables the identification of regions where positive feedbacks predominate, negative feedbacks facilitate recovery, and ecological thresholds may be present, thereby informing targeted interventions and adaptive governance (Minaei et al., 2018; Ingrisch & Bahn, 2018).

3. SOIL PROPERTIES THAT DETERMINE RESILIENCE AND RECOVERY

Soil resilience and recovery are governed by a complex interplay of physical, chemical, and biological properties and their interactions under disturbance regimes. The literature converges on several core soil attributes and mechanisms, with resilience conceptualized as the capacity to maintain or return to functional states following perturbation, and recovery defined as the rate and extent of reestablishing pre-disturbance conditions (Griffiths & Philippot, 2013; Lal, 2015). The following properties and associated processes are identified as the most consistently influential.

3.1. Physical structure and texture underpin porosity, aggregation, and hydraulic behavior

Soil structure and aggregate stability exert a critical influence on water movement, drainage, and aeration, which in turn govern microbial activity, nutrient accessibility, and plant regrowth following disturbance. Soils characterized by well-developed micro-aggregates and robust microstructure (e.g., Ferralsols in forest restoration contexts) demonstrate superior physical properties that facilitate more rapid recovery of soil function after disturbance (Allek et al., 2022). In arable and clay-rich soils, physical stability under overburden stress is closely linked to organic matter content and texture, underscoring the buffering capacity of soil organic matter (SOM) in maintaining physical resilience (Debeljak et al., 2009). Meta-analyses of hydrologic recovery frequently employ changes in saturated hydraulic conductivity as a key metric of resilience (Ebel & Martin, 2017). Mechanical resistance and the reorganization of pore networks are thus central determinants of the rate at which infiltration, drainage, and erosion processes recover after disturbance (Ebel & Martin, 2017).

3.2. Soil organic matter (SOM) and associated carbon pools

Soil organic matter (SOM) provides substrates for diverse microbial communities, promotes soil aggregation, and modulates nutrient availability, all of which influence recovery trajectories after perturbation. Comparative studies indicate that soils with higher SOM levels support greater microbial diversity and functional redundancy, thereby enhancing resilience to disturbance and accelerating recovery in certain contexts (Girvan et al., 2005). Broader syntheses further emphasize SOM's central role in sustaining biogeochemical cycling and maintaining soil structure, supporting resilience across various climatic and disturbance regimes (Griffiths & Philippot, 2013).

3.3. Biological community properties: microbial diversity, biomass, and enzymatic activity

- Microbial community diversity and biomass are key determinants of resistance and resilience in soil functions following perturbation. Elevated microbial diversity is linked to increased functional redundancy and ecosystem stability, facilitating the recovery of ecological processes after stressors such as metal pollution or drought (Girvan et al., 2005). Reviews of soil microbial resistance and resilience highlight that overall stability emerges from the interplay between biotic communities and abiotic soil structure, rather than microbial composition alone, with aggregation and substrate quality modulating the response to disturbance (Griffiths & Philippot, 2013). Experimental findings also indicate that

microbial activity and metabolic capacity can accelerate recovery in certain low-quality soils where microbial communities rapidly exploit available substrates (Calsamiglia et al., 2017).

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3.4. Chemical properties that govern nutrient availability and pH-related mobility

Chemical soil properties including pH, cation exchange capacity, organic carbon content, and nutrient pools directly influence microbial activity, metal and pollutant bioavailability, and plant regeneration following disturbance. Studies investigating soil contamination demonstrate that chemical availability, as mediated by soil pH and SOM content, governs both resistance to perturbation and the pace of recovery, underscoring the pivotal chemistry–biology–structure nexus that controls resilience (Butler et al., 2011; Debeljak et al., 2009). Integrating chemical indicators with physical and biological properties is widely advocated as part of a comprehensive soil health assessment to monitor and guide recovery after disturbance (Kibblewhite et al., 2007).

3.5. Hydrological connectivity and moisture regime

Soil moisture regimes and hydraulic properties play a crucial role in regulating biogeochemical processes and microbial metabolism, thereby shaping resilience to drought, flooding, and fire-induced perturbations. Meta-analyses of field-saturated hydraulic conductivity following fire events demonstrate that hydrologic response and rainfall characteristics are critical to characterizing resilience (Ebel & Martin, 2017). Understanding resilience in soil moisture regimes facilitates the anticipation of transitions between functional states and informs recovery pathways under changing precipitation patterns (Feng et al., 2019).

3.6. Biotic–abiotic interactions and ecosystem context

The ability of soils to resist and recover from disturbances is determined by the interplay among physical structure, SOM, microbial communities, nutrient dynamics, and plant–soil feedbacks, all within a particular disturbance history and landscape context. Conceptual syntheses emphasize that soil stability arises from the combined influence of biotic and abiotic characteristics, such as aggregation, substrate quality, and vegetation effects, and recognize that resistance and resilience are disturbance-specific and history-dependent (Griffiths & Philippot, 2013). Restoration research across tropical, temperate, and dryland ecosystems underscores the importance of aligning soil health indicators with restoration objectives and highlights that varying soil types and land-use histories result in distinct resilience trajectories (Allek et al., 2022).

3.7. Soil health indicators and management practices

A comprehensive suite of indicators encompassing biological (e.g., microbial diversity, enzyme activities), chemical (e.g., organic carbon, pH, nutrients), and physical (e.g., bulk density, porosity, aggregation) properties is recommended for monitoring resilience and informing management decisions. The literature consistently supports the use of integrated soil health indicators to evaluate restoration effectiveness and anticipate recovery potential under different management interventions (Kibblewhite et al., 2007; Sharma et al., 2023). Management practices that promote rooting depth, increase soil organic matter, and enhance nutrient cycling contribute to resilience by reinforcing the soil system's capacity to absorb disturbances and restore functional integrity (Costantini et al., 2015).

Resilience and recovery arise from the integration of physical structure, SOM, microbial community composition, chemical environment, and hydrological dynamics within a given disturbance context. A robust framework for assessing soil resilience should include: (a) physical, chemical, and biological soil health indicators; (b) hydrological metrics such as saturated hydraulic conductivity and soil moisture regime characteristics; (c) evaluation of disturbance type, intensity, and history; and (d) consideration of landscape and land-use context, including vegetation cover and restoration status. This integrated approach is substantiated by multiple perspectives from microbial ecology, soil health assessment, and hydrologic resilience metrics in post-disturbance environments (Girvan et al., 2005; Griffiths & Philippot, 2013; Ebel & Martin, 2017).

4. PLANT PROPERTIES THAT DETERMINE RESILIENCE AND RECOVERY

Plant-driven resilience in drylands arises from the interplay among functional traits, regeneration strategies, and plant–soil–microbe feedbacks operating under disturbance regimes and climatic variability. In this context, *resilience* is defined as the capacity to maintain or return to functional states following perturbation, while *recovery* refers to the rate and extent of reestablishing pre-disturbance conditions. Both trait-based and disturbance ecology demonstrate that plant characteristics govern resource capture, carbon allocation to soil, and the integration of aboveground and belowground processes that shape resistance and recovery trajectories (Lavorel & Garnier, 2002; Fry et al., 2018).

6.1 Functional traits that influence resilience pathways

Plant communities characterized by traits conferring rapid regrowth, efficient water use, and persistent belowground connectivity (e.g., deep rooting, clonal propagation, mycorrhizal associations) buffer key ecosystem processes against disturbance and accelerate the recovery of productivity and biogeochemical cycling (Lavorel & Garnier, 2002; Fry et al., 2018). In Mediterranean and temperate drylands, linkages between functional traits and ecosystem processes connect plant architecture and tissue quality to soil aggregation, nutrient cycling, and structural restoration following fire, grazing, or drought (Fry et al., 2018). Traits that enhance structural inputs (litter quantity and quality, fine-root biomass, root exudation) and symbiotic capacity also feedback to promote microbial activity and soil organic matter dynamics, thereby reinforcing recovery (Fry et al., 2018).

6.2 Aboveground–belowground linkages and plant–soil feedback

Plant–soil feedback (PSFs) mediates the influence of plant traits on microbial composition, enzymatic activity, and nutrient mineralization, which collectively regulate plant regrowth following disturbance (Farrer & Suding, 2016). The effects of microbial mediation on resilience depend on litter quality and soil conditions, determining whether post-disturbance communities reassemble with trait syndromes that stabilize ecosystem functions (Farrer & Suding, 2016; Trevenen et al., 2017). Case studies of fire demonstrate that regeneration strategy (e.g., resprouting versus seeding) shapes subsequent PSFs, influences biomass accumulation, and affects soil carbon inputs, thereby modulating both vegetation and soil functional resilience (Marzano et al., 2012).

6.3 Regeneration strategies and community composition

Resilience often depends on the functional composition that reestablishes after pulse or press disturbances. Communities exhibiting complementary regeneration strategies and composed of native functional groups that stabilize soils and recycle nutrients tend to restore essential ecosystem functions more rapidly. Functional redundancy provides a buffer for ecosystem services against species losses by maintaining key processes through overlapping trait effects (Biggs et al., 2020). Disturbance legacies that alter species richness, life-history strategies, or dominance patterns (e.g., shrub encroachment versus perennial grass recovery) can shift resilience profiles to herbivory, drought, and fire along abiotic stress gradients (Speed et al., 2010; Seipel et al., 2018).

6.4 Disturbance context, biotic interactions, and climate legacies

Resilience is inherently disturbance-specific and contingent on disturbance history: the type, severity, and frequency of disturbances interact with plant–plant and plant–microbe relationships to determine recovery trajectories (Wardle & Jonsson, 2014). Integrated assessments of above- and belowground compartments are critical, as trait composition and litter or root turnover govern the pace of soil function recovery (e.g., infiltration and mineralization) (Wardle & Jonsson, 2014; Biggs et al., 2020). Climate anomalies and precipitation legacies further restructure plant communities and their associated soil feedback, influencing future resilience; a history of drought can select for tolerant trait syndromes that stabilize processes or, alternatively, drive transitions to novel ecosystem states (Duniway et al., 2023; Perez et al., 2024).

6.5 Soil–plant–microbe integration as a holistic resilience framework

Plant-mediated resilience is intrinsically linked to soil properties (e.g., aggregation, soil organic matter, salinity, and sodicity) and microbial networks. Post-disturbance recovery, particularly following fire or drought, often necessitates the coordinated restoration of plant communities and microbial activity, with plant litter and root exudates supporting enzymatic processes and rebuilding soil structure (Pérez-Valera et al., 2020). This integrated perspective encompassing traits, inputs, microbes, soil structure and chemistry, and resulting feedback accounts for variation in recovery rates across different soil types and land-use histories, elucidating why drylands with disrupted PSFs and limited carbon inputs exhibit slow recovery (Marzano et al., 2012; Pérez-Valera et al., 2020; Piton et al., 2020).

6.6 Practical implications for prediction and management

Predictive frameworks should integrate trait distributions (e.g., specific leaf area, leaf dry matter content, rooting depth, resprouting capacity), community composition (species richness, functional diversity, and redundancy), and regeneration strategies to forecast resilience to drought, fire, or herbivory (Lavorel & Garnier, 2002; Fry et al., 2018; Biggs et al., 2020). Management interventions that (i) promote trait diversity, (ii) support regeneration pathways (e.g., protect resprouters and facilitate seedling recruitment), and (iii) maintain native functional groups (such as deep-rooted perennials, nitrogen-fixers, and mycorrhizal hosts) enhance resilience by stabilizing vegetation structure and the associated soil processes (Marzano et al., 2012; Biggs et al., 2020). Integrating trait data with soil indicators (e.g., aggregate stability, infiltration rates, soil organic carbon, electrical conductivity/exchangeable sodium percentage) provides a practical basis for monitoring and anticipating recovery potential and ecological thresholds in drylands.

7. Conclusion

Ecosystem resilience the capacity to maintain or return to functional states after disturbance and recovery the rate and extent of reestablishing pre-disturbance conditions are not discrete traits, but emergent properties of intricately coupled plant–soil–microbe–climate systems. Plant functional traits and community composition regulate litter inputs, root turnover, rooting depth, and mycorrhizal associations, these factors, in turn, shape soil structure, carbon dynamics, hydrological processes, and microbial activity. When this feedback remains robust, dryland ecosystems demonstrate greater resistance to drought, grazing, and fire, and regain essential functions such as nutrient cycling, primary production, and infiltration more rapidly.

Trait-based approaches offer a predictive framework for understanding resilience. Trait syndromes characterized by rapid regrowth, efficient resource acquisition, conservative water use, and persistent belowground connectivity tend to accelerate post-disturbance functional recovery. Functional diversity and redundancy buffer ecosystem services against species losses, while regeneration strategies (such as resprouting and reliable seeding) and the presence of native functional groups determine both vegetation structure and soil inputs during the recovery process.

Context is critical. The type, severity, frequency, and historical sequence of disturbances along with climate variability and soil constraints (such as salinity, sodicity, surface crusting, and low soil organic carbon) modulate how plant traits are translated into ecosystem outcomes. Plant–soil feedback may either enhance or constrain resilience depending on substrate quality, microbial community structure, and land-use legacies; consequently, the same trait can yield divergent outcomes under drought, fire, herbivory, or nutrient enrichment. Exceeding key thresholds such as loss of soil organic carbon, expansion of bare ground, or hydraulic disconnection can shift systems toward degraded states characterized by slow or uncertain recovery.

These insights carry direct management implications. Enhancing resilience necessitates integrated strategies that (i) conserve and restore key plant functional groups and trait diversity, (ii) increase root depth and the input of litter and exudates to sustain microbial networks and soil organic matter, (iii) protect soil structure and hydrological function (such as aggregate stability and infiltration), and (iv) address chemical constraints (including pH, electrical conductivity, and exchangeable sodium percentage/sodium adsorption ratio). Monitoring should employ a comprehensive suite of indicators linking biotic and abiotic dimensions for example, soil organic carbon (0–30 cm and, where feasible, 0–100 cm), aggregate stability, infiltration or saturated hydraulic conductivity and available water, pH–EC–ESP/CEC and nutrients, microbial biomass and enzyme activities, and vegetation functional diversity and cover supplemented by remote-sensing data (e.g., NDVI, EVI, LAI, bare-soil fraction).

Looking forward, trait-based models that explicitly couple plant community composition to soil processes and microbial dynamics while incorporating climate legacies and disturbance regimes offer a practical approach to forecasting recovery rates, detecting emerging thresholds, and informing targeted interventions. Ultimately, resilient dryland futures depend on the co-management of soils and vegetation as a unified system, operationalizing an integrated, context-specific framework that unites plant trait ecology with soil health and hydrological metrics to guide sustainable recovery.

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The authors have no conflicts of interest to declare.

REFERENCES

Allek, A., Prieto, P., Koryś, K., Rodrigues, A., Latawiec, A., & Crouzeilles, R. (2022). How does forest restoration affect the recovery of soil quality? a global meta-analysis for tropical and temperate regions. Restoration Ecology, 31(3). https://doi.org/10.1111/rec.13747

Assennato, F., Leginio, M., d'Antona, M., Marinosci, I., Congedo, L., Riitano, N., … & Munafò, M. (2020). Land degradation assessment for sustainable soil management. Italian Journal of Agronomy, 15(4), 1770. https://doi.org/10.4081/ija.2020.1770

Biggs, C., Yeager, L., Bolser, D., Bonsell, C., Dichiera, A., Hou, Z., … & Erisman, B. (2020). Does functional redundancy affect ecological stability and resilience? a review and meta-analysis. Ecosphere, 11(7). https://doi.org/10.1002/ecs2.3184

Bisaro, A., Kirk, M., Zdruli, P., & Zimmermann, W. (2013). Global drivers setting desertification research priorities: insights from a stakeholder consultation forum. Land Degradation and Development, 25(1), 5-16. https://doi.org/10.1002/ldr.2220

Burrell, A., Evans, J., & Kauwe, M. (2020). Anthropogenic climate change has driven over 5 million km2 of drylands towards desertification. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-17710-7

Butler, E., Whelan, M., Ritz, K., Sakrabani, R., & Egmond, R. (2011). Effects of triclosan on soil microbial respiration. Environmental Toxicology and Chemistry, 30(2), 360-366. https://doi.org/10.1002/etc.405

Calsamiglia, A., Lucas-Borja, M., Fortesa, J., García-Comendador, J., & Estrany, J. (2017). Changes in soil quality and hydrological connectivity caused by the abandonment of terraces in a mediterranean burned catchment. Forests, 8(9), 333. https://doi.org/10.3390/f8090333

Costantini, E., Branquinho, C., Nunes, A., Schwilch, G., Stavi, I., Valdecantos, A., … & Zucca, C. (2015). Soil indicators to assess the effectiveness of restoration strategies in dryland ecosystems.. https://doi.org/10.5194/sed-7-3645-2015

Debeljak, M., Kocev, D., Towers, W., Jones, M., Griffiths, B., & Hallett, P. (2009). Potential of multi-objective models for risk-based mapping of the resilience characteristics of soils: demonstration at a national level. Soil Use and Management, 25(1), 66-77. https://doi.org/10.1111/j.1475-2743.2009.00196.x

Dharumarajan, S., Bishop, T., Hegde, R., & Singh, S. (2017). Desertification vulnerability index—an effective approach to assess desertification processes: a case study in anantapur district, andhra pradesh, india. Land Degradation and Development, 29(1), 150-161. https://doi.org/10.1002/ldr.2850

Duniway, M., Higgens, R., Geiger, E., Hoover, D., Pfennigwerth, A., Knight, A., … & Belnap, J. (2023). Ecosystem resilience to invasion and drought: insights after 24 years in a rare never-grazed grassland. Global Change Biology, 29(20), 5866-5880. https://doi.org/10.1111/gcb.16882

Ebel, B. and Martin, D. (2017). Meta-analysis of field-saturated hydraulic conductivity recovery following wildland fire: applications for hydrologic model parameterization and resilience assessment. Hydrological Processes, 31(21), 3682-3696. https://doi.org/10.1002/hyp.11288

Enfors, E. and Gordon, L. (2007). Analysing resilience in dryland agro-ecosystems: a case study of the makanya catchment in tanzania over the past 50 years. Land Degradation and Development, 18(6), 680-696. https://doi.org/10.1002/ldr.807

Farrer, E. and Suding, K. (2016). Teasing apart plant community responses to n enrichment: the roles of resource limitation, competition and soil microbes. Ecology Letters, 19(10), 1287-1296. https://doi.org/10.1111/ele.12665

Feng, M., Liu, P., Cai, X., Wallington, K., Shi, L., & Li, Y. (2019). Understanding the resilience of soil moisture regimes. Water Resources Research, 55(9), 7541-7563. https://doi.org/10.1029/2018wr024495

Fleskens, L. and Stringer, L. (2014). Land management and policy responses to mitigate desertification and land degradation. Land Degradation and Development, 25(1), 1-4. https://doi.org/10.1002/ldr.2272

Fraser, E., Dougill, A., Hubacek, K., Quinn, C., Sendzimir, J., & Termansen, M. (2011). Assessing vulnerability to climate change in dryland livelihood systems: conceptual challenges and interdisciplinary solutions. Ecology and Society, 16(3). https://doi.org/10.5751/es-03402-160303

Frutos, Á., Navarro, T., Pueyo, Y., & Alados, C. (2015). Inferring resilience to fragmentation-induced changes in plant communities in a semi-arid mediterranean ecosystem. Plos One, 10(3), e0118837. https://doi.org/10.1371/journal.pone.0118837

Fry, E., Savage, J., Hall, A., Oakley, S., Pritchard, W., Ostle, N., … & Bardgett, R. (2018). Soil multifunctionality and drought resistance are determined by plant structural traits in restoring grassland. Ecology, 99(10), 2260-2271. https://doi.org/10.1002/ecy.2437

Girvan, M., Campbell, C., Killham, K., Prosser, J., & Glover, L. (2005). Bacterial diversity promotes community stability and functional resilience after perturbation. Environmental Microbiology, 7(3), 301-313. https://doi.org/10.1111/j.1462-2920.2005.00695.x

Griffiths, B. and Philippot, L. (2013). Insights into the resistance and resilience of the soil microbial community. Fems Microbiology Reviews, 37(2), 112-129. https://doi.org/10.1111/j.1574-6976.2012.00343.x

Higginbottom, T. and Symeonakis, E. (2014). Assessing land degradation and desertification using vegetation index data: current frameworks and future directions. Remote Sensing, 6(10), 9552-9575. https://doi.org/10.3390/rs6109552

Jafari, R. and Bakhshandehmehr, L. (2013). Quantitative mapping and assessment of environmentally sensitive areas to desertification in central iran. Land Degradation and Development, 27(2), 108-119. https://doi.org/10.1002/ldr.2227

Keane, R., Loehman, R., Holsinger, L., Falk, D., Higuera, P., Hood, S., … & Hessburg, P. (2018). Use of landscape simulation modeling to quantify resilience for ecological applications. Ecosphere, 9(9). https://doi.org/10.1002/ecs2.2414

Kibblewhite, M., Ritz, K., & Swift, M. (2007). Soil health in agricultural systems. Philosophical Transactions of the Royal Society B Biological Sciences, 363(1492), 685-701. https://doi.org/10.1098/rstb.2007.2178

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875-5895. https://doi.org/10.3390/su7055875

Lavorel, S. and Garnier, É. (2002). Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the holy grail. Functional Ecology, 16(5), 545-556. https://doi.org/10.1046/j.1365-2435.2002.00664.x

Lin, M., Chen, C., Wang, Q., Cao, Y., Shih, J., Lee, Y., … & Wang, S. (2009). Fuzzy model-based assessment and monitoring of desertification using modis satellite imagery. Engineering Computations, 26(7), 745-760. https://doi.org/10.1108/02644400910985152

Lucash, M., Scheller, R., Gustafson, E., & Sturtevant, B. (2017). Spatial resilience of forested landscapes under climate change and management. Landscape Ecology, 32(5), 953-969. https://doi.org/10.1007/s10980-017-0501-3

Marzano, R., Lingua, E., & Garbarino, M. (2012). Post-fire effects and short-term regeneration dynamics following high-severity crown fires in a mediterranean forest. Iforest - Biogeosciences and Forestry, 5(1), 93-100. https://doi.org/10.3832/ifor0612-005

Minaei, M., Shafizadeh-Moghadam, H., & Tayyebi, A. (2018). Spatiotemporal nexus between the pattern of land degradation and land cover dynamics in iran. Land Degradation and Development, 29(9), 2854-2863. https://doi.org/10.1002/ldr.3007

Pereira, I. and Nascimento, F. (2016). Susceptibility to desertification in chicualacuala, republic of mozambique. International Journal of Geosciences, 07(02), 229-237. https://doi.org/10.4236/ijg.2016.72018

Perez, S., Hammond, M., & Lau, J. (2024). Precipitation anomalies may affect productivity resilience by shifting plant community properties. Journal of Ecology, 113(3), 542-554. https://doi.org/10.1111/1365-2745.14471

Pérez-Valera, E., Verdú, M., Navarro-Cano, J., & Goberna, M. (2020). Soil microbiome drives the recovery of ecosystem functions after fire. Soil Biology and Biochemistry, 149, 107948. https://doi.org/10.1016/j.soilbio.2020.107948

Petrosillo, I., Valente, D., Mulder, C., Li, B., Jones, K., & Zurlini, G. (2021). The resilient recurrent behavior of mediterranean semi-arid complex adaptive landscapes. Land, 10(3), 296. https://doi.org/10.3390/land10030296

Piton, G., Legay, N., Arnoldi, C., Lavorel, S., Clément, J., & Foulquier, A. (2020). Using proxies of microbial community-weighted means traits to explain the cascading effect of management intensity, soil and plant traits on ecosystem resilience in mountain grasslands. Journal of Ecology, 108(3), 876-893. https://doi.org/10.1111/1365-2745.13327

Plaiklang, S., Sutthivanich, I., Sritarapipat, T., Panurak, K., Ogawa, S., Charungthanakij, S., … & Thongrueang, N. (2020). Desertification assessment using medalus model in upper lamchiengkrai watershed, thailand. The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences, XLIII-B3-2020, 1257-1262. https://doi.org/10.5194/isprs-archives-xliii-b3-2020-1257-2020

Rastgoo, M. and Hasanfard, A. (2022). Desertification in agricultural lands: approaches to mitigation.. https://doi.org/10.5772/intechopen.98795

Reynolds, J., Stafford-Smith, M., Lambin, É., Turner, B., Mortimore, M., Batterbury, S., … & Walker, B. (2007). Global desertification: building a science for dryland development. Science, 316(5826), 847-851. https://doi.org/10.1126/science.1131634

Riva, M., Baeza, J., Bautista, S., Christoforou, M., Daliakopoulos, I., Hadjimitsis, D., … & Schwilch, G. (2018). How does land management contribute to the resilience of mediterranean forests and rangelands? a participatory assessment. Land Degradation and Development, 29(10), 3721-3735. https://doi.org/10.1002/ldr.3104

Seipel, T., Rew, L., Taylor, K., Maxwell, B., & Lehnhoff, E. (2018). Disturbance type influences plant community resilience and resistance to bromus tectorum invasion in the sagebrush steppe. Applied Vegetation Science, 21(3), 385-394. https://doi.org/10.1111/avsc.12370

Sharma, S., Lishika, B., Shubham, S., & Kaushal, S. (2023). Soil quality indicators: a comprehensive review. International Journal of Plant & Soil Science, 35(22), 315-325. https://doi.org/10.9734/ijpss/2023/v35i224139

Speed, J., Cooper, E., Jónsdóttir, I., Wal, R., & Woodin, S. (2010). Plant community properties predict vegetation resilience to herbivore disturbance in the arctic. Journal of Ecology, 98(5), 1002-1013. https://doi.org/10.1111/j.1365-2745.2010.01685.x

Trevenen, E., Mucina, L., Trevenen, M., Cresswell, A., & Renton, M. (2017). A simulation model for exploring the effects of plant-soil feedbacks on the resilience of plant communities.. https://doi.org/10.36334/modsim.2017.b3.trevenen

Verón, S., Paruelo, J., & Oesterheld, M. (2006). Assessing desertification. Journal of Arid Environments, 66(4), 751-763. https://doi.org/10.1016/j.jaridenv.2006.01.021

Verstraete, M. and Schwartz, S. (1991). Desertification and global change. Plant Ecology, 91(1-2), 3-13. https://doi.org/10.1007/bf00036043

Vieira, R., Tomasella, J., Álvala, R., Sestini, M., Affonso, A., Rodríguez, D., … & Santana, M. (2015). Identifying areas susceptible to desertification in the brazilian northeast. Solid Earth, 6(1), 347-360. https://doi.org/10.5194/se-6-347-2015

Vogt, J., Safriel, U., Maltitz, G., Sokona, Y., Zougmoré, R., Bastin, G., … & Hill, J. (2011). Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. Land Degradation and Development, 22(2), 150-165. https://doi.org/10.1002/ldr.1075

Wardle, D. and Jonsson, M. (2014). Long-term resilience of above- and belowground ecosystem components among contrasting ecosystems. Ecology, 95(7), 1836-1849. https://doi.org/10.1890/13-1666.1

Zwain, F., Al-Samarrai, T., & Al-Saady, Y. (2021). A study of desertification using remote sensing techniques in basra governorate, south iraq. Iraqi Journal of Science, 912-926. https://doi.org/10.24996/ijs.2021.62.3.22

Assessing Desertification Severity in Aridland Mining Landscapes: A Review of Pathways and Metrics

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Abstract: Mining in drylands alters soil, vegetation, and hydrology to a degree that can accelerate desertification. Typical pathways include wholesale soil removal, disruption of surface and subsurface flow, dust generation, secondary salinization, and acid mine drainage. These processes degrade ecosystem functions, diminish air and water quality, and complicate mine closure and post-mining land use. Although research on mine-related degradation is substantial, findings are dispersed across commodities, biomes, and methods, which hampers decision-making for rehabilitation and policy. This review addresses that gap by synthesizing evidence on desertification processes and recovery in mine-affected drylands from 1990 to the present. We focus on three questions: (i) What are the principal drivers of desertification in mining landscapes? (ii) Which indicators and measurement approaches are used to detect and monitor degradation and recovery (field metrics and remote sensing)? (iii) Which rehabilitation strategies demonstrate effectiveness across contexts? By collating results from peer-reviewed studies and selected grey literature, we provide an integrated view of indicator performance (e.g., NDVI/NBR, vegetation cover and richness soil organic matter, pH/EC, infiltration, particulate emissions) and relate rehabilitation outcomes to site conditions and design choices. We also highlight geographic and methodological imbalances such as the concentration on open-pit coal and metal mines and identify recurrent limitations, including short monitoring horizons and limited use of robust designs (e.g., BACI). The synthesis culminates in a pragmatic indicator set and practice-oriented recommendations to support transparent monitoring of mine closure and restoration in drylands.

Keywords: mining landscapes; drylands; desertification; severity/degree; process pathways; indicators

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1. INTRODUCTION

Mining in arid regions alters soils, plants, and hydrology, potentially expediting desertification. Disruptions including extensive soil loss, interference with surface and subsurface flow, dust production, secondary salinization, and acid mine drainage impair ecosystem functioning, reduce air and water quality, and complicate mine closure and post-mining land utilization. Despite the extensive study on mine-related degradation, the information is fragmented across many commodities, biomes, indicators, and methodologies, complicating the comparison of results, assessment of severity, and selection of pertinent decision-making criteria. This review fills the gap by synthesizing evidence (1990–present) on process pathways and measurement methodologies for evaluating the severity of desertification in dryland mining landscapes, and by converting those insights into a practical set of indicators for closure-phase monitoring and restoration planning.

Drylands are areas characterized by restricted and extremely variable water supply, where low precipitation in relation to evaporative demand results in a mosaic of vegetated and barren patches that are susceptible to climatic variations (Wang et al., 2015; Huang et al., 2017; Reynolds et al., 2007; Maestre et al., 2016). They are generally categorized as arid, semi-arid, or dry sub-humid based on aridity indices (e.g., PET/precipitation) and are found in tropical, subtropical, and temperate regions (Stavi et al., 2023; Kar et al., 2020). Due to variations in definitions based on scale and methodology, investigations must specify the operational meaning of "drylands" utilized (Reynolds et al., 2007; Ji et al., 2015). In these contexts, mining landscapes operate as integrated social-ecological systems where extractive activities engage with delicate biophysical processes. Transitions from disturbed to restored states entail modifications in hydrologic fluxes, soil characteristics, vegetation patterns, and biogeochemical cycles in climates marked by aridity and significant variability; interactions between mining and land use can thus expedite degradation and heighten the risk of desertification (Stavi et al., 2023; Maestre et al., 2016; Bestelmeyer et al., 2015).

Desertification is characterized as the prolonged degradation of ecosystem structure and function in arid regions, driven by biophysical and socio-economic factors, such as climate variability and land-use alterations (Reynolds et al., 2007; Verstraete et al., 2009). Embracing a state-change and land-use change (SC–LUC) viewpoint highlights that deterioration occurs through process pathways influenced by land use, management, and governance, rather than a singular biophysical threshold (Bestelmeyer et al., 2015; Ganem et al., 2022). In this context, severity refers to the extent of desertification indicated by quantifiable measures of biophysical condition, ecological integrity, and, when applicable, socio-economic impacts. Severity grading distinguishes between stages of transformation (e.g., baseline → moderate → severe), facilitates

the prioritization of treatments, and must be associated with clear management thresholds and closure criteria (Bestelmeyer et al., 2015; Reynolds et al., 2007; Verstraete et al., 2009).

Our conceptual framework connects disruption to decisions via four components. Initially, process routes emerge from the interplay of natural and artificial influences. Natural factors such as aridity, rainfall variability, evaporative demand, and dryland hydrological responses determine ecosystem structure and function (Wang et al., 2015; Feng et al., 2018; Kar et al., 2020). Human-induced factors such as mining tenure and design, land-use alterations, water extraction, soil disruption, and operational methodologies interact with ecohydrological and biogeochemical cycles, hence modifying resilience and degradation pathways (Stavi et al., 2023; Maestre et al., 2016). Degradation and recovery can occur through patch-scale dynamics, front propagation, or gradual transitions, influenced by spatial heterogeneity and vegetation-soil interactions; desertification may be either gradual or abrupt, with spatial patterns affecting stability and reversibility under management (Zelnik et al., 2017; David et al., 2022). Secondly, indicators furnish quantifiable signals regarding state and process: biophysical (vegetation cover/richness, soil organic matter or carbon, soil moisture, erosion, hydrologic metrics), biogeochemical (nutrient cycling proxies, soil microbial activity, plant–microbe interactions), and, when applicable, socio-economic (livelihood security, resilience) (Maestre et al., 2016; Maestre et al., 2017; Feng et al., 2018; Kar et al., 2020; Reynolds et al., 2007; Hobbs et al., 2023). Third, severity grading consolidates various indicators into distinct categories based on baselines or controls and corresponds with decision thresholds, recognizing the possibility of reversibility through policy and restoration measures (Bestelmeyer et al., 2015; Reynolds et al., 2007; Verstraete et al., 2009). Ultimately, policy, management, and restoration decisions utilize severity levels and pathway diagnoses to refine landform and drainage design, cover and amendment systems, species/trait selection, and controls for dust or salinity/AMD, in alignment with the Drylands Development Paradigm's focus on connecting scientific knowledge to practical implementation (Reynolds et al., 2007; Verstraete et al., 2009).

Informed by this approach, the review seeks to achieve four objectives: (i) to establish operational definitions for drylands, mining landscapes, desertification, and severity that facilitate consistent, reproducible assessments (Wang et al., 2015; Huang et al., 2017; Reynolds et al., 2007; Maestre et al., 2016); (ii) to develop an integrated framework linking pathways, indicators, severity, and decision-making for monitoring and assessment (Bestelmeyer et al., 2015; Verstraete et al., 2009); (iii) to identify essential indicators and data requirements for monitoring desertification risk and severity in dryland mining contexts, encompassing temporal dynamics and socio-ecological factors (Maestre et al., 2017; Maestre et al., 2016; Hobbs et al., 2023; Ji et al., 2015); and (iv) to formulate review questions that direct empirical research and policy formulation: Which definitions most effectively facilitate comparison evaluations in mining landscapes? In what ways can mining activities modify process pathways, and how are these alterations reflected in quantifiable indicators? Which indicators most effectively monitor severity, and how may they be incorporated into decision-support systems? What governance and restoration techniques effectively prevent or reverse desertification, and in what ways does SC–LUC framing guide closure criteria and adaptive management? Through the synthesis of peer-reviewed studies and curated grey literature, we intend to assess indicator performance across various contexts, highlight geographic and methodological disparities, and provide a practical indicator set and severity rubric to facilitate transparent and reproducible monitoring of mine closure and restoration in arid regions.

2. MINING IN ARID LANDS

Arid land mining takes place in hydro-ecological environments that are characterized by water shortages, dynamic events, and vulnerable soils. These factors significantly influence the effects of disturbances and the capacity for recovery. This section will: (i) outline the climatic and ecohydrological constraints that affect degradation pathways; (ii) link various mining methods and commodities to these pathways; and (iii) summarize the typical disturbance regimes during the mine's lifecycle and into closure, while emphasizing their implications for indicators and decision-making.

2.1. Dryland climate and hydro-ecological constraints in mining regions

Arid and semi-arid regions present unique hydrological and ecological challenges that affect mining operations and the pathways for post-mining restoration. Key limitations include restricted and highly variable water supplies, low availability of surface water, deep groundwater sources, and a significant interconnection between hydrological flows and vegetation dynamics. Research conducted in dry mining environments highlights how water scarcity impacts ecological water requirements and creates seasonal variations in water use. These challenges necessitate careful consideration of land-use and water dynamics in both operational and closure planning (Wang et al., 2023; Wu et al., 2019). Additionally, climate-induced aridity alters ecohydrological processes, affecting soil moisture, evapotranspiration, and vegetation patterns all of which influence the potential for rehabilitation after extraction (Wang et al., 2017; Wu et al., 2021). The extent and intensity of water-related challenges increase with aridity, underscoring the need for localized hydro-ecological assessments to guide mine design, water sourcing, and restoration strategies (Wang et al., 2023; Jia & Li, 2013).

2.2. Mining modalities in arid landscapes

Mining in drylands commonly encompasses open-pit, underground, and tailings operations, with coal, metals, and industrial minerals as dominant commodity classes. Importantly, the choice of mining method interacts with hydro-ecological constraints to influence disturbance patterns and the potential for recovery throughout the life cycle of the mine and the closure phase (Chen et al., 2017).

- **Open-pit mining,** is well-documented in arid and semi-arid regions. This method of extracting coal and metals leads to significant surface disturbances, the creation of waste dumps, and long-lasting ecological impacts. The consequences include extensive land-cover transformation, a decline in soil quality, and persistent disturbances that complicate the reclamation process (Jiancheng et al., 2020; Zhang et al., 2012; Shou-gang et al., 2020).

- **Underground mining,** which includes longwall and other subsurface methods, can result in groundwater drawdown, land subsidence, and vegetation stress. These issues contribute to drying trends and changes in soil conditions, making revegetation and ecological recovery more difficult (He et al., 2020; Wang & Ma, 2019; Wang et al., 2017).

- **Tailings storage and waste facilities,** present unique challenges in arid environments. High evaporation rates, dust generation, and losses due to infiltration increase risks, highlighting the need for strong containment measures, effective water-balance controls, and stabilization techniques during mining operations and after site closure (Zhang et al., 2021; Costantini et al., 2016).

2.3. Typical disturbance regimes across life-of-mine and closure

Disturbance regimes in arid mining landscapes are characterized by spatially extensive surface disruption, topsoil loss, vegetation removal, habitat fragmentation, and altered hydrological fluxes.

- **Open-pit phases** induce immediate, near-surface disturbance with broad land-cover change, soil compaction, and loss of structure, followed by progressive landform modification and waste emplacement that propagate impacts over large areas. Without effective reclamation, landscape-level degradation and reduced ecosystem services can persist long after operations cease (Jiancheng et al., 2020; Zhang et al., 2012; Shou-gang et al., 2020).

- **Underground phases** introduce subsidence and hydrological perturbations that propagate vertically and laterally, with consequences for soil moisture, cohesion, and vegetation establishment in surrounding areas—factors that shape restoration feasibility in arid soils (Ma et al., 2019).

- **Tailings and waste storage** create persistent disturbance via dust, seepage, and potential chemical leaching, requiring long-term monitoring and stabilization to minimize ecological degradation and support rehabilitation goals (Zhang et al., 2021; Costantini et al., 2016).

In many arid regions, disturbance interacts with climate variability: episodic rainfall pulses can trigger runoff and erosion at patch to watershed scales, depending on aridity, landscape heterogeneity, and catchment characteristics. This coupling informs both erosion risk during operations and the potential for natural regeneration post-closure (Groner et al., 2023). Contemporary closure strategies emphasize staged reclamation, revegetation, soil restoration, and hydrological reconfiguration to re-establish function and reduce desertification susceptibility (Zhu et al., 2024; Song et al., 2024).

2.4 Indicators and decision relevance for arid mining landscapes

Effective monitoring and management rely on a suite of indicators spanning biophysical, hydro-ecological, and socio-economic dimensions:

- **Biophysical indicators:** soil organic matter and fertility, structure/compaction, soil moisture, vegetation cover and health, erosion and sediment transport, and landform stability—proxies for hydro-ecological status and recovery likelihood under arid conditions (Costantini et al., 2016; Jia & Li, 2013; Guangkuo et al., 2023).

- **Hydrological indicators:** water balance, groundwater-depth dynamics, surface-water availability, and ecological water demand—metrics to ensure mining does not compromise critical water resources or ecosystem services (Wang et al., 2023; Wu et al., 2021).

- **Socio-economic indicators:** livelihood security and community resilience, recognizing that desertification risk and restoration success are intertwined with human well-being and governance (Abduallah, 2018).

Integrating these indicators across life-of-mine stages supports risk-based decision-making for operating efficiency, water stewardship, and robust closure planning, aligning with frameworks that advocate site-specific, hydrologically informed restoration and land-use planning in drylands (Bestelmeyer et al., 2015; Verstraete et al., 2009).

2.5 Implications for research, planning, and policy

A coherent understanding of dryland hydro-ecological constraints, mining modalities, and disturbance regimes is essential for responsible mining in arid lands. Effective practices include: (a) selecting mine designs and water-management strategies that minimize hydrological disruption and maximize post-closure resilience; (b) implementing proactive reclamation and revegetation with drought-tolerant species and soil-amelioration techniques to accelerate recovery; (c) employing remote sensing, landscape-scale health assessments, and soil indicators to monitor degradation and guide adaptive management; and (d) integrating governance approaches consistent with state-change–land-use-change (SC–LUC) perspectives so restoration decisions reflect both ecological processes and land-use trajectories (Bestelmeyer et al., 2015; Verstraete et al., 2009; Reynolds et al., 2007).

Synthesis. Across arid mining literature, groundwater drawdown, land subsidence, soil degradation, and vegetation loss recur as constraints shaped by modality (open-pit vs. underground) and tailings practices (Ma et al., 2019; Jiancheng et al., 2020; Wang & Ma, 2019). These disturbances determine operational risk and recovery potential, underscoring the need for hydro-ecological monitoring and reclamation tailored to arid settings (Zhang et al., 2021; Zhu et al., 2024). Remote-sensing and landscape-health frameworks provide practical tools for assessing restoration potential and prioritizing interventions (Chen et al., 2017; Guangkuo et al., 2023; Shou-gang et al., 2020; Costantini et al., 2016), while governance-focused syntheses remind us that desertification risk must be analyzed within policy and land-use contexts aligned with the Drylands Development Paradigm (Reynolds et al., 2007; Verstraete et al., 2009).

3. PROCESS PATHWAYS TO DESERTIFICATION IN MINING-IMPACTED DRYLANDS

This section synthesizes the mechanistic pathways by which desertification emerges in drylands affected by mining, and emphasizes the key process linkages, feedbacks, and modifiers. The synthesis draws on the references provided and frames the pathways in a governance- and restoration-relevant context.

3.1 Wholesale soil removal and profile truncation

Bulk stripping of topsoil and subsoil eliminates organic matter, nutrients, moisture storage, aggregates, seed banks, and soil biota, immediately lowering water-holding capacity and structural stability in arid and semi-arid landscapes. Revegetation potential declines while susceptibility to erosion and thermal stress increases (Jiancheng et al., 2020; Ma et al., 2019). Reduced infiltration and elevated runoff propagate sediment loss and landscape connectivity of degradation, creating legacies that can constrain restoration for decades, especially where aridity limits natural soil development and plant establishment (Wang et al., 2023; Wu et al., 2021).

3.2 Disruption of surface and subsurface flow; infiltration–runoff balance

Compaction, rutting, and altered landforms reduce infiltration and interception, shifting water toward overland flow and flash runoff, which accelerates sediment transport and reduces groundwater recharge in arid settings (Wang et al., 2023; Wu et al., 2021; Jiancheng et al., 2020). Subsurface disturbance and subsidence can reorganize fracture networks and lateral groundwater movement, further altering recharge patterns and drying adjacent ecosystems (He et al., 2020). These hydrologic shifts depress soil moisture, hinder vegetation establishment, and interact with salinity and geochemical legacies.

3.3 Dust generation and particulate deposition

Exposed benches, dumps, haul roads, and tailings surfaces emit mineral dust, including fine particulates that may be enriched in trace metals. Aeolian transport and dry deposition modify surface chemistry, reduce photosynthesis, and disperse contaminants well beyond the mine footprint (Gil-Loaiza et al., 2018; Caliani et al., 2013). Strong winds and dry surfaces typical of arid climates intensify emissions and transport (Wiggs et al., 2003; Meza-Figueroa et al., 2009). Dust crusting and loading can compact soils, suppress microbial activity, and contribute to secondary salinization or sodicity in the root zone, linking air pathways to soil and geochemical degradation (Caliani et al., 2013).

3.4 Secondary salinization and sodicity

High evaporative demand and capillary rise mobilize salts upward in disturbed profiles, concentrating salinity at or near the surface. Water withdrawals, seepage from tailings, and drainage alterations exacerbate salinity and sodicity, lowering hydraulic conductivity and creating hostile conditions for plant roots and soil biota (Wang et al., 2023; Wu et al., 2021; Ma et al., 2019). Salt accumulation interacts with reduced infiltration and dust deposition, limiting germination and

microbial recovery and mediating metal mobility and long-term geochemical behavior (Costantini et al., 2016; Caliani et al., 2013).

3.5 Acid mine drainage (AMD) and geochemical legacies

Exposure of sulfide-bearing waste rock and tailings to oxygen and water generates acidity and mobilizes metals, producing drainage plumes that can persist long after closure and degrade soils and waters across connected landscapes (Caliani et al., 2013; Stovern et al., 2016). Acidic conditions alter microbial communities, suppress nutrient cycling, and impair infiltration and plant establishment, reinforcing other degradation pathways and exporting desertification risks downstream.

3.6 Feedbacks and modifiers: aridity, substrate, topography

Pathways rarely act in isolation. Soil stripping lowers storage and infiltration, which increases runoff and erosion, further degrading structure and vegetation; vegetation loss increases surface heating and vapor pressure deficit, elevating evapotranspiration and impairing establishment (Ma et al., 2019). Aridity amplifies dust production, accelerates transitions to runoff-dominated regimes, and reduces natural revegetation potential (Reynolds et al., 2007; Kar et al., 2020; Wang et al., 2023). Substrate texture, mineralogy, and initial SOM condition susceptibility to erosion, salinity, and leaching, making fragile mine substrates particularly vulnerable (Jiancheng et al., 2020; Costantini et al., 2016). Topography governs erosion risk, flow accumulation, and dust corridors, concentrating impacts in predictable zones and informing restoration priorities (Jiancheng et al., 2020; Costantini et al., 2016). These dynamics argue for integrated monitoring and for governance aligned with state-change–land-use-change perspectives (Reynolds et al., 2007; Bestelmeyer et al., 2015; Verstraete et al., 2009).

3.7 Decision-relevant indicators

Soils: profile depth, bulk density/porosity, soil organic carbon, pH, electrical conductivity (salinity), exchange capacity, and microbial activity core signals of biogeochemical status and recovery potential (Costantini et al., 2016; Ma et al., 2019).

Hydrology: infiltration capacity/KSAT, runoff coefficients, groundwater depth and chemistry, and surface-water permanence metrics of water balance and ecosystem water security (Wang et al., 2023; Wu et al., 2021).

Dust/air: dust fluxes and PM10/PM2.5 near dumps and tailings; deposition patterns exposure and ecological/health risk indicators (Gil-Loaiza et al., 2018; Caliani et al., 2013).

Geochemistry: acid–base accounting, net acid generation, redox indicators, and metal loads in soils/waters tracking AMD potential and legacy effects (Caliani et al., 2013; Stovern et al., 2016).

Vegetation/biota: cover, functional composition, richness, recruitment, and soil microbial community metrics trajectory indicators for rehabilitation success and resilience (Costantini et al., 2016; Ma et al., 2019).

3.8 Implications for practice

Desertification in mining-impacted drylands arises from direct actions such as soil stripping, hydrologic alteration, exposure of reactive materials, that propagate through hydrologic, geochemical, and biotic channels. Dust, salinity/sodicity, and AMD operate as reinforcing conduits of degradation (Bestelmeyer et al., 2015; Reynolds et al., 2007; Verstraete et al., 2009). Effective restoration therefore pairs landform stability and hydrologic reconnection with geochemical encapsulation and dust management, while integrating remote sensing (e.g., NDVI/NBR, albedo, LST) and field indicators to track spatially explicit dynamics from operations through post-closure (Costantini et al., 2016; Guangkuo et al., 2023; Stovern et al., 2016). Severity classes should be tied to explicit thresholds linked to closure criteria and adaptive management triggers.

4. INDICATORS AND METRICS FOR ASSESSING DESERTIFICATION SEVERITY

Time-series remote sensing combined with focused field measurements provides the necessary resolution, coverage, and indicators to identify and assess the severity of desertification in arid mining environments. Indices derived from remote sensing, such as NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), and NBR (Normalized Burn Ratio) for evaluating vegetation status and structural changes; albedo and land surface temperature (LST) for assessing exposure and crusting; and, when available, SAR (Synthetic Aperture Radar) backscatter for analyzing moisture and roughness, facilitate comprehensive monitoring. These tools help distinguish between natural climate fluctuations and the impacts of specific treatments through the analysis of trends and anomalies (Maestre et al., 2016; Huang et al., 2017; Ji et al., 2015).

Field indicators help validate remote sensing signals and assess various pathways. Important indicators include: vegetation cover (especially perennial species), functional composition, and recruitment; soil profile depth, bulk density, penetration resistance, aggregate stability, soil organic carbon, pH, electrical conductivity (EC), and sodium adsorption ratio (SAR); infiltration rates and crust strength; hydrologic responses (like runoff coefficients, event sediment yield, groundwater depth and chemistry, and baseflow persistence); dust exposure (measured through PM_{10} and $PM_{2.5}$ fluxes and deposition at haul roads, dumps, and tailings storage facility (TSF) beaches); and geochemical assessments for legacy risks (such as acid-base accounting, net acid generation, pore water and surface water pH, EC, metals, and redox state) (Costantini et al., 2016; Gil-Loaiza et al., 2018; Caliani et al., 2013; Stovern et al., 2016; Wang et al., 2023; Wu et al., 2021).

The selection of indicators must align with the identified pathways (e.g., EC/SAR for salinity, acid-base accounting for acid mine drainage (AMD), dust flux for aeolian sources), integrate scales (from plots to pixels), and include explicit counterfactuals (such as reference sites or Before-After-Control-Impact studies) to account for climate variability (Bestelmeyer et al., 2015; Reynolds et al., 2007; Verstraete et al., 2009). A concise and verifiable severity rubric aligned with management thresholds is crucial for effective decision-making.

- ✓ Class 0 (Baseline/Reference): Indicators show natural fluctuations.
- ✓ Class 1 (Mild): Minor, consistent deviations with high recoverability once the pressure is removed.
- ✓ Class 2 (Moderate): Several indicators are out of range (e.g., reduced infiltration, increased EC/SAR, persistent dust exceedances), requiring management to prevent worsening conditions.
- ✓ Class 3 (Severe): Functional failure evident through crusted or disintegrating surfaces, persistent AMD or seepage non-compliance, and seasonal vegetation failure, necessitating engineered interventions.
- ✓ Class 4 (Critical/Legacy Hotspot): Persistent geochemical or geomorphic instability (such as active AMD plumes or eroding TSF beaches) that requires long-term management and monitoring.

To effectively standardize each indicator to a benchmark (such as percentage difference or z-score), it is important to prioritize pathway-critical metrics, including Electrical Conductivity (EC), erosion, and acid mine drainage (AMD). Implement a traffic-light system where the severity of issues escalates with the quantity and significance of exceedances. Each metric class should be linked to predetermined actions, such as regrading triggers, cover enhancements, dust suppression intensity, and water treatment processes. Additionally, present uncertainty through confidence intervals and quality assurance/quality control flags.

A minimal, pragmatic set of indicators that balances cost and decision-making value typically includes:

1. Perennial cover measurements (using plots or transects) alongside NDVI (Normalized Difference Vegetation Index) and NBR (Normalized Burn Ratio) time series for each landform unit.
2. Soil physical and chemical core analyses (including bulk density or penetrometer readings, infiltration/KSAT, soil organic carbon, pH/EC ± SAR).
3. PM_{10} measurements at primary sources, in addition to deposition collectors.
4. Event-based monitoring of runoff and erosion on critical slopes, as well as groundwater depth and chemistry where dewatering or seepage is significant.
5. Acid-base accounting (ABA) and neutralization potential (NAG), along with routine analysis of pH, electrical conductivity (EC), and metals for reactive waste rock and tailings (Costantini et al., 2016; Gil-Loaiza et al., 2018; Stovern et al., 2016).

Sampling should be both seasonal and event-driven, particularly after storms and during windy conditions, with reporting aligned to closure milestones and established criteria for adaptive management (Huang et al., 2017; Ji et al., 2015; Verstraete et al., 2009).

5.STUDY DESIGNS AND ANALYTICAL APPROACHES FOR DETECTING AND GRADING SEVERITY

Robust detection of desertification and defensible severity grading in dryland mining landscapes depend on designs that separate mining effects from climate variability and background trends, integrate plots - pixels, and tie statistics to decision thresholds. At minimum, studies should (i) include a counterfactual, (ii) capture event-driven dynamics, and (iii) report uncertainty in ways that map to closure triggers (Bestelmeyer et al., 2015; Huang et al., 2017; Ji et al., 2015; Maestre et al., 2016; Reynolds et al., 2007; Verstraete et al., 2009).

- **Counterfactuals and attribution:** Before–After/Control–Impact (BACI) designs (or quasi-BACI with matched reference areas when pre-impact data are unavailable) strengthen causal inference by contrasting impacted landforms with stable references across time. Where references are scarce, gradient (distance/downslope) designs, “synthetic controls” built from multi-site pixels, or phased rollouts can provide useful counterfactuals, provided covariates (aridity, substrate, slope) are balanced (Bestelmeyer et al., 2015).

- **Plots-pixels integration:** Field plots quantify mechanisms (e.g., infiltration, EC/SAR, PM flux, perennial cover), while dense satellite time series (NDVI/NBR, albedo, LST; optionally SAR) resolve timing and extent across facilities. Co-location of plots within pixel footprints enables calibration/validation, hierarchical models, and bias correction for mixed pixels and sensor drift (Maestre et al., 2016; David et al., 2022).

- **Temporal design in pulse-driven climates:** Drylands respond to events more than means. Pair seasonal baselines with event-based sampling after major storms and windy periods to capture runoff/erosion and dust pulses; analyze satellite trends with break-point or anomaly methods to distinguish climate oscillations from management effects (Huang et al., 2017; Ji et al., 2015).

- **Replication, power, and spatial scaling:** Replicate at the landform unit (e.g., dump slopes, TSF beaches, regrades) rather than over-aggregating the whole site; use power analyses to set plot numbers and revisit frequency for key indicators (cover, infiltration, EC, PM_{10}). Stratify by aridity, substrate, and topography so modifiers of severity are explicit (Costantini et al., 2016).

- **Effect sizes and thresholds:** Report standardized effects (e.g., % deviation from reference, Hedges' g, log-ratios) alongside management thresholds that define severity classes (Section 4). For closure decisions, consider equivalence or non-inferiority tests (e.g., vegetation cover within $\pm\Delta$ of reference; seepage EC below criterion) rather than significance alone.

- **Uncertainty, QA/QC, and transparency:** Provide confidence intervals, method detection limits, and data-quality flags; archive protocols, georeferenced plots, and code. For remote sensing, document sensors, compositing rules, and cloud masks; for field data, record soil depth, antecedent moisture, and event magnitude. Summaries should show both site-wide and landform-level severity.

- **Synthesis across studies:** For literature reviews or portfolio-level assessments, follow transparent screening (e.g., PRISMA-style), code indicators, pathways, and designs (BACI vs. control-impact, time-series only), and use meta-analytic or vote-count methods with sensitivity analyses to aridity and modality (open-pit vs. underground vs. tailings) (Reynolds et al., 2007; Verstraete et al., 2009).

- **Decision workflow:** (1) Diagnose dominant pathways (Section 3) per landform; (2) select fit-for-purpose indicators (Section 4); (3) choose a design with a counterfactual and event capture; (4) pre-register severity thresholds mapped to actions; (5) analyze effect sizes and uncertainty; (6) report a severity map and action table linking exceedances to timelines.

6. CONCLUSIONS

Mining in arid regions disrupts soils, vegetation, and hydrology through a limited number of recurring mechanisms. These include comprehensive soil removal, changes in surface and subsurface flow and infiltration, dust production, secondary salinization and sodicity, and acid mine drainage. These mechanisms interact through feedback influenced by factors such as aridity, substrate, and topography. Our synthesis demonstrates that assessing the severity of desertification is both achievable and relevant for decision-making. This is particularly true when monitoring is clearly aligned with these mechanisms, incorporates both plots and pixels, and roots interpretation in reference conditions or counterfactuals. An effective and verifiable framework that links indicator deviations to severity categories and predetermined management responses can establish a connection between diagnosis and resolution.

Three notable contributions emerge from this work. First, we clarify the alignment between pathways and indicators by identifying which metrics effectively diagnose each degradation mechanism. For example, electrical conductivity and sodium adsorption ratio (EC/SAR) are useful for assessing salinity, while acid-base accounting (ABA/NAG) and pH/metal combinations are indicators for acid mine drainage. Similarly, particulate matter flux and deposition help track aeolian sources, while infiltration and saturated hydraulic conductivity (KSAT) along with landscape cover indicate hydrologic and soil structure alterations. Remote sensing metrics like NDVI/NBR and land surface temperature (LST) provide insights into landscape-scale status and trends.

Second, we emphasize that research design is the primary factor influencing the quality of evidence in pulse-driven drylands. Utilizing Before-After-Control-Impact (BACI) or robust reference designs, event-based sampling during storms and windy periods, and transparent reporting of uncertainties are essential for distinguishing mining signals from climate variability.

Third, we propose a severity grading framework that translates indicator behavior into actionable categories: Baseline, Mild, Moderate, Severe, and Critical/Legacy. This framework can directly inform management actions, such as regrading,

enhancing cover, dust suppression, drainage reconfiguration, and water treatment, thereby facilitating adaptive management and measurable progress toward closure criteria.

Despite a growing body of literature, several disparities persist. These include a geographic focus on a limited range of commodities (mainly open-pit coal and metals), short monitoring periods relative to the long recovery times of soil and vegetation, inadequate implementation of rigorous counterfactual assessments, and insufficient integration of analyses combining ground data with extensive time series. Risks specific to tailings in arid climates, such as deflation, evaporative salinity, and geochemical persistence, as well as groundwater-surface water interactions related to dewatering and rebound, are not adequately reflected in long-term datasets. Addressing these deficiencies will help reduce uncertainty in severity ratings and enhance their applicability across different locations.

We recommend that mine operators and regulators establish a core set of indicators, which may include: perennial cover along with NDVI/NBR; soil bulk density, infiltration, soil organic carbon (SOC), pH, and EC +/- SAR; particulate matter (PM_{10}) and its deposition; event-based measurements of runoff and erosion, as well as groundwater depth and chemistry as relevant; and ABA/NAG plus seepage chemistry for reactive materials. They should also produce severity maps categorized by landform unit and associate each severity class with documented triggers and timelines. Program governance must enforce the inclusion of counterfactuals during the design phase, utilize event-aligned sampling schedules, and ensure the availability of data and protocols to guarantee comparability and transparency in auditing.

Research priorities include: (i) calibrating severity thresholds to ecological functionality, such as infiltration and perennial cover objectives that predict erosion mitigation and vegetation recruitment; (ii) developing composite indices that retain mechanistic interpretability; (iii) quantifying the resilience of rehabilitation efforts under extreme climatic conditions; and (iv) enhancing the understanding of risks associated with arid tailings storage facilities and subsurface-induced subsidence, particularly concerning salinity and acid mine drainage. Cross-site syntheses utilizing agreed-upon indicators and methodologies will facilitate meta-analytic effect sizes, advancing the field from case-study generalizations to evidence-based closure criteria.

In conclusion, desertification in mining-affected arid regions is driven by a finite number of manageable pathways. By employing pathway-aligned indicators, resilient research designs, and a practical severity framework, stakeholders can assess risks, prioritize interventions, and validate recovery in a transparent manner that promotes responsible mine closure and post-mining land utilization.

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REFERENCES

Abduallah, M. (2018). "satellite vs. uavs remote sensing of arid ecosystems: a review with in an ecological perspective". Environmental Analysis & Ecology Studies, 2(3). https://doi.org/10.31031/eaes.2018.02.000540

Bestelmeyer, B., Okin, G., Duniway, M., Archer, S., Sayre, N., Williamson, J., … & Herrick, J. (2015). Desertification, land use, and the transformation of global drylands. Frontiers in Ecology and the Environment, 13(1), 28-36. https://doi.org/10.1890/140162

Caliani, J., Rosa, J., Campa, A., Castanedo, Y., & Castillo, S. (2013). Mineralogy of atmospheric dust impacting the rio tinto mining area (spain) during episodes of high metal deposition. Mineralogical Magazine, 77(6), 2793-2810. https://doi.org/10.1180/minmag.2013.077.6.07

Chen, G., Wang, M., Liu, Z., & Chi, W. (2017). The biogeophysical effects of revegetation around mining areas: a case study of dongsheng mining areas in inner mongolia. Sustainability, 9(4), 628. https://doi.org/10.3390/su9040628

Costantini, E., Branquinho, C., Nunes, A., Schwilch, G., Stavi, I., Valdecantos, A., … & Zucca, C. (2016). Soil indicators to assess the effectiveness of restoration strategies in dryland ecosystems. Solid Earth, 7(2), 397-414. https://doi.org/10.5194/se-7-397-2016

David, R., Rosser, N., & Donoghue, D. (2022). Remote sensing for monitoring tropical dryland forests: a review of current research, knowledge gaps and future directions for southern africa. Environmental Research Communications, 4(4), 042001. https://doi.org/10.1088/2515-7620/ac5b84

Feng, T., Su, T., Ji, F., Zhi, R., & Han, Z. (2018). Temporal characteristics of actual evapotranspiration over china under global warming. Journal of Geophysical Research Atmospheres, 123(11), 5845-5858. https://doi.org/10.1029/2017jd028227

Ganem, K., Xue, Y., Rodrigues, A., Franca-Rocha, W., Oliveira, M., Carvalho, N., … & Shimabukuro, Y. (2022). Mapping south america's drylands through remote sensing—a review of the methodological trends and current challenges. Remote Sensing, 14(3), 736. https://doi.org/10.3390/rs14030736

Gil-Loaiza, J., Field, J., White, S., Csavina, J., Félix, O., Betterton, E., … & Maier, R. (2018). Phytoremediation reduces dust emissions from metal(loid)-contaminated mine tailings. Environmental Science & Technology, 52(10), 5851-5858. https://doi.org/10.1021/acs.est.7b05730

Groner, E., Babad, A., Swiderski, N., & Shachak, M. (2023). Toward an extreme world: the hyper-arid ecosystem as a natural model. Ecosphere, 14(6). https://doi.org/10.1002/ecs2.4586

Guangkuo, W., Liu, J., Ting-ning, Z., Jian-ying, Y., Li, R., Guoxian, K., … & Xiao, F. (2023). Evaluate the reclamation suitability of dumps of open-pit coal mines based on niche fitness in the eastern arid desert area in northwest china. Journal of Resources and Ecology, 14(4). https://doi.org/10.5814/j.issn.1674-764x.2023.04.013

He, X., Zhang, C., & Han, P. (2020). Overburden damage degree-based optimization of high-intensity mining parameters and engineering practices in china's western mining area. Geofluids, 2020, 1-21. https://doi.org/10.1155/2020/8889663

Hobbs, N., Hug, J., & Pee, S. (2023). High non-affordability of diets and malnutrition in africa's drylands: systems analysis to guide action. Food and Nutrition Bulletin, 44(2_suppl), S45-S57. https://doi.org/10.1177/03795721231178065

Huang, J., Li, Y., Fu, C., Chen, F., Fu, Q., Dai, A., … & Wang, G. (2017). Dryland climate change: recent progress and challenges. Reviews of Geophysics, 55(3), 719-778. https://doi.org/10.1002/2016rg000550

Ji, M., Huang, J., Xie, Y., & Liu, J. (2015). Comparison of dryland climate change in observations and cmip5 simulations. Advances in Atmospheric Sciences, 32(11), 1565-1574. https://doi.org/10.1007/s00376-015-4267-8

Jia, Z. and Li, W. (2013). Theoretical study on establishing hydro-eco dynamic monitoring system in large-scale and arid irrigation district. Advanced Materials Research, 726-731, 3787-3791. https://doi.org/10.4028/www.scientific.net/amr.726-731.3787

Jiancheng, Y., Liu, Y., & Gao, J. (2020). Research on identification of land damage types and analysis of damage process in opencast coal mine of steppe. E3s Web of Conferences, 194, 04032. https://doi.org/10.1051/e3sconf/202019404032

Kar, S., Sen, E., & Mukherjee, S. (2020). A geospatial technique-based site suitability analysis for construction of water reservoirs in arsha and balarampur blocks, purulia. World Water Policy, 6(1), 52-88. https://doi.org/10.1002/wwp2.12021

Ma, K., Zhang, Y., Ruan, M., Guo, J., & Chai, T. (2019). Land subsidence in a coal mining area reduced soil fertility and led to soil degradation in arid and semi-arid regions. International Journal of Environmental Research and Public Health, 16(20), 3929. https://doi.org/10.3390/ijerph16203929

Maestre, F., Eldridge, D., Soliveres, S., Kéfi, S., Delgado-Baquerizo, M., Bowker, M., … & Berdugo, M. (2016). Structure and functioning of dryland ecosystems in a changing world. Annual Review of Ecology Evolution and Systematics, 47(1), 215-237. https://doi.org/10.1146/annurev-ecolsys-121415-032311

Maestre, F., Solé, R., & Singh, B. (2017). Microbial biotechnology as a tool to restore degraded drylands. Microbial Biotechnology, 10(5), 1250-1253. https://doi.org/10.1111/1751-7915.12832

Meza-Figueroa, D., Maier, R., O-Villanueva, M., Gómez-Álvarez, A., Moreno-Zazueta, A., Rivera, J., … & Palafox-Reyes, J. (2009). The impact of unconfined mine tailings in residential areas from a mining town in a semi-arid

environment: nacozari, sonora, mexico. Chemosphere, 77(1), 140-147. https://doi.org/10.1016/j.chemosphere.2009.04.068

Reynolds, J., Stafford-Smith, M., Lambin, É., Turner, B., Mortimore, M., Batterbury, S., … & Walker, B. (2007). Global desertification: building a science for dryland development. Science, 316(5826), 847-851. https://doi.org/10.1126/science.1131634

Shou-gang, W., Huang, J., Yu, H., & Ji, C. (2020). Recognition of landscape key areas in a coal mine area of a semi-arid steppe in china: a case study of yimin open-pit coal mine. Sustainability, 12(6), 2239. https://doi.org/10.3390/su12062239

Song, D., Hu, Z., Yu, Y., Zhang, F., & Sun, H. (2024). Assessing ecological impacts and recovery in coal mining areas: a remote sensing and field data analysis in northwest china. Remote Sensing, 16(12), 2236. https://doi.org/10.3390/rs16122236

Stavi, I., Xu, C., & Argaman, E. (2023). Climate-smart forestry in the world's drylands: a review of challenges and opportunities. The Anthropocene Review, 11(1), 67-90. https://doi.org/10.1177/20530196231182354

Stovern, M., Guzmán, H., Rine, K., Félix, O., King, M., Ela, W., … & Sáez, A. (2016). Windblown dust deposition forecasting and spread of contamination around mine tailings. Atmosphere, 7(2), 16. https://doi.org/10.3390/atmos7020016

Verstraete, M., Scholes, R., & Stafford-Smith, M. (2009). Climate and desertification: looking at an old problem through new lenses. Frontiers in Ecology and the Environment, 7(8), 421-428. https://doi.org/10.1890/080119

Wang, L., Manzoni, S., Ravi, S., Riveros-Iregui, D., & Caylor, K. (2015). Dynamic interactions of ecohydrological and biogeochemical processes in water-limited systems. Ecosphere, 6(8), 1-27. https://doi.org/10.1890/es15-00122.1

Wang, Q., Geng, C., Wang, L., Zheng, T., Jiang, Q., Yang, T., … & Wang, Z. (2023). Water conservation and ecological water requirement prediction of mining area in arid region based on rs-gis and invest: a case study of bayan obo mine in baotou, china. Sustainability, 15(5), 4238. https://doi.org/10.3390/su15054238

Wang, S. and Ma, L. (2019). Characteristics and control of mining induced fractures above longwall mines using backfilling. Energies, 12(23), 4604. https://doi.org/10.3390/en12234604

Wang, Y., Bian, Z., Lei, S., & Zhang, Y. (2017). Investigating spatial and temporal variations of soil moisture content in an arid mining area using an improved thermal inertia model. Journal of Arid Land, 9(5), 712-726. https://doi.org/10.1007/s40333-017-0065-8

Wiggs, G., O'Hara, S., Wegerdt, J., Meer, J., Small, I., & Hubbard, R. (2003). The dynamics and characteristics of aeolian dust in dryland central asia: possible impacts on human exposure and respiratory health in the aral sea basin. Geographical Journal, 169(2), 142-157. https://doi.org/10.1111/1475-4959.04976

Wu, Z., Lei, S., He, B., Bian, Z., Wang, Y., Lu, Q., … & Duo, L. (2019). Assessment of landscape ecological health: a case study of a mining city in a semi-arid steppe. International Journal of Environmental Research and Public Health, 16(5), 752. https://doi.org/10.3390/ijerph16050752

Wu, Z., Lu, Q., Lei, S., & Yan, Q. (2021). Study on landscape ecological classification and landscape types evolution: a case study of a mining city in semi-arid steppe. Sustainability, 13(17), 9541. https://doi.org/10.3390/su13179541

Zelnik, Y., Uecker, H., Feudel, U., & Meroni, E. (2017). Desertification by front propagation?. Journal of Theoretical Biology, 418, 27-35. https://doi.org/10.1016/j.jtbi.2017.01.029

Zhang, L., Zhou, X., Yan, Z., Zhou, J., Guo, J., Zhai, Z., … & Qiao, Y. (2021). Surface coal mining impacts on land use change and ecological service value: a case study in the shengli coalfield, inner mongolia.. https://doi.org/10.21203/rs.3.rs-910523/v1

Zhang, M., Wang, J., Bai, Z., & Liu, C. (2012). The topsoil quality variation under different reclamation modes in pasture opencast coal mine of china. Advanced Materials Research, 518-523, 4790-4795. https://doi.org/10.4028/www.scientific.net/amr.518-523.4790

Zhu, T., Li, C., Liu, X., & Zhao, X. (2024). Assessing ecological restoration in arid mining regions: a progressive evaluation system. Sustainability, 16(6), 2266. https://doi.org/10.3390/su16062266

A Comprehensive Review of Habitat Suitability Modelling in the Context of Desertification and Land Degradation

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Abstract: Habitat suitability modeling (HSM) provides a framework for estimating potential species distributions and assessing habitat quality across various environmental gradients. Desertification, which refers to the degradation of drylands caused by climate variability and human activities, impacts vegetation, soils, and landscape structure in arid, semi-arid, and dry sub-humid areas. This paper consolidates core concepts of HSM and biophysical indicators of desertification, exploring ways to integrate these two areas. We demonstrate how output from HSM can be used to conceptualize and quantify the effects of desertification on habitat quality, fragmentation, and the spatial dynamics of species. A typical process involves integrating climate, soil, and land-use variables with remote-sensing metrics (such as NDVI, land surface temperature, and soil moisture) to create Habitat Suitability Models (HSMs), which are then analyzed alongside desertification risk layers. Current challenges include sample and publication bias, inconsistencies in geographic and temporal resolution among datasets, limited transferability across scales and species, and variable treatment and reporting of uncertainty. We emphasize the importance of optimal methodologies for variable selection, cross-validation, and uncertainty propagation, and we provide a reporting checklist to enhance repeatability. Incorporating HSM into desertification assessments offers a practical decision-support framework for prioritizing conservation efforts, managing land, and restoring ecosystems in arid regions.

Keywords: Species distribution; desertification; land degradation; remote sensing; conservation planning; restoration

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1. INTRODUCTION

Drylands, which include arid, semiarid, and dry sub-humid areas, represent a significant portion of the Earth's surface and hold considerable ecological and socio-economic value. However, these regions are particularly susceptible to land degradation and desertification. Habitat Suitability Modeling (HSM), a type of Species Distribution Modeling (SDM), provides a structured method for translating environmental conditions into probabilistic assessments regarding the suitability of habitats for various species or ecosystems.

Several recent developments have made this integration particularly timely. Climate variability, ongoing droughts, and intensified land use change vegetation structure, soil characteristics, hydrological patterns, and landscape configurations, key factors that affect habitat suitability in arid regions. The growing availability of remote-sensing indicators (such as NDVI/EVI, land surface temperature, and soil moisture), land-use and land-cover products, and composite degradation indices enable comprehensive evaluations of desertification conditions and trends. HSM and SDM can translate environmental changes into species-specific responses, while desertification assessments contextualize these responses within broader social-ecological dynamics (Barbero-Sierra et al., 2015; Sterk & Stoorvogel, 2020; Bisaro et al., 2013). Together, they form a decision-support framework that links process understanding, spatial planning, and policymaking for conservation, land management, and restoration in degraded landscapes.

However, there are still methodological challenges to address. Occurrence data often shows bias towards easily accessible locations; environmental predictors may be collinear or mismatched across different geographical and temporal scales; and model evaluation often presents an overly optimistic perspective when spatial autocorrelation is ignored. The selection of indicators and the formulation of indices related to desertification vary significantly from one location to another, complicating comparisons and meta-analyses. Furthermore, uncertainty ranges from observations through model structures to outputs, and it is often inadequately communicated. This review aims to fill existing gaps by integrating concepts, data sources, and methods at the HSM-desertification interface while offering practical guidance for effective and policy-relevant applications in arid regions (Burrell et al., 2020; Fumei et al., 2021).

This review examines desertification and land degradation in arid regions as interconnected social-ecological processes that impact habitat quality and availability. It utilizes Habitat Suitability Modeling (HSM) and Species Distribution Modeling (SDM) to identify potential habitat distributions under current and future scenarios, considering climate, land use, soil, topography, vegetation, and remote sensing indicators. Within this framework, we will: (i) standardize key terminology related to desertification, land degradation, drylands, and HSM/SDM to align with both policy and scholarly usage; (ii) establish the conceptual connections through which climate variability, land-use change, and soil/vegetation

dynamics alter habitat structure, availability, and quality for targeted species and ecosystem services; (iii) create a comprehensive integration pathway for incorporating desertification dynamics into HSM/SDM workflows. This includes selecting ecologically meaningful predictor sets, implementing spatial/temporal blocking for calibration and validation, managing uncertainty propagation, and conducting scenario analyses to predict habitat responses to degradation and climate change; (iv) provide actionable, risk-informed outputs such as priority maps for restoration, planning conservation efforts in fragmented dryland landscapes, identifying connectivity and refugia, and offering guidance for monitoring desertification trends using habitat suitability indicators. These efforts aim to support evidence-based conservation, land management, and policy decisions.

1.1. Definitions and Terminology

Desertification and Land Degradation: Desertification as the degradation of land in arid, semi-arid, and dry sub-humid areas caused by multiple interacting factors, including climate variability and human activities (Sterk & Stoorvogel, 2020; Burrell et al., 2020). This definition is consistent with international interpretations that emphasize the interconnectedness of environmental and developmental factors rather than attributing causes to a single source (Barbero-Sierra et al., 2015; Bisaro et al., 2013). Desertification negatively impacts habitat suitability by altering soil properties, changes in vegetation structure and composition, and affecting hydrological systems, these changes can often be captured by Habitat Suitability Models (HSM) and Species Distribution Models (SDM) (Fan et al., 2020; Zotos et al., 2024).

Drylands: Drylands ecosystems characterized by limited water availability, where desertification and land degradation are most prevalent. In these regions, even small changes in climate or management practices can lead to significant impacts on habitat availability and species distributions (Barbero-Sierra et al., 2015; Sterk & Stoorvogel, 2020; Bisaro et al., 2013).

HSM/SDM: Habitat Suitability Models (HSM) and Species Distribution Models (SDM) are approaches used to relate species or ecosystem characteristics to environmental factors to predict the locations of suitable habitats. Common methods include presence-only models (e.g., MaxEnt) and presence-absence or detection frameworks that integrate various factors such as climate, soil, land use, topography, and vegetation conditions. Best practices for these models emphasize the importance of data quality, spatially explicit validation, and scenario-based projections (Burrell et al., 2020; Fumei et al., 2021).

1.2. Conceptual links between desertification processes and habitat suitability

Mechanistic Linkage: Desertification alters both abiotic and biotic conditions that affect habitat suitability. Processes such as soil erosion, carbon loss, salinization, reduced moisture retention, and vegetation decline change the ecological niches and the spatial distribution and quality of habitable areas. This establishes a direct connection between degradation processes and altered habitat suitability (Barbero-Sierra et al., 2015; Bisaro et al., 2013).

Feedback and Resilience: Habitat suitability not only responds to desertification but also plays a role in ecosystem resilience. Intact habitat networks characterized by vegetation cover, ground cover, and soil stability enhance resilience, while degraded habitats weaken ecosystem services and increase vulnerability to further degradation and climate stressors. This highlights the necessity for an integrated approach that combines natural and social sciences (Sterk & Stoorvogel, 2020; Bisaro et al., 2013).

Predictive Utility in Degraded Landscapes: Habitat Suitability Models (HSM) and Species Distribution Models (SDM) serve as structured tools to predict how habitat suitability may change due to desertification and climate change. Typical workflows involve analyzing variables related to climate, soil, land use, and remote-sensing indicators (such as NDVI, land surface temperature, and soil moisture) to create HSMs. These models can then be compared or conditioned based on desertification risk layers. This information aids in restoration prioritization, connectivity planning, and identifying refugia under future scenarios (Burrell et al., 2020; Fumei et al., 2021).

Methodological Anchors: There is a growing shift toward service-based, integrative approaches in desertification research, such as ecosystem-service balance and governance. This aligns with HSM/SDM's focus on environmental drivers and their validation against empirical patterns (Barbero-Sierra et al., 2015; Bisaro et al., 2013). Empirical studies demonstrate that land-use transitions and infrastructure developments (like road networks) influence degradation trajectories and habitat quality. Therefore, it is essential to include these factors in HSM/SDM for producing reliable predictions in degraded areas (Zhang et al., 2023). Incorporating climate change signals into HSM/SDM has become standard practice and is crucial for anticipating habitat shifts driven by desertification (Burrell et al., 2020; Fumei et al., 2021).

2. HABITAT SUITABILITY MODELING (HSM): CONCEPTS AND FAMILIES OF METHODS

Habitat suitability modeling (HSM) and species distribution modeling (SDM) translate environmental covariates into spatially explicit estimates of where habitats or species are likely to occur, under current or future conditions. These models accommodate presence-only data (e.g., MaxEnt) as well as presence-absence data, and they integrate climate, land cover, soil, topography, and vegetation variables to produce predictive habitat or distribution maps used for conservation planning, restoration, and land management in degraded landscapes (Worku et al., 2024; Dameneh et al., 2021).

Major modeling families and their characteristics:

✓ Generalized Linear Models (GLM) and Generalized Additive Models (GAM): Parametric or semi-parametric frameworks that relate occurrence probability to covariates, allowing interpretable relationships and smooth functions in GAMs for nonlinear responses (Worku et al., 2024).

✓ Maximum Entropy (MaxEnt): Presence-only method widely used for ecological niche modeling; robust in small sample contexts and capable of handling diverse environmental layers to produce habitat suitability surfaces (Worku et al., 2024).

✓ Boosted Regression Trees (BRT) and Random Forests (RF): Ensemble machine-learning approaches that handle nonlinearities and interactions among predictors; they often yield higher predictive accuracy in complex dryland systems and can accommodate high-dimensional covariate spaces (Dameneh et al., 2021).

✓ Ecological Niche Factor Analysis (ENFA): A presence-only method that characterizes species' ecological niches relative to the available environmental space, useful for exploration habitat analyses in data-poor settings (Worku et al., 2024).

✓ Ensemble approaches: Combine multiple models (e.g., MaxEnt, RF, GAM/GLM) to improve predictive performance and account for model-to-model uncertainty, a practice increasingly recommended in desertification-related habitat assessments (Dameneh et al., 2021).

Practical considerations in HSM/SDM for degraded drylands:

✓ Predictor selection: Ecologically meaningful predictors include climate (temperature, precipitation), soil properties, vegetation indices, land use/land cover, topography, and moisture proxies, chosen for ecological relevance to target habitats and for reducing collinearity to avoid model overfitting (Worku et al., 2024).

✓ Data quality and bias: Presence-only methods require careful background sampling and bias correction to avoid spatial sampling bias; presence-absence methods rely on robust survey data or well-designed pseudo-absence strategies (Worku et al., 2024).

✓ Validation and uncertainty: Model validation (e.g., cross-validation, AUC, TSS) and reporting of uncertainty (prediction intervals, ensemble consensus) are essential for credible habitat projections, especially under climate and desertification scenarios (Dameneh et al., 2021).

✓ Scenario analysis: Incorporating future climate, land-use change, and degradation trajectories enables exploration of habitat resilience, refugia, and restoration prioritization under DLDD (desertification, land degradation, and drought) contexts (Worku et al., 2024).

Relevance to desertification and drylands: HSM/SDM offer a structured, quantitative pathway to translate desertification drivers (climate variability, anthropogenic pressure, soil and vegetation dynamics) into spatially explicit habitat outcomes, supporting management decisions around restoration prioritization, habitat connectivity, and monitoring signals of degradation or recovery using habitat-suitability indicators (Liao et al., 2024; Dameneh et al., 2021).

2.1. Desertification: drivers, processes, and spatial–temporal patterns

Concept and framing: Desertification is land degradation in arid, semiarid, and dry sub-humid areas arising from interacting climatic and human drivers, with consequences for habitat quality and ecosystem-service provisioning. This integrated view aligns with UNCCD and the broader DLDD literature, emphasizing environmental–development linkages over single-cause narratives (Gichenje & Godinho, 2018).

Drivers and interactions: Proximate and underlying drivers include climate variability (drought, heat extremes), land-use change (overgrazing, cultivation expansion, infrastructure), soil degradation (erosion, salinization, nutrient loss), and

hydrological disturbance. These processes reduce soil moisture, vegetation cover, and biodiversity, thereby constraining habitat suitability for biotic communities and ecosystem services (Gichenje & Godinho, 2018; Xu et al., 2009).

Spatial and temporal patterns: Desertification exhibits strong heterogeneity linked to soils, rainfall regimes, topography, and land-use intensity. Temporal dynamics range from gradual productivity declines to abrupt shifts following droughts or land-use shocks, underscoring the value of time-series remote-sensing indicators for tracking DLDD trajectories and informing HSM/SDM inputs and validation (Huang & Siegert, 2006; Xu et al., 2016).

Policy and governance context: Treating desertification as an integrated DLDD issue foregrounds governance, sustainable land management, and ecosystem-service trade-offs. Stakeholder-driven prioritization and multi-indicator assessments help align science outputs (e.g., HSM maps) with decision-making in restoration and resilience building (Gichenje & Godinho, 2018).

2.2. Biophysical indicators and proxies (NDVI/EVI, LST, soil moisture, albedo, LULC, aridity)

Vegetation health and productivity: NDVI and EVI are foundational proxies for cover, greenness, and productivity trends in drylands. They capture vegetation responses to degradation, climate forcing, and management, and frequently serve as HSM/SDM predictors and as validation/monitoring signals (Huang & Siegert, 2006; Vorovencii, 2015).

Surface temperature and moisture: Land Surface Temperature (LST) and soil-moisture products (in situ and satellite) reflect aridity stress, evapotranspiration regimes, and hydrological status key controls on suitability for many taxa and restoration prospects. LST commonly interacts with vegetation indices in desertification studies and is a critical covariate in dryland HSM (Liao et al., 2024; Vorovencii, 2015).

Albedo and spectral indices: Surface albedo and related spectral metrics convey information about soil brightness, vegetation structure, and land-cover transitions. In combination with NDVI/EVI, these indices improve discrimination of degraded vs. non-degraded surfaces and can sharpen DLDD assessments used as HSM predictors or comparison layers (Vorovencii, 2015).

Land use/land cover and aridity: LULC products capture anthropogenic intensification, fragmentation, and habitat loss; aridity indices quantify long-term dryness. Integrating LULC and aridity with biophysical proxies strengthens ecological realism and supports cross-scale interpretation of degradation processes in HSM/SDM (Dameneh et al., 2021; Vorovencii, 2015).

Proxy integration for modeling: Given the interlinked nature of DLDD drivers and habitat dynamics, multi-indicator predictor sets, combining NDVI/EVI, LST, soil moisture, albedo, LULC, and aridity, enable robust HSM/SDM performance, facilitate scenario testing under DLDD trajectories, and support targeted restoration planning in drylands (Dameneh et al., 2021; Vorovencii, 2015).

Scale considerations: Align the spatial grain of indicators with organismal perception (home range, movement) via ecologically justified aggregation/downscaling; synchronize temporal windows with phenology and lagged effects (e.g., prior-season moisture); and set the model extent to reflect dispersal and biogeographic limits.

Integration pathways: Indicators connect to HSM/SDM through three complementary pathways: conditioning (include indicators as predictors), comparison (overlay suitability with independent risk surfaces to map concordance/discordance), and coupling (iterate or jointly model dynamic DLDD processes with habitat responses for scenario analysis). Each pathway should include explicit uncertainty accounting and sensitivity analysis.

2.3. Synthesis

This background establishes a coherent bridge between HSM/SDM methodologies, desertification processes, and the biophysical indicators that diagnose degradation in drylands. Three propositions follow. First, desertification reshapes the same abiotic and biotic gradients that HSM/SDM exploit (climate, soils, moisture, vegetation structure), so suitability surfaces can serve as sensitive readouts of degradation impacts on habitat quality, fragmentation, and connectivity. Second, remote-sensing indicators (e.g., NDVI/EVI, LST, soil moisture), aridity metrics, and LULC products provide scalable, policy-relevant evidence streams that can enter HSM/SDM either as predictors (conditioning), as independent comparators (concordance/discordance mapping with risk layers), or within coupled dynamic frameworks for scenario analysis. Third, ecological realism and decision value hinge on scale alignment (spatial grain, temporal cadence, model extent) and transparent uncertainty accounting across data, algorithm, and scenario choices.

Practically, robust HSM–desertification integration rests on five pillars: (i) ecologically justified predictor sets that minimize collinearity while capturing key degradation pathways; (ii) bias-aware occurrence design (target-group backgrounds, thinning, pseudo-absence strategy); (iii) spatially explicit validation (blocked cross-validation, calibration

diagnostics) to avoid over-optimism; (iv) uncertainty propagation via resampling and ensembles, reported alongside point estimates; and (v) scenario workflows that blend climate and land-use/degradation trajectories to test resilience, refugia, and restoration options.

For policy and practice, the synthesis implies a decision pathway: map suitability → compare/condition with degradation indicators → identify high-suitability × high-risk intersections for protection and management, low-suitability × high-restoration-potential areas for intervention, and connectivity corridors resilient to projected aridification. Deliverables include priority maps, risk-informed action portfolios, and monitoring dashboards that track both desertification indicators and habitat-suitability signals.

This integrated view also clarifies research gaps: uneven indicator standards across regions, limited transferability testing across taxa/scales, and inconsistent reporting of uncertainty and reproducibility. Addressing these gaps requires community checklists, benchmark datasets, and shared code/data to standardize HSM–desertification studies.

3. DATA FOUNDATIONS

3.1 Species occurrence data (presence-only, presence–absence, detection/non-detection)

Data typologies and definitions: HSM relies on:

- Presence-only data: records indicating where the target habitat or species has been observed, without confirmed absences (e.g., museum records, citizen science, field surveys). Presence-only methods like MaxEnt are commonly applied in data-poor contexts where absence data are unavailable or unreliable (Worku et al., 2024).

- Presence–absence data: verified detections of presence and non-presence across surveyed sites, enabling conventional regression-based or machine-learning SDMs that leverage both classes for discrimination and calibration (Worku et al., 2024).

- Detection/non-detection data: repeated surveys at a site to distinguish true absence from non-detection, enabling occupancy modeling and explicit accounting for detection probability in inference about habitat occupancy and suitability (Worku et al., 2024).

- Implications for model choice and interpretation: The data type informs model selection (e.g., presence-only vs. presence–absence frameworks) and affects bias control, validation strategies, and uncertainty characterization. Presence-only approaches require careful background sampling and bias correction to avoid geographic sampling bias, whereas presence–absence and detection/non-detection data enable more explicit estimation of true occupancy or habitat use probabilities (Worku et al., 2024).

- Links to desertification context: In degraded drylands where field survey effort may be uneven due to accessibility or resource constraints, presence-only data are common, necessitating robust bias correction and careful interpretation of habitat-suitability outputs in light of sampling effort and detection likelihood (Liao et al., 2024; Dameneh et al., 2021).

3.2 Environmental covariates (climate, soil, topography, land use)

Core covariate classes:

Climate variables: baseline and scenario-based temperature and precipitation (and derived indices such as aridity) that capture moisture and energy regimes controlling habitat viability under DLDD trajectories (Liao et al., 2024; Dameneh et al., 2021).

Soil properties: texture, organic carbon, salinity, depth, and nutrient indicators that influence soil moisture retention, root-zone conditions, and vegetation structure essential to habitat suitability in desertified landscapes (Liao et al., 2024; Dameneh et al., 2021).

Topography: elevation, slope, aspect, and related derivatives that shape microclimates, water catchment, and erosion risk, influencing habitat heterogeneity and connectivity (Dameneh et al., 2021).

Land use/land cover (LULC): current and historical land use classes, fragmentation metrics, and vegetation structure that reflect degradation state, resilience, and potential restoration opportunities (Dameneh et al., 2021).

Rationale for covariate selection in DLDD contexts: Desertification processes alter soil moisture regimes, vegetation cover, and landscape configuration. Ecologically meaningful covariates capture drivers of degradation and recovery (e.g.,

rainfall variability, soil salinization, grazing pressure, urbanization) and enable scenario-based projections of habitat changes under DLDD futures (Liao et al., 2024; Dameneh et al., 2021).

Data considerations: Covariates should be ecologically interpretable for the target taxa or ecosystem services, sufficiently spatially aligned with occurrence data, and free from excessive collinearity to support stable model inference. Where possible, temporally matched covariates (e.g., concurrent climate and LULC snapshots) improve the realism of dynamic habitat projections in degraded drylands Dameneh et al., 2021; Vorovencii, 2015).

3.3 Remote sensing data sources and resolutions

Sensor families and data streams:

Optical sensors: Landsat, Sentinel-2, and MODIS provide vegetation indices (e.g., NDVI, EVI), land cover, and surface reflectance data at moderate to high spatial resolutions and varying revisit times, enabling tracking of vegetation dynamics, habitat vegetation structure, and land-cover change relevant to desertification monitoring Dameneh et al., 2021; Vorovencii, 2015).

Thermal and moisture-sensitive sensors: Landsat and MODIS LST products, along with soil moisture proxies, inform aridity and water stress conditions that constrain habitat suitability in drylands (Liao et al., 2024; Vorovencii, 2015).
Radar sensors: Radar data contribute to soil moisture estimation and surface roughness, resilient to atmospheric conditions, and useful for detecting vegetation structural changes and surface moisture patterns in desertified areas Dameneh et al., 2021; Vorovencii, 2015).

Temporal granularity and spatial resolution:

Temporal: High-temporal-resolution imagery supports monitoring DLDD trajectories, seasonality of vegetation, and short-term responses to droughts or management actions; longer-term archives enable trend detection and change-point analyses essential for model validation under DLDD scenarios Dameneh et al., 2021; , Vorovencii, 2015).

Integration into HSM: Remote-sensing data serve as primary covariates (e.g., NDVI/EVI, LST, albedo, land-cover change) and as monitoring signals for model validation and scenario analysis, enabling repeated sampling of habitat conditions and facilitating updates of suitability maps as desertification progresses or reverses under restoration (Liao et al., 2024; , Dameneh et al., 2021; , Vorovencii, 2015).

3.4 Data quality issues: sampling bias, class imbalance, positional error

Sampling bias and background selection (presence-only data): In presence-only SDMs, geographic sampling bias arises when occurrence records cluster in accessible or studied areas, biasing habitat inferences. Corrective strategies include bias files, target-group background sampling, spatial thinning, or using presence–absence data where feasible to mitigate bias and improve model transferability to degraded landscapes (Dameneh et al., 2021).

- Class imbalance (presence–absence data): When presence data are rare relative to absences, models can become biased toward predicting the majority class. Techniques such as upsampling of the minority class, penalized loss functions, or cost-sensitive modeling can help balance predictions and preserve sensitivity to degraded habitat signals Dameneh et al., 2021).

- Positional error: Inaccuracies in occurrence records can blur associations between occurrences and covariates, especially at fine scales typical of desertified microhabitats. Spatial uncertainty should be quantified and incorporated into modeling via error models, probabilistic occurrence representations, or by aggregating data to match the effective resolution of covariates Dameneh et al., 2021).

- Data quality and harmonization across DLDD contexts: Desertification studies often integrate heterogeneous data sources across time and space. Ensuring consistent projection, scale, and thematic resolution is essential to avoid spurious inferences about habitat changes and to enable robust cross-regional comparisons under DLDD scenarios (Liao et al., 2024; , Vorovencii, 2015).

- Validation, uncertainty, and communication: Transparent reporting of model validation metrics (AUC, TSS, kappa), ensemble agreement, and prediction uncertainty is critical for informing restoration prioritization and policy decisions in degraded drylands. Uncertainty analyses help contextualize habitat-change projections under climate and degradation trajectories Dameneh et al., 2021; Vorovencii, 2015).

Synthesis for the Data Foundations section

The Data Foundations framework integrates (i) occurrence data types aligned with appropriate modeling approaches, (ii) ecologically informed environmental covariates capturing climate, soil, topography, and land-use drivers of desertification and habitat change, (iii) multi-source remote-sensing data with attention to spatial and temporal resolution to monitor and project habitat dynamics, and (iv) rigorous treatment of data quality issues (sampling bias, class imbalance, positional error) to ensure credible HSM outcomes in DLDD contexts (Liao et al., 2024; , Dameneh et al., 2021; , Vorovencii, 2015).

4. MODELING APPROACHES AND EVALUATION

The synthesis integrates guidance from contemporary species distribution modeling (SDM)/HSM methodology and pertinent discussions on model validation under spatial dependence, desertification trajectories, and climate-impacted scenarios, drawing on multiple sources to ground each claim with evidence (Hao et al., 2020; , (Ploton et al., 2020; , Mushagalusa et al., 2024; , Valavi et al., 2023), Valavi et al., 2018).

4.1. Model specification and feature engineering

Model specification: HSM/SDM can be implemented with a spectrum of modeling frameworks, spanning traditional parametric forms (generalized linear models GLM, generalized additive models GAM) to nonparametric and machine-learning approaches (maximum entropy MaxEnt, boosted regression trees BRT, random forests RF, ecological niche factor analysis ENFA) and ensemble frameworks that combine multiple models to improve predictive robustness and account for model uncertainty (Hao et al., 2020; , Valavi et al., 2023), Valavi et al., 2018). The choice depends on data type (presence-only vs. presence–absence vs. detection/non-detection), sample size, and the ecological questions at hand. Ensemble strategies are increasingly recommended in degraded landscapes to mitigate individual model biases and capture diverse ecological responses Valavi et al., 2023), Valavi et al., 2018).

Feature engineering and predictors: Ecologically meaningful covariates include climate and aridity metrics, soil properties, topography, land use/land cover, vegetation indices, and other biophysical signals that mechanistically relate to habitat suitability in drylands. Feature engineering may involve nonlinear transformations, interaction terms, and scale harmonization to align predictors with the ecological processes driving habitat provision under desertification and land degradation (DLDD) conditions (Hao et al., 2020; , Valavi et al., 2023). Regularization and variable selection are important to manage collinearity and overfitting, particularly in high-dimensional predictor spaces typical of dryland analyses Valavi et al., 2023), Valavi et al., 2018).

Handling presence-only versus presence–absence data: Presence-only models (e.g., MaxEnt) are common when absence data are unreliable or unavailable, requiring careful background sampling and bias correction to reduce sampling bias and overestimation of suitability (Hao et al., 2020; , Valavi et al., 2023). Presence–absence and detection/non-detection data permit occupancy-style modeling and explicit estimation of detection probability, influencing model interpretation and inference about habitat occupancy Valavi et al., 2023), Valavi et al., 2018).

5.2 Cross-validation strategies

Rationale for CV design: Standard k-fold CV can yield optimistic estimates when data exhibit spatial and/or temporal autocorrelation typical of DLDD contexts. Therefore, spatially aware and temporally aware cross-validation schemes are recommended to assess predictive performance in realistic deployment scenarios, including transfer to new locations or time periods (Ploton et al., 2020; , Mushagalusa et al., 2024; , Valavi et al., 2018).

Spatially structured CV: Blocked or spatially stratified CV partitions data into spatial blocks to minimize leakage between training and test sets due to spatial autocorrelation. Blocked CV-type approaches can reveal model generalization to unsampled areas and reduce overestimation of predictive performance in spatially structured landscapes (Ploton et al., 2020; , Mushagalusa et al., 2024; , Valavi et al., 2018). The architecture of blocks (e.g., checkerboard, irregular tiling) should reflect landscape heterogeneity and sampling design Mushagalusa et al., 2024; , Valavi et al., 2018).

Temporal CV: Temporal cross-validation partitions data by time to evaluate how well models generalize across temporal contexts, which is crucial when modeling habitat dynamics under climate change and desertification trajectories. Temporal CV helps assess robustness to interannual variability and trend shifts in DLDD scenarios Mushagalusa et al., 2024; , Valavi et al., 2023).

Practical recommendations: When using ensemble or machine-learning SDMs, consider adopting blocked spatial CV to test extrapolative transfer to new spatial contexts, and incorporate temporal CV when suitable to simulate future climate/degradation regimes. Tools such as dedicated CV frameworks (e.g., blockCV) facilitate the implementation of spatially or environmentally separated folds (Ploton et al., 2020; , Valavi et al., 2018).

5.3 Performance metrics (AUC, TSS, Boyce, calibration plots)

Discrimination metrics:

✓ AUC (Area Under the Receiver Operating Characteristic) is widely used to summarize the ability to distinguish presence from background/pseudo-absence but can be sensitive to prevalence and spatial structure Valavi et al., 2023), Valavi et al., 2018).

✓ True Skill Statistic (TSS) balances sensitivity and specificity and is commonly reported for presence–absence predictions, providing a threshold-dependent measure of performance that is interpretable for management decisions Valavi et al., 2023), Valavi et al., 2018).

Presence-only specific metrics:

✓ Boyce index and related calibration-oriented metrics assess how much model-predicted suitability aligns with observed presences, offering a threshold-free assessment useful for presence-only contexts (Ploton et al., 2020; Mushagalusa et al., 2024).

Calibration and reliability:

✓ Calibration plots and reliability diagrams examine how well predicted probabilities match observed frequencies, informing model trustworthiness for decision-making under DLDD futures (Hao et al., 2020; , Valavi et al., 2023).

Supplementary evaluation:

✓ Brier scores, precision-recall metrics, and continuous rank probability scores may be informative in imbalanced or presence-only settings, complementing AUC/TSS/Boyce to provide a fuller picture of predictive performance Valavi et al., 2023), Valavi et al., 2018).

5.4 Uncertainty quantification and propagation (bootstraps, ensembles, scenario envelopes)

Uncertainty sources: Model selection, predictor uncertainty, sampling variability, and future scenario assumptions all contribute to predictive uncertainty in HSM/SDM outputs, especially under changing DLDD conditions (Hao et al., 2020; Valavi et al., 2023).

- Resampling and bootstrapping: Bootstrapped ensembles and resampling approaches quantify parameter uncertainty and enable estimation of prediction intervals, enhancing interpretability of habitat-suitability maps under uncertainty Valavi et al., 2023), Valavi et al., 2018).

- Ensembles and model averaging: Multi-model ensembles (e.g., averaging GLM, GAM, MaxEnt, BRT, RF) or stacked ensembling reduce individual-model biases and yield more reliable projections across environmental gradients and degradation scenarios (Hao et al., 2020; , Valavi et al., 2023).

- Scenario envelopes: Building envelopes of predictions across climate and degradation scenarios (e.g., RCP/Shared Socioeconomic Pathways and DLDD trajectories) provides a transparent depiction of potential habitat futures, facilitating risk-informed decision-making for restoration and management (Hao et al., 2020; , Valavi et al., 2023).

5.5 Transferability and extrapolation in changing environments

- Transferability challenges: Habitat models trained in one region or time may underperform when projected to novel environmental spaces or future climates due to non-stationarity, novel combinations of covariates, or unrepresented target conditions, a concern highlighted in recent validation work on SDMs in changing environments (Ploton et al., 2020; , Mushagalusa et al., 2024; , Valavi et al., 2023).

- Testing extrapolation and non-stationarity: Employ spatially explicit cross-validation, environmental novelty assessment, and multi-scenario testing to evaluate how models perform under novel conditions and to identify regions where extrapolation exceeds credible bounds (Ploton et al., 2020; , Mushagalusa et al., 2024; , Valavi et al., 2023).

- Practical guidance: Prioritize collecting representative data across the full spectrum of expected environmental states (including degraded and recovering landscapes) to enhance transferability, and use ensemble- and scenario-based

projections to bound uncertainties associated with extrapolation into future DLDD regimes (Hao et al., 2020; , Valavi et al., 2023).

Modeling approaches for habitat suitability in desertified drylands should integrate a spectrum of specification choices (GLM, GAM, MaxEnt, BRT, RF, ENFA) with ensemble strategies to capture diverse ecological responses and mitigate single-model biases (Hao et al., 2020; Valavi et al., 2023), Valavi et al., 2018). Cross-validation should be deliberately spatially and temporally structured to reflect the dependencies and non-stationarity inherent in desertification dynamics, with tools like BlockCV facilitating rigorous evaluation (Ploton et al., 2020; Mushagalusa et al., 2024; Valavi et al., 2018). Performance should be assessed using a set of complementary metrics (AUC, TSS, Boyce, calibration plots) to capture discrimination, error balance, and reliability, while explicitly reporting uncertainty through bootstrapping and ensemble-consensus intervals (Hao et al., 2020; Valavi et al., 2023). Finally, attention to transferability and extrapolation is essential in the face of changing environments, necessitating multi-scenario analyses, explicit reporting of novelty in covariate space, and validation across spatially diverse contexts to support robust, policy-relevant inferences for restoration and land-management planning (Ploton et al., 2020; Valavi et al., 2023).

6. CONCLUSIONS

This review synthesizes the integration of habitat suitability modeling (HSM), a member of the broader species distribution model (SDM) family, with assessments of desertification and land degradation to generate actionable insights for dryland ecosystems. Desertification alters essential abiotic and biotic gradients such as water balance, thermal stress, soil properties, and vegetation structure upon which HSM relies. In turn, HSM provides spatially explicit evaluations of how these environmental changes influence habitat quality, fragmentation, and connectivity. Framing the issue in this way elevates HSM from a purely predictive tool to a mechanism that bridges process understanding and policy development.

Three complementary integration pathways have emerged. The first involves conditioning, which incorporates degradation indicators (e.g., NDVI/EVI trends, land surface temperature, soil moisture, aridity, and land use/land cover) as predictors within HSMs. The second juxtaposes independently generated suitability maps with desertification risk layers to elucidate patterns of concordance or discordance. The third associates dynamic degradation models with HSMs for scenario-based analyses. Across all approaches, proper alignment of spatial and temporal scales, as well as rigorous uncertainty management, is imperative.

Methodologically robust studies are underpinned by five foundational pillars: (i) the use of ecologically justified predictor sets exhibiting minimal collinearity; (ii) occurrence data design that systematically addresses sampling bias (e.g., through target-group backgrounds, spatial thinning, and principled pseudo-absence selection); (iii) spatial and temporal blocking for model validation using both discrimination and calibration metrics; (iv) explicit propagation of uncertainty via resampling and ensemble modeling, with uncertainty estimates reported alongside point predictions; and (v) scenario-based workflows that integrate climatic and land-use/degradation trajectories to assess resilience, refugia, and restoration potential. Adoption of a concise reporting checklist can substantially enhance reproducibility and comparability across studies and taxa.

The applied utility of these approaches is direct and substantial. Risk-informed overlays of habitat suitability and degradation delineate zones of high suitability and high risk that warrant immediate protection or management, as well as low-suitability but high-restoration-potential areas suitable for intervention. They also identify connectivity corridors likely to remain resilient under anticipated aridification. Such outputs support evidence-based conservation planning, targeted land management, and the development of monitoring dashboards that track desertification indicators alongside habitat suitability metrics.

Nonetheless, significant limitations persist. Indicator selection criteria and data quality vary regionally; transferability across spatial scales and taxa remains inconsistent; and uncertainty is often insufficiently documented. Additionally, social-ecological feedback and governance constraints may shape ecological responses in ways that extend beyond biophysical predictors. Addressing these gaps requires the development of benchmark datasets, the sharing of collaborative code and metadata, and the strengthening of linkages between ecological models, local knowledge systems, management objectives, and policy instruments.

Looking ahead, the integration of process-based and correlative models, the harnessing of near-real-time remote-sensing data, and the deployment of cloud-native, open-access workflows have the potential to enhance both the timeliness and robustness of analyses. Further, embedding HSM within restoration ecology, connectivity science, and ecosystem service assessments will strengthen the connection between biodiversity outcomes and human well-being in arid environments.

In summary, the integration of rigorous HSM methodologies with desertification research establishes a cohesive and scalable framework for understanding and managing habitat dynamics in arid landscapes. This synthesis has the capacity

to accelerate evidence-based conservation, restoration, and sustainable land management, particularly by addressing scale, uncertainty, and decision-making needs in the context of rapid environmental change.

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REFERENCES

Barbero-Sierra, C., Marqués, M., Ruiz-Pérez, M., Escadafal, R., & Exbrayat, W. (2015). How is desertification research addressed in spain? land versus soil approaches. Land Degradation and Development, 26(5), 423-432. https://doi.org/10.1002/ldr.2344

Bisaro, A., Kirk, M., Zdruli, P., & Zimmermann, W. (2013). Global drivers setting desertification research priorities: insights from a stakeholder consultation forum. Land Degradation and Development, 25(1), 5-16. https://doi.org/10.1002/ldr.2220

Burrell, A., Evans, J., & Kauwe, M. (2020). Anthropogenic climate change has driven over 5 million km2 of drylands towards desertification. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-17710-7

Dameneh, H., Gholami, H., Telfer, M., Rodrigo-Comino, J., Collins, A., & Jansen, J. (2021). Desertification of iran in the early twenty-first century: assessment using climate and vegetation indices. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-99636-8

Fan, M., Li, J., Tang, Z., & Shangguan, Z. (2020). Soil bacterial community succession during desertification in a desert steppe ecosystem. Land Degradation and Development, 31(13), 1662-1674. https://doi.org/10.1002/ldr.3545

Fumei, X., Liu, J., Chen, C., Wang, Y., & Jia, L. (2021). Evaluating the influence of climate change on sophora moorcroftiana (benth.) baker habitat distribution on the tibetan plateau using maximum entropy model. Forests, 12(9), 1230. https://doi.org/10.3390/f12091230

Gichenje, H. and Godinho, S. (2018). Establishing a land degradation neutrality national baseline through trend analysis of gimms ndvi time-series. Land Degradation and Development, 29(9), 2985-2997. https://doi.org/10.1002/ldr.3067

Hao, T., Elith, J., Lahoz-Monfort, J., & Guillera-Arroita, G. (2020). Testing whether ensemble modelling is advantageous for maximising predictive performance of species distribution models. Ecography, 43(4), 549-558. https://doi.org/10.1111/ecog.04890

Harhash, K., El-Henawy, M., Farouk, H., & Antar, M. (2015). Conservation oriented habitat classification scheming and mapping of egypt. Environmental Systems Research, 4(1). https://doi.org/10.1186/s40068-015-0034-1

Huang, S. and Siegert, F. (2006). Land cover classification optimized to detect areas at risk of desertification in north china based on spot vegetation imagery. Journal of Arid Environments, 67(2), 308-327. https://doi.org/10.1016/j.jaridenv.2006.02.016

Liao, J., Yang, X., Ye, Q., Wan, K., Sheng, J., Zhang, S., … & Song, X. (2024). Assessing spatial–temporal characteristics of land desertification from 1990 to 2020 in the heihe river basin using landsat series imagery. Sustainability, 16(15), 6556. https://doi.org/10.3390/su16156556

Mushagalusa, C., Fandohan, A., & Kakaï, R. (2024). Random forest and spatial cross-validation performance in predicting species abundance distributions. Environmental Systems Research, 13(1). https://doi.org/10.1186/s40068-024-00352-9

Ploton, P., Mortier, F., Réjou-Méchain, M., Barbier, N., Picard, N., Rossi, V., … & Pélissier, R. (2020). Spatial validation reveals poor predictive performance of large-scale ecological mapping models. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-18321-y

Qiao, F., Du, H., Xia, Z., Feng, C., Tan, Z., Yu, Y., … & Liu, Z. (2024). The protection and management of wapiti in desert oases: bare land poses a limitation to wapiti conservation. Biology, 13(9), 737. https://doi.org/10.3390/biology13090737

Sterk, G. and Stoorvogel, J. (2020). Desertification–scientific versus political realities. Land, 9(5), 156. https://doi.org/10.3390/land9050156

Valavi, R., Elith, J., Lahoz-Monfort, J., & Guillera-Arroita, G. (2018). blockcv: an r package for generating spatially or environmentally separated folds for k-fold cross-validation of species distribution models. Methods in Ecology and Evolution, 10(2), 225-232. https://doi.org/10.1111/2041-210x.13107

Valavi, R., Elith, J., Lahoz-Monfort, J., & Guillera-Arroita, G. (2023). Flexible species distribution modelling methods perform well on spatially separated testing data. Global Ecology and Biogeography, 32(3), 369-383. https://doi.org/10.1111/geb.13639

Vorovencii, I. (2015). Assessing and monitoring the risk of desertification in dobrogea, romania, using landsat data and decision tree classifier. Environmental Monitoring and Assessment, 187(4). https://doi.org/10.1007/s10661-015-4428-3

Worku, E., Evangelista, P., Atickem, A., Bekele, A., Bro-Jørgensen, J., & Stenseth, N. (2024). Modeling habitat suitability for the lesser-known populations of endangered mountain nyala (tragelaphus buxtoni) in the arsi and ahmar mountains, ethiopia. Ecology and Evolution, 14(4). https://doi.org/10.1002/ece3.11235

Xu, D., Song, A., He-feng, T., Ren, H., Zhuang, D., & Shao, Q. (2016). A spatial system dynamic model for regional desertification simulation – a case study of ordos, china. Environmental Modelling & Software, 83, 179-192. https://doi.org/10.1016/j.envsoft.2016.05.017

Xu, D., Xiangwu, K., Qiu, D., Zhuang, D., & Pan, J. (2009). Quantitative assessment of desertification using landsat data on a regional scale – a case study in the ordos plateau, china. Sensors, 9(3), 1738-1753. https://doi.org/10.3390/s90301738

Zhang, S., Yan, W., Li, C., Wu, Y., Yin, Y., & Zhang, C. (2023). The response of rocky desertification to the development of road networks in karst ecologically fragile areas. International Journal of Environmental Research and Public Health, 20(4), 3130. https://doi.org/10.3390/ijerph20043130

Zotos, A., Kokkoris, I., Charalampopoulos, I., Bekri, E., & Dimopoulos, P. (2024). Wetlands in crisis: the silent desertification threat on the greek wetlands. Land, 13(10), 1567. https://doi.org/10.3390/land13101567

Relationships Between GLCM-Derived Texture Metrics and Plant Species Diversity

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Abstract: Texture metrics derived from the Gray Level Co-occurrence Matrix (GLCM) have emerged as powerful proxies for capturing environmental heterogeneity and structural complexity in ecological systems. Unlike conventional topographic or climatic predictors, these texture features act as hidden environmental factors, quantifying spatial patterns such as contrast, dissimilarity, and entropy. Their capacity to represent microhabitat variability, boundary sharpness, and landscape irregularity makes them particularly valuable for biodiversity modeling. Beyond ecology, GLCM metrics are widely applied in remote sensing, land-use planning, precision agriculture, and even medical imaging, underscoring their interdisciplinary relevance. In this study, we evaluated the relationship between GLCM-derived texture variables and three commonly used plant diversity indices: species richness, Shannon diversity, and Simpson diversity. Our findings demonstrate that contrast and dissimilarity metrics are highly intercorrelated, essentially encoding similar structural information, while entropy provides an orthogonal dimension by capturing randomness and disorder in the spatial configuration. This distinction highlights the importance of variable selection in diversity modeling, as redundancy among texture measures can inflate model complexity without improving explanatory power. Entropy, in particular, offers a unique perspective by revealing associations with plant diversity indices that differ from those explained by contrast or dissimilarity. Overall, integrating GLCM-based texture metrics into spatial models of biodiversity enables a more nuanced understanding of how structural heterogeneity influences ecological patterns. This approach advances the development of robust, data-driven tools for ecosystem management, conservation planning, and risk assessment under scenarios of global change.

Keywords: Biodiversity, contrast, dissimilarity, entropy, GLCM texture analysis, remote sensing

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1. INTRODUCTION

Quantifying biodiversity patterns across heterogeneous landscapes remains a central challenge in ecology. Traditional predictors such as climate and topography have proven effective in explaining large-scale variation, yet they often fail to capture fine-grained structural heterogeneity that directly shapes species distributions and community assembly processes. To overcome this limitation, remote sensing techniques and image-derived indices have been increasingly adopted to provide additional explanatory power in ecological modeling (Turner et., 2003; Gillespie et al., 2008; Rocchini et al., 2015).

Among these approaches, texture metrics derived from the Gray Level Co-occurrence Matrix (GLCM) have emerged as powerful tools for characterizing spatial structure (Özkan et al., 2023). GLCM-based features—such as contrast, dissimilarity, and entropy—quantify pixel-to-pixel relationships in raster data and thereby capture hidden environmental factors not directly measurable through conventional variables (Haralick et al., 1973). These metrics are widely applied in disciplines ranging from land-use analysis and precision agriculture to medical imaging and material science (Early and Long, 2002; Castelluccio et al., 2015; Castelluccio et al., 2017; Özkan et al., 2023). In ecology, they provide a novel means of quantifying habitat complexity, landscape heterogeneity, and microhabitat variability, all of which are strongly linked to biodiversity (Rocchini et al., 2010; He et al., 2015).

Despite their potential, the application of GLCM-derived texture features to plant diversity modeling has been limited. Previous studies have demonstrated that spectral and structural heterogeneity are often correlated with species richness and functional composition (Oldeland et al., 2010) yet the redundancy among texture variables (e.g., contrast and dissimilarity) and their distinct contributions (e.g., entropy as a proxy for spatial randomness) remain underexplored. Addressing this gap is crucial for improving the accuracy and interpretability of biodiversity models.

In this study, we investigate the relationship between GLCM-based texture features and three widely used diversity indices: species richness, Shannon diversity, and Simpson diversity. By examining contrast, dissimilarity, and entropy across different neighborhood configurations, we aim to (i) identify representative texture variables through dimensionality reduction, and (ii) evaluate their associations with plant diversity indices. This integrative approach

highlights the role of structural heterogeneity in shaping biodiversity and underscores the potential of texture metrics as complementary predictors in ecological modeling.

2. MATERIAL AND METHOD

2.1. Study area

Araştırma alanı olarak seçilen Türkmen Dağı yöresi Ege Bölgesi'nin İç Batı Anadolu Bölümü sınırındaki İran-Turan flora bölgesinde yer amaktadır (Zohary, 1973). Türkmen Dağı (1826 m), İç Anadolu Bölgesi'nin etrafında yer alan dağlardan birisidir. Eskişehir ve Kütahya İlleri arasında 39°16' – 39°38' kuzey enlemleri ile 30°06' – 30°36' doğu boylamları arasında bozkıra geçiş bölgesinde bulunmaktadır. Üç flora bölgesinin (İran-Turan, Akdeniz ve Avrupa-Sibirya) kesişim alanına oldukça yakın bir konumdadır. Birbirinden farklı ekolojik istekleri olan orman vejetasyonuna sahiptir.

2.2. Data collection

Bu çalışma kapsamında, 20 x 20 m boyutlarında ki örnek alanlarda, ağaç ve çalı türleri tespit edilerek ilgili türlerin kaplama alan değerleri ölçülmüştür. (Fontaine vd., 2007). Orman vejetasyonu bitki toplumlarının belirlenmesinde ve tür çeşitliliğinin hesaplanmasında kullanılmak üzere Braun-Blanquet yöntemi ve skalası kullanılmıştır (Braun-Blanquet 1932). Bu bağlamda, toplamda 244 örnek alanda tespitler yapılmış ve her bir örnek alanda yer alan bitki türlerine ait boluk-örtüş değerleri ile yetişme ortamı özellikleri (yükselti, bakı, eğim ve yamaç konumu) arazi karnelerine kaydedilmiştir. Örnekleme yapılan çalışma alanının yükseltisi 790-1825 metre arasında değişmektedir. Ayrıca örnek alanların koordinatları GPS ile kaydedilmiştir.

2.3. Diversity indices

Plant diversity was quantified using three complementary indices that capture different aspects of community structure: species richness, Shannon diversity, and Simpson diversity.

Species richness (S) represents the simplest measure, defined as the total number of species observed within a sampling unit. Although richness provides a fundamental descriptor of diversity, it does not incorporate relative abundance.

Shannon diversity index (H') accounts for both species richness and evenness of abundances (Shannon, 1948):

$$H' = -\sum_{i=1}^{S} p_i \, lnp_i$$

Where pi is the proportional abundance of species i. Higher values of H' indicate greater diversity, reflecting both a larger number of species and a more equitable distribution of individuals.

Simpson diversity index (D) emphasizes dominance and is less sensitive to rare species (Simpson, 1949):

$$D = 1 - \sum_{i=1}^{S} p_i^2$$

Where higher values indicate greater diversity and lower dominance by a few species.

All indices were calculated using the BİÇEB software, which provides a standardized computational framework for ecological diversity assessment (Özkan et al., 2020).

2.4. Environmental predictors

Environmental predictors were derived from a digital elevation model (DEM) obtained from the EarthData repository at a spatial resolution of 30 m. The DEM provides detailed topographic information suitable for capturing local terrain variability, which is known to exert strong control on microclimate, soil properties, and hydrological conditions. Such topographic drivers are among the most influential abiotic factors shaping plant community composition and diversity (Wilson & Gallant, 2000; Guisan & Zimmermann, 2000).

The DEM was processed to extract core terrain attributes including elevation, slope, and aspect, each of which serves as a proxy for ecological gradients relevant to vegetation patterns. Elevation is closely linked to climatic variation, slope influences soil depth and water availability, and aspect determines incoming solar radiation, thereby modulating local energy and moisture regimes. Collectively, these predictors provide a robust environmental baseline for evaluating the relationship between habitat heterogeneity and plant species diversity (Guisan & Zimmermann, 2000).

2.5. Texture metrics (GLCM-derived variables)

Texture metrics were derived from the digital elevation model (DEM) using the Gray Level Co-occurrence Matrix (GLCM) approach (Haralick, Shanmugam, & Dinstein, 1973). GLCM is a second-order statistical method that quantifies the spatial relationship between pairs of pixels in a raster image. By analyzing how often gray-level values co-occur within a defined neighborhood, GLCM captures fine-scale spatial heterogeneity that cannot be represented by first-order statistics. Such texture features are increasingly recognized as proxies for hidden environmental factors, reflecting habitat complexity and microstructural variability across landscapes (Baraldi & Parmiggiani, 1995; Clausi, 2002).

In this study, three widely used groups of GLCM-derived metrics were computed: contrast, dissimilarity, and entropy. Contrast measures the intensity variation between neighboring pixels, thereby highlighting sharp boundaries and topographic discontinuities. Dissimilarity captures the degree of heterogeneity by linearly weighting gray-level differences, and is particularly sensitive to gradual changes in elevation. Entropy quantifies the randomness or disorder in pixel arrangements, serving as an indicator of spatial unpredictability and landscape irregularity.

For each metric, values were calculated across multiple neighborhood configurations defined by pixel distance (d = 1–5) and orientation (all directions). This allowed us to capture both fine- and coarse-scale texture information while reducing directional bias by averaging across orientations.

2.6. Statistical analysis

The relationships between plant diversity indices (species richness, Shannon index, and Simpson index) and texture metrics were assessed using correlation analysis. Pairwise associations were quantified with Pearson's correlation coefficient (r), which measures the strength and direction of linear relationships between variables.

All statistical analyses were conducted in the R environment (R Core Team, 2023). Correlation matrices and significance levels were visualized using the package psych (Revelle, 2023), which provide robust tools for exploratory multivariate analysis and graphical representation.

3. RESULTS

3.1. Diversity indices

A total of 130 vascular plant species were identified across 244 sampling plots, providing a comprehensive overview of the floristic composition within the study area. Diversity metrics highlighted marked variation among plots. Species richness ranged from 3 to 26 species per plot, with an average of approximately 12 species, reflecting substantial heterogeneity in taxonomic composition. Shannon diversity values varied between 0.12 and 2.66 (mean = 1.39), indicating pronounced differences in both richness and evenness across sites. Simpson diversity showed a comparable pattern, ranging from 0.04 to 0.90 (mean = 0.57), and pointed to clear gradients in species dominance.
Together, these indices reveal that the plant communities of the study area are far from uniform, comprising a mosaic of species-poor plots dominated by a few taxa and species-rich plots with more balanced assemblages.

3.2. Digital elevation model (DEM)

A digital elevation model (DEM) obtained from the EarthData repository at 30 m spatial resolution was used as the sole environmental predictor in this study. The DEM provided a detailed representation of topographic variability across the study area and served as the basis for subsequent texture analysis. Figure 1 presents the DEM of the region, illustrating the elevational gradients that potentially influence local patterns of plant diversity.

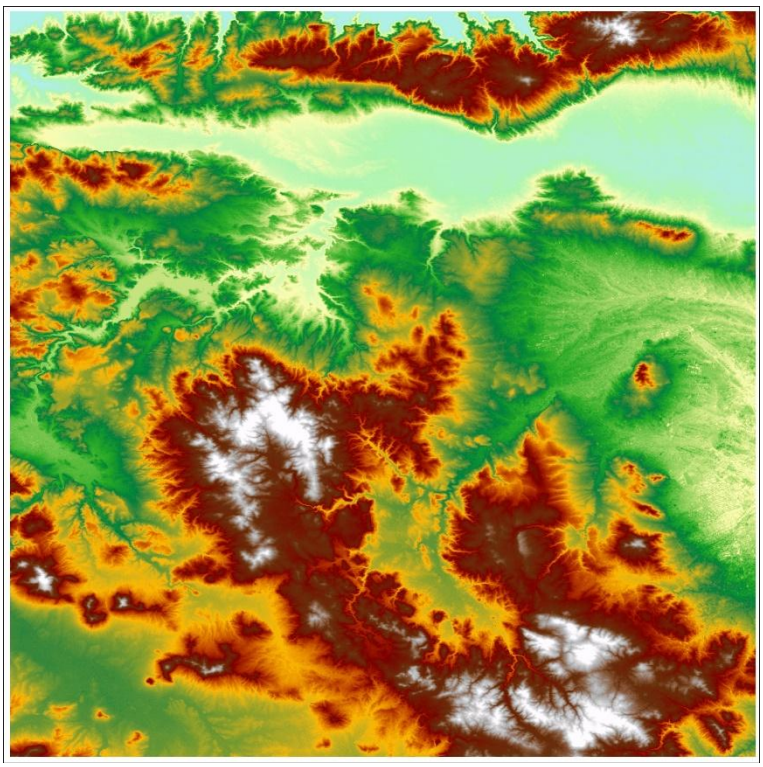

Figure 1. Digital elevation model (DEM) of the study area at 30 m spatial resolution, obtained from the EarthData repository.

3.3. Texture metrics

Texture metrics derived from the digital elevation model (DEM) were calculated using the Gray Level Co-occurrence Matrix (GLCM). Three widely applied features—contrast, dissimilarity, and entropy—were selected to represent structural heterogeneity in the study area. Contrast highlights sharp topographic differences, dissimilarity captures gradual variation among neighboring pixels, and entropy quantifies spatial randomness and disorder. These metrics provide complementary perspectives on environmental heterogeneity and serve as indirect predictors of plant diversity patterns.

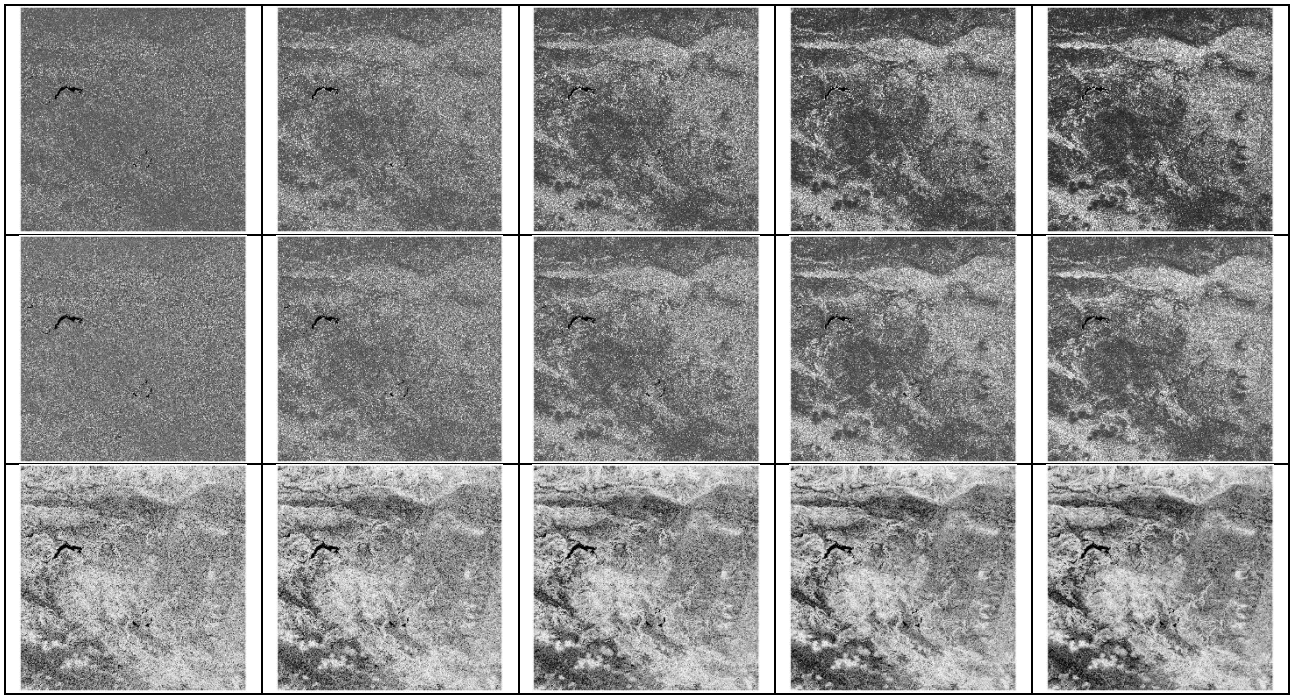

Figure 2. Spatial distribution of GLCM-derived texture metrics—contrast, dissimilarity, and entropy—computed from the 30 m DEM of the study area. Each metric represents a distinct dimension of topographic heterogeneity.

3.4. Correlation between diversity indices and texture metrics

Correlation analysis revealed contrasting patterns between diversity indices and GLCM-derived texture metrics (Figure X). Species richness showed weak positive associations with contrast and dissimilarity at short neighborhood distances, but no consistent relationships with entropy. Shannon and Simpson indices were highly correlated with each other, yet their links to texture metrics were generally weaker.

Among the texture variables, contrast and dissimilarity were strongly intercorrelated ($r > 0.95$), indicating that they capture largely overlapping structural information. By contrast, entropy exhibited negative correlations with both contrast and dissimilarity, suggesting that it represents an independent dimension of heterogeneity associated with spatial disorder. This pattern underscores the complementary roles of texture metrics, where contrast and dissimilarity highlight structural gradients while entropy reflects stochastic variability.

Overall, the analysis suggests that while GLCM-derived metrics are strongly related to each other, their direct correlations with species diversity are modest. Entropy emerged as the most distinctive predictor, showing inverse relationships with other texture groups and offering potential to explain variation in diversity not captured by richness alone.

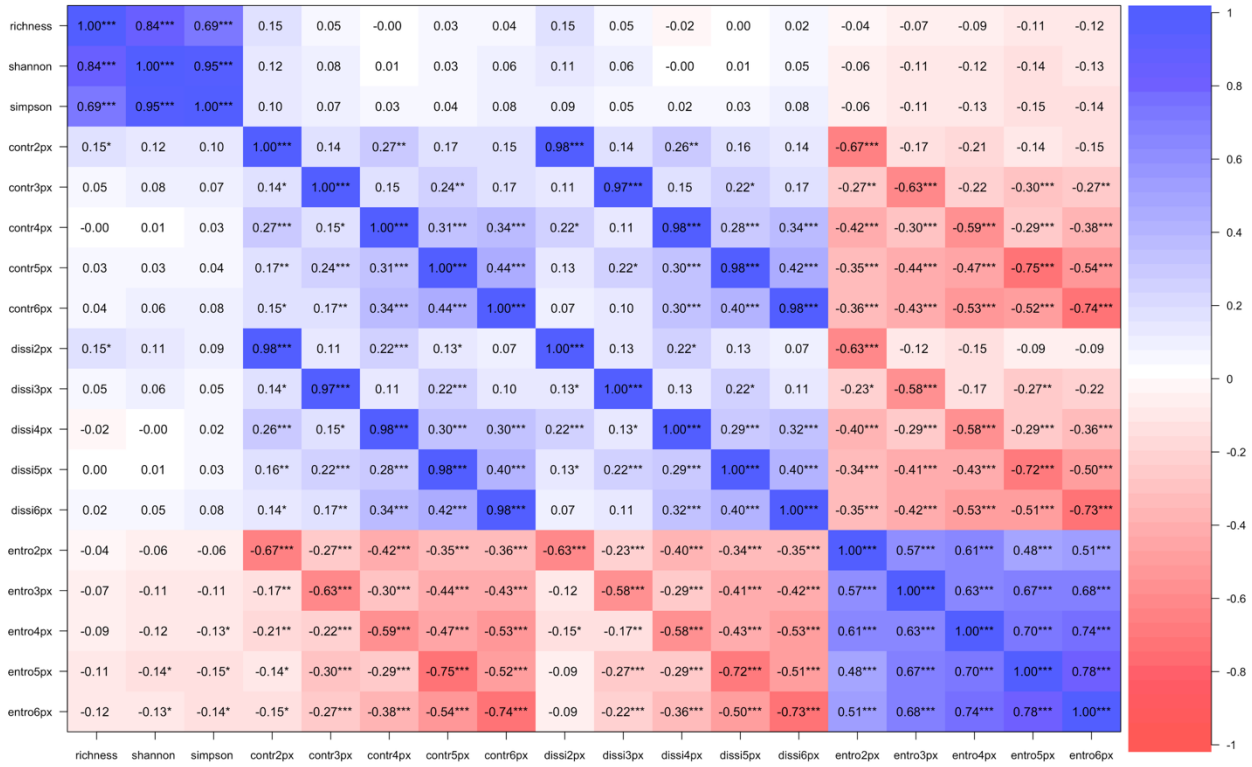

Figure 3. Correlation matrix between diversity indices (richness, shannon, simpson) and GLCM-derived texture metrics (contrast, dissimilarity, entropy) across multiple neighborhood distances. Positive correlations are shown in blue and negative correlations in red, with significance levels indicated by asterisks.

4. DISCUSSION AND CONCLUSION

This study combined field-based diversity assessments with DEM-derived texture metrics to evaluate the extent to which structural heterogeneity can explain variation in plant community diversity. A total of 130 species were identified across 244 sampling plots, with species richness ranging from 3 to 26. Shannon and Simpson indices further indicated pronounced variation in evenness and dominance, confirming that the study area supports a heterogeneous mosaic of plant assemblages. Such diversity gradients are consistent with ecological theory, which emphasizes that habitat heterogeneity fosters higher biodiversity by providing a wider range of niches and microclimatic conditions (Magurran, 2004; Gotelli & Colwell, 2001).

Topographic information derived from the DEM provided a solid environmental baseline. Elevational gradients, even without the inclusion of other climatic or edaphic variables, are known to shape plant diversity by influencing temperature, soil moisture, and radiation regimes (Guisan & Zimmermann, 2000; Wilson & Gallant, 2000). In our analysis, DEM data proved sufficient to generate texture metrics that act as proxies for hidden environmental factors otherwise difficult to measure directly.

The GLCM-derived texture features—contrast, dissimilarity, and entropy—captured complementary dimensions of topographic heterogeneity. Contrast and dissimilarity were strongly intercorrelated, indicating redundancy in the structural information they convey. This finding aligns with previous remote sensing studies reporting high collinearity among second-order texture features (Clausi, 2002). Entropy, however, emerged as a distinct variable, showing negative correlations with contrast and dissimilarity. Entropy reflects randomness or disorder in spatial configuration, and its relative independence highlights its potential as a unique predictor of biodiversity (Haralick et al., 1973; Rocchini et al., 2010).

The correlations between diversity indices and texture metrics were generally modest, suggesting that diversity patterns are influenced by a complex interplay of multiple drivers. Nevertheless, the positive associations between entropy and Shannon diversity imply that greater spatial unpredictability may facilitate more balanced species assemblages. This supports earlier findings that spectral or structural heterogeneity can serve as effective surrogates for biodiversity (Hernández-Stefanoni et al., 2012; Rocchini et al., 2015). The weaker or negative correlations with contrast and dissimilarity further demonstrate that not all texture metrics are equally informative, reinforcing the importance of variable selection in biodiversity modeling.

From a methodological perspective, this study underscores the potential of DEM-based GLCM metrics as cost-effective, scalable predictors of biodiversity patterns. Unlike purely spectral data, DEM-derived textures capture structural and geomorphological heterogeneity, which are particularly relevant in mountainous or topographically complex regions. Although our analysis focused on correlations, future research could integrate these variables into predictive frameworks such as generalized additive models or machine learning approaches to assess their relative contributions alongside climatic and edaphic predictors.

In conclusion, our findings highlight three key points. First, plant diversity in the study area is highly variable, reflecting the strong influence of environmental heterogeneity. Second, GLCM-derived texture metrics effectively quantify fine-scale structural variation, with entropy emerging as the most independent and ecologically meaningful descriptor. Third, while contrast and dissimilarity exhibit redundancy, entropy holds promise as a complementary predictor in biodiversity–environment models. Overall, this study demonstrates that incorporating texture metrics derived from DEMs can enhance our understanding of biodiversity patterns and provide a pathway toward more integrative, spatially explicit conservation planning in the face of global change.

REFERENCES

Braun-Blanquet, J. (1932). Plant Sociology (Translated: Fuller, DG and Conard SH 1983). West Germany, 439.

Castelluccio, M., Poggi, G., Sansone, C., & Verdoliva, L. (2015). Land use classification in remote sensing images by convolutional neural networks. *arXiv preprint arXiv:1508.00092.*

Castelluccio, M., Poggi, G., Sansone, C., & Verdoliva, L. (2017, March). Training convolutional neural networks for semantic classification of remote sensing imagery. In *2017 Joint Urban Remote Sensing Event (JURSE)* (pp. 1-4). IEEE.

Clausi, D. A. (2002). An analysis of co-occurrence texture statistics as a function of grey level quantization. *Canadian Journal of Remote Sensing, 28*(1), 45–62. https://doi.org/10.5589/m02-004

Early, D. S., & Long, D. G. (2002). Image reconstruction and enhanced resolution imaging from irregular samples. *IEEE Transactions on Geoscience and Remote Sensing*, *39*(2), 291-302.

Fontaine, M., Aerts, R., Özkan, K., Mert, A., Gülsoy, S., Süel, H., ... & Muys, B. (2007). Elevation and exposition rather than soil types determine communities and site suitability in Mediterranean mountain forests of southern Anatolia, Turkey. *Forest Ecology and Management*, *247*(1-3), 18-25.

Gillespie, T. W., Foody, G. M., Rocchini, D., Giorgi, A. P., & Saatchi, S. (2008). Measuring and modelling biodiversity from space. *Progress in Physical Geography, 32*(2), 203–221. https://doi.org/10.1177/0309133308093606

Gotelli, N. J., & Colwell, R. K. (2001). Quantifying biodiversity: Procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters, 4*(4), 379–391. https://doi.org/10.1046/j.1461-0248.2001.00230.x

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling, 135*(2–3), 147–186. https://doi.org/10.1016/S0304-3800(00)00354-9

Haralick, R. M., Shanmugam, K., & Dinstein, I. (1973). Textural features for image classification. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-3*(6), 610–621. https://doi.org/10.1109/TSMC.1973.4309314

He, K. S., Bradley, B. A., Cord, A. F., Rocchini, D., Tuanmu, M. N., Schmidtlein, S., ... & Pettorelli, N. (2015). Will remote sensing shape the next generation of species distribution models? *Remote Sensing in Ecology and Conservation, 1*(1), 4–18. https://doi.org/10.1002/rse2.7

Hernández-Stefanoni, J. L., Castillo-Santiago, M. Á., Mas, J. F., Wheeler, C. E., Andres-Mauricio, J., Tun-Dzul, F. J., ... & Dupuy, J. M. (2012). Improving species diversity mapping by remote sensing and spatial modeling. *Ecological Informatics, 11,* 10–19.

Magurran, A. E. (2004). *Measuring biological diversity.* Oxford: Blackwell Publishing.

Oldeland, J., Wesuls, D., Rocchini, D., Schmidt, M., & Jürgens, N. (2010). Does using species abundance data improve estimates of species diversity from remotely sensed spectral heterogeneity? *Ecological Indicators, 10*(2), 390–396. https://doi.org/10.1016/j.ecolind.2009.07.012

Özkan, K., Küçüksille, E., Mert, A., Gülsoy, S., Suel, H., & Başar, M. (2020). A software for Estimating Biodiversity Components (BİÇEB). *Turkish Journal of Forestry*, *21*(3), 344-348.

R Core Team. (2023). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Revelle, W. (2023). *psych: Procedures for psychological, psychometric, and personality research*. R package version 2.3.9. https://CRAN.R-project.org/package=psych

Rocchini, D., Balkenhol, N., Carter, G. A., Foody, G. M., Gillespie, T. W., He, K. S., ... & Zhevelev, H. M. (2010). Remotely sensed spectral heterogeneity as a proxy of species diversity: Recent advances and open challenges. *Ecological Informatics, 5*(5), 318–329. https://doi.org/10.1016/j.ecoinf.2010.06.001

Rocchini, D., Hernández-Stefanoni, J. L., & He, K. S. (2015). Advancing species diversity estimate by remotely sensed proxies: A conceptual review. *Ecological Informatics, 25,* 22–28. https://doi.org/10.1016/j.ecoinf.2014.10.006

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution, 18*(6), 306–314. https://doi.org/10.1016/S0169-5347(03)00070-3

Wilson, J. P., & Gallant, J. C. (2000). *Terrain analysis: Principles and applications*. New York: Wiley.

Zohary, M. (1973). Geobotanical Foundatitons of theMiddle East. Vol: 1-2, Gustav Fisher Verlag, Stuttgrad.

The Protective Role of Moderate Exercise Against Age-Related Pulmonary Oxidative Stress

MUSTAFA SAYGIN[1*]

Abstract: The effect of regular moderate swimming exercise on pulmonary oxidative stress in aged rats was investigated. Thirty-two male Sprague-Dawley rats (350-500 g) aged 11-12 months and 15-16 months were used in the study. The study was divided into four groups, with 8 rats in each group, and the groups were randomised. The groups were: Control 1 (K1/11-12 months), Exercise 1 (E1/11-12 months), Control 2 (K2/15-16 months), and Exercise 2 (E2/15-16 months). The rats were subjected to moderate-intensity exercise for 30 minutes per day, 5 days per week, for 8 weeks. At the end of the study, lung tissue was homogenised and analysed for malondialdehyde (MDA), catalase (CAT) and superoxide dismutase (SOD). No statistically significant differences were found between the E1 and K1 groups in terms of MDA, CAT, and SOD ($p>0.05$), but an increase in SOD values was observed in the E1 group. A statistically significant difference was found between the E2 and K2 exercise groups in terms of SOD values ($p=0.040$), with an increase observed in the E2 group. Similarly, KAT and MDA increased in the E2 group but were not statistically significant. The results suggest that regular moderate aerobic exercise during the ageing process or middle age may be effective in improving quality of life through its protective effect against pulmonary oxidative stress.

Keywords: Lung, Exercise, Ageing, Oxidant, Antioxidant

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INTRODUCTION

The aging process is a primary risk factor for the decline of physiological function and the onset of chronic diseases across all organ systems. While much attention is given to the cardiovascular and nervous systems, the lung is also profoundly affected by senescence, a process termed "pulmonary aging" (1). This decline is characterized by significant structural changes, including alveolar simplification and a loss of elastic recoil, which collectively impair gas exchange and reduce respiratory capacity (2,3). At a cellular level, the aging lung is defined by a state of chronic, low-grade inflammation and, most critically, a dysregulated redox environment. This disruption in the balance between the production of reactive oxygen species (ROS) and the capacity of the cell's antioxidant defenses is known as oxidative stress and is considered a central pillar in the pathogenesis of age-related lung dysfunction and disease (4).

The primary cellular antioxidant defense system relies on a cascade of enzymes to neutralize harmful ROS. Superoxide dismutase (SOD) serves as the first line of defense, converting the highly reactive superoxide anion (O_2^-) into hydrogen peroxide (H_2O_2). Subsequently, catalase (CAT) and glutathione peroxidase catalytically degrade H_2O_2 into harmless water and oxygen (5). During aging, the efficiency of this enzymatic network often diminishes while ROS production increases, leading to widespread cellular damage. The accumulation of malondialdehyde (MDA), a toxic byproduct of lipid peroxidation, is a widely accepted and reliable biomarker of such oxidative membrane damage (6). Consequently, measuring the levels of MDA alongside the activities of SOD and CAT provides a robust snapshot of the oxidative stress status within pulmonary tissue.

Regular physical exercise stands as a powerful, non-pharmacological strategy to combat the deleterious effects of aging. The benefits of exercise are systemic, and its protective mechanisms are increasingly understood to operate through the principle of hormesis. According to this theory, each session of moderate exercise creates a mild, transient state of oxidative stress. This manageable challenge stimulates the cell's adaptive responses, leading to the upregulation and strengthening of the endogenous antioxidant defense network, including enzymes like SOD and CAT (7). Over time, this adaptation enhances the tissue's overall resilience, making it better equipped to handle the chronic oxidative burden associated with aging (8).

Our research group has previously established the systemic efficacy of a specific 8-week, moderate-intensity swimming protocol. In a prior study using this exact model, we demonstrated that this regimen induced significant improvements in learning and memory in aged rats, which was correlated with molecular changes in the hippocampus (9). This proves that the intervention is potent enough to elicit beneficial adaptations in a distant and complex organ system. However, it remains unknown whether these systemic protective effects also manifest in the lung, which is equally vulnerable to age-related oxidative decline. Given the established link between exercise and antioxidant defense, it is plausible that the same protocol could mitigate pulmonary oxidative stress. Therefore, the present study was designed to investigate the effects

of this well-defined, moderate-intensity swimming regimen on the key pulmonary oxidative stress markers malondialdehyde (MDA), superoxide dismutase (SOD), and catalase (CAT) in aged rats.

MATERIALS AND METHODS

Ethical approval

This study was conducted at the Research Laboratory of Suleyman Demirel University, Faculty of Medicine, Department of Physiology. All procedures were certified and approved by the Animal Experiments Local Ethics Committee of Mehmet Akif Ersoy University, Burdur, Turkey (17.07.2019/532).

Animals

In this study, a total of thirty-two male Sprague Dawley rats, weighing 350-500 g were used. Rats were kept at a constant temperature of 24-26 °C, 55-60% humidity, 12/12 hr light/dark cycle. Food (Standard rat chow, Korkuteli Yem, Turkey) and water were given ad libitum. The cages were changed weekly, and rats' fluids were changed every two days.

Experimental design

The rats were randomly divided into 4 groups with 8 rats in each: Control- C1 (11-12 months old), Exercise-E1 (11-12 months old), Control-C2 (15-16 months old), Exercise-E2 (15-16 months old). The swimming program consisted of two stages: adaptation and training. The rats were floated by keeping the training time constant for 30 min. Moderate exercise intensity was applied at an intensity of 30 min/day, 5 days/week, with the training period lasting 8 weeks.

Exercise program

Daily swimming training was performed at the water temperature of 32±2 °C, kept constant by a thermostat immersed in a wide water tank [130 cm diameter×45 cm height]. Care was taken that the rats never touched the ground with their feet during the swimming exercise. The animals were swimming in groups of eight. The swimming program consisted of two stages: adaptation and training. Adaptation training time was gradually increased from 10 min in the first week to 30 min on the last day (10). The adaptation stage was used to prevent water-induced stress-causing excessive physiological changes. Following one week of the adaptation period, the actual exercise training started in proportion to the adaptation period. The intensive training period lasted 30 min/day, 5 days/week for 8 weeks (11,12). In the training period, moderate-intensity exercise was assigned (13) at the same time each day (from 09:00 am to 11:00 am). After swimming training, the rats were dried with a towel and remained warm under an electric heater.

Biochemical analysis

The preparation of the tissue samples and biochemical analysis

At the end of 30 days, all groups were decapitated under anesthesia (ketamin HCl 90 mg/kg xylazine HCl 10 mg/kg) (14). Forbiochemical analyses, tissue samples from the lung were collected and washed with physiological saline. Tissue samples were suspended in 3 mL Tris-HCl buffer of pH 7.3, contained 0.25mol/L sucrose and stored at 80 ^{0}C, until further analysis. Lung tissues were homogenized in a motor-driven tissue homogenizer (IKA Ultra-Turrax T25 Basic; Labortechnic, Staufen, Germany) with phosphate buffer (pH 7.4). Unbroken cells, cell debris, and nuclei were sedimented by centrifugation at 2000g for 10min. The levels of protein, thiobarbituric acid reactive substances assay (TBARS) and the activities of SOD, and CAT were determined in the supernatants. Determination of SOD activity was estimated in the supernatant according to the method described by Sun et al. (1988) (15), and its activity is expressed as units per milligram protein. CAT activity was measured using the method described by Aebi (1974) (16), and is expressed as kilounits per gram protein. Protein levels in the homogenate and supernatant were determined according to the method of Bradford et al. (1976) (17). The TBARS levels in tissues were determined from the homogenate by following the double heating method of Draper and Hadley (1990) (18). The concentration of TBARS is expressed as micromoles per gram protein in the lung. An autoanalyser (Olympus AU 2700, New York, USA) was used to determine the activities of SOD and CAT, and a spectrophotometer (ShimadzuUV-1601; Shimadzu, Kyoto, Japan) was used to estimate the TBARS levels.

Statistical analysis

Statistical analyses were performed using SPSS software, version 25.0 Kolmogorov–Smirnov test was performed for normality of the distributions of variables. Data are expressed as the mean ± SD. The data were analyzed using paired sample t-test for comparisons between multiple groups and two groups. $P < 0.05$ was considered as statistically significant.

RESULTS

No statistically significant differences were found between the E1 and K1 groups in terms of MDA, CAT, and SOD ($p>0.05$), but an increase in SOD values was observed in the E1 group. A statistically significant difference was found between the E2 and K2 exercise groups in terms of SOD values ($p=0.040$), with an increase observed in the E2 group. Similarly, KAT and MDA increased in the E2 group but were not statistically significant.

Table 1: Analysis of oxidant-antioxidant parameters in lung tissue

Groups	MDA (µmol/mg prt)	SOD (U/mg prt)	CAT (ku/mg prt)	P value
Control- C1	0.5968±0.0879	0.4711±0.0759	0.1773±0.1504	
Exercise-E1	0.5921±0.3485	0.4799±0.0382	0.1343±0.0719	P>0.05
Control-C2	0.5929±0.0758	0.4756±0.0541	0.1184±0.0827	
Exercise-E2	0.6719±0.1062	0.5423±0.0432[a]	0.1491±0.1774	P<0.05

malondialdehyde (MDA) levels, superoxide dismutase (SOD) and catalase (CAT) activities
a: compared to control-c2 group

DISCUSSION

The primary finding of this study is that an 8-week protocol of moderate-intensity swimming exercise induces a significant, age-dependent adaptive response in the antioxidant defense system of rat pulmonary tissue. Specifically, we observed a statistically significant increase in the activity of superoxide dismutase (SOD) in the older exercise group (E2) compared to its sedentary counterpart (C2), whereas no significant changes were noted in the younger aged group (E1). This suggests that moderate physical activity is a potent stimulus for bolstering the primary line of antioxidant defense, but its efficacy is most pronounced in an older organism already experiencing a greater degree of age-related redox imbalance.

The increase in SOD activity in the E2 group is a critical finding and aligns with the well-established theory of exercise-induced hormesis. Hormesis posits that repeated exposure to a mild, transient stressor in this case, the temporary increase in reactive oxygen species (ROS) generated during physical activity stimulates a beneficial adaptive response that enhances the organism's resilience to more severe or chronic stress (19).SOD is the first and most crucial enzymatic defense against the superoxide anion, a primary ROS. The upregulation of SOD activity in the older rats indicates that the exercise protocol successfully triggered a protective adaptation, strengthening the lung's capacity to neutralize this specific free radical. This is consistent with previous research demonstrating that regular exercise can reduce oxidative stress and enhance the expression of antioxidant enzymes, including SOD, in the lungs of aged animals, thereby preserving pulmonary structure and function (20,21).

The age-dependent nature of our results is particularly noteworthy. The lack of a significant change in the younger aged group (E1) does not necessarily imply a lack of effect, but rather suggests that these animals may possess a more robust baseline antioxidant capacity or a higher "antioxidant reserve" (22). It is plausible that their existing defenses were sufficient to manage the exercise-induced ROS, making a significant upregulation of enzymes unnecessary. In contrast, the older rats (E2), who are likely experiencing a more pronounced age-related decline in antioxidant capacity and higher baseline oxidative stress, are more sensitive to the hormetic stimulus of exercise. For them, the exercise regimen represents a necessary challenge that effectively forces the system to adapt and strengthen its defenses, leading to the measurable increase in SOD activity (23,24).

The analysis of malondialdehyde (MDA), a marker of lipid peroxidation, provides further insight. The non-significant trend towards an increase in MDA in the E2 group can be interpreted within the hormetic framework. It suggests that the exercise itself did indeed cause a minor degree of oxidative stress the very signal required to initiate the adaptive response. The fact that this increase did not reach statistical significance, especially in the face of significantly upregulated SOD activity, implies that the adaptive antioxidant response was largely successful in containing the potential for widespread damage (25,26). Similarly, the non-significant trend of increased CAT activity in the E2 group can be viewed as a supportive, albeit less statistically powerful, component of this broad antioxidant adaptation.

This study is not without its limitations. The investigation was confined to three key markers of oxidative stress. Future studies should expand this analysis to include markers of inflammation (e.g., TNF-α, IL-6) and apoptosis (e.g., caspase-3) to provide a more comprehensive picture of the protective effects of exercise on the aging lung. Furthermore, exploring the upstream molecular signaling pathways, such as the Nrf2 pathway, which is a master regulator of the antioxidant response and is known to be activated by exercise, would be a critical next step in elucidating the precise mechanisms at play (27,28). Finally, only one intensity and duration of exercise was tested; investigating a dose-response relationship would further clarify the optimal exercise prescription for pulmonary health.

CONCLUSION

In conclusion, this study demonstrates that an 8-week regimen of moderate-intensity swimming exercise significantly enhances the primary antioxidant defense system in the lungs of older aged rats, specifically by increasing the activity of superoxide dismutase. This effect appears to be age-dependent, manifesting most clearly in the older animals who are more susceptible to age-related oxidative stress. These findings provide direct evidence for the hormetic benefits of physical activity on pulmonary redox homeostasis, supporting the role of regular, moderate exercise as a potent, non-pharmacological strategy to mitigate the oxidative burden of aging and promote healthy lung function throughout the lifespan.

REFERENCES

1. Schneider JL, Rowe JH, Garcia-de-Alba C, Kim CF, Sharpe AH, Haigis MC. The aging lung: Physiology, disease, and immunity. Cell. Nisan 2021;184(8):1990-2019.

2. Hecker L. Mechanisms and consequences of oxidative stress in lung disease: therapeutic implications for an aging populace. Am J Physiol-Lung Cell Mol Physiol. 01 Nisan 2018;314(4):L642-53.

3. Rodriguez-Roisin R, Burgos F, Roca J, Barbera J, Marrades R, Wagner P. Physiological changes in respiratory function associated with ageing. Eur Respir J. 01 Aralık 1999;14(6):1454.2-1456.

4. MacNee W, Rahman I. Is oxidative stress central to the pathogenesis of chronic obstructive pulmonary disease? Trends Mol Med. Şubat 2001;7(2):55-62.

5. Ighodaro OM, Akinloye OA. First line defence antioxidants-superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPX): Their fundamental role in the entire antioxidant defence grid. Alex J Med. 01 Aralık 2018;54(4):287-93.

6. Ayala A, Muñoz MF, Argüelles S. Lipid Peroxidation: Production, Metabolism, and Signaling Mechanisms of Malondialdehyde and 4-Hydroxy-2-Nonenal. Oxid Med Cell Longev. 2014;2014:1-31.

7. Simpson RJ, Kunz H, Agha N, Graff R. Exercise and the Regulation of Immune Functions. Içinde: Progress in Molecular Biology and Translational Science [Internet]. Elsevier; 2015 [a.yer 11 Ağustos 2025]. s. 355-80. Erişim adresi: https://linkinghub.elsevier.com/retrieve/pii/S1877117315001842

8. Garatachea N, Santos-Lozano A, Hughes DC, Gómez-Cabello A, Ara I. Physical Exercise as an Effective Antiaging Intervention. BioMed Res Int. 2017;2017:1-2.

9. Tunca U, Saygin M, Ozmen O, Aslankoc R, Yalcin A. The impact of moderate-intensity swimming exercise on learning and memory in aged rats: The role of Sirtuin-1. Iran J Basic Med Sci [Internet]. Eylül 2021 [a.yer 11 Ağustos 2025];(Online First). Erişim adresi: https://doi.org/10.22038/ijbms.2021.58145.12920

10. Minaii B, Moayeri A, Shokri S, Habibi Roudkenar M, Golmohammadi T, Malek F, vd. Melatonin improve the sperm quality in forced swimming test induced oxidative stress in nandrolone treated Wistar rats. Acta Med Iran. 2014;52(7):496-504.

11. Marcelino TB, Longoni A, Kudo KY, Stone V, Rech A, De Assis AM, vd. Evidences that maternal swimming exercise improves antioxidant defenses and induces mitochondrial biogenesis in the brain of young Wistar rats. Neuroscience. Ağustos 2013;246:28-39.

12. Stone V, Kudo KY, Marcelino TB, August PM, Matté C. Swimming exercise enhances the hippocampal antioxidant status of female Wistar rats. Redox Rep. Mayıs 2015;20(3):133-8.

13. Seo DY, Lee SR, Kim N, Ko KS, Rhee BD, Han J. Humanized animal exercise model for clinical implication. Pflüg Arch - Eur J Physiol. Eylül 2014;466(9):1673-87.

14. Saygin M, Ozguner MF, Onder O, Doguc DK, Ilhan I, Peker Y. The impact of sleep deprivation on hippocampal-mediated learning and memory in rats. Bratisl Med J. 2017;118(07):408-16.

15. Sun Y, Oberley LW, Li Y. A simple method for clinical assay of superoxide dismutase. Clin Chem. Mart 1988;34(3):497-500.

16. Aebi H. Catalase in vitro. Methods Enzymol. 1984;105:121-6.

17. Bradford MM. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem. 07 Mayıs 1976;72:248-54.

18. Draper HH, Hadley M. Malondialdehyde determination as index of lipid peroxidation. Methods Enzymol. 1990;186:421-31.

19. Szentesi P, Csernoch L, Dux L, Keller-Pintér A. Changes in Redox Signaling in the Skeletal Muscle with Aging. Oxid Med Cell Longev. 17 Ocak 2019;2019:1-12.

20. Wang X, Wang Z, Tang D. Aerobic Exercise Alleviates Inflammation, Oxidative Stress, and Apoptosis in Mice with Chronic Obstructive Pulmonary Disease. Int J Chron Obstruct Pulmon Dis. Mayıs 2021;Volume 16:1369-79.

21. Perez R, Lopez M, Barjadequiroga G. Aging and lung antioxidant enzymes, glutathione, and the lipid peroxidation in the rat☆. Free Radic Biol Med. 1991;10(1):35-9.

22. Liguori I, Russo G, Curcio F, Bulli G, Aran L, Della-Morte D, vd. Oxidative stress, aging, and diseases. Clin Interv Aging. Nisan 2018;Volume 13:757-72.

23. Liguori I, Russo G, Curcio F, Bulli G, Aran L, Della-Morte D, vd. Oxidative stress, aging, and diseases. Clin Interv Aging. Nisan 2018;Volume 13:757-72.

24. Monti DM, Rigano MM, Monti SM, Peixoto HS. Role of Antioxidants in the Protection from Aging-Related Diseases. Oxid Med Cell Longev. 08 Ocak 2019;2019:1-2.

25. Szentesi P, Csernoch L, Dux L, Keller-Pintér A. Changes in Redox Signaling in the Skeletal Muscle with Aging. Oxid Med Cell Longev. 17 Ocak 2019;2019:1-12.

26. Ayala A, Muñoz MF, Argüelles S. Lipid Peroxidation: Production, Metabolism, and Signaling Mechanisms of Malondialdehyde and 4-Hydroxy-2-Nonenal. Oxid Med Cell Longev. 2014;2014:1-31.

27. Kasai S, Shimizu S, Tatara Y, Mimura J, Itoh K. Regulation of Nrf2 by Mitochondrial Reactive Oxygen Species in Physiology and Pathology. Biomolecules. 17 Şubat 2020;10(2):320.

28. Xiong T, Bai X, Wei X, Wang L, Li F, Shi H, vd. Exercise Rehabilitation and Chronic Respiratory Diseases: Effects, Mechanisms, and Therapeutic Benefits. Int J Chron Obstruct Pulmon Dis. Haziran 2023;Volume 18:1251-66.

Patients With Amyotrophic Lateral Sclerosis And Nursing Care

ERIND THARTORI[1*]

Abstract: Nursing care in patients with Amyotrophic Lateral Sclerosis is essential to maintain function, prevent complications and improve the quality of life of patients. ALS, also known as Motor Neuron Disease (MND), is a progressive neurodegenerative disease that affects motor neurons in the brain and spinal cord, leading to muscle weakness, loss of motor skills and, in advanced stages, the inability to perform vital functions such as breathing and swallowing. The cause of the disease remains unclear and is often associated with a complex interaction between genetic (mutations in SOD1, C9orf72, TARDBP, FUS) and environmental (toxic exposures, trauma and nutritional factors) factors. The global prevalence is estimated at 1.5 to 3 cases per 100,000 population. Quality of life in patients with ALS is significantly affected by disease progression, especially in motor, respiratory and social aspects. Multidisciplinary nursing care has a key role in supporting patients and their families, improving physical function, psychological well-being. The most effective nursing care strategies include systematic monitoring of vital parameters, management of respiratory and nutritional symptoms, health education and prevention of pressure ulcers.

Keywords: Palliative Care, Quality of Life, Respiratory Support, Symptom Management

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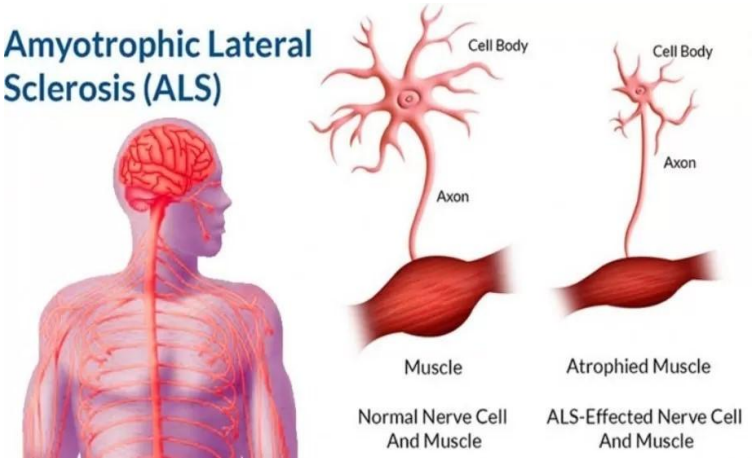
INTRODUCTION

Nursing care in patients with Amyotrophic Lateral Sclerosis is essential to maintain function, prevent complications and improve the quality of life of patients. ALS, also known as Motor Neuron Disease (MND), is a progressive neurodegenerative disease that affects motor neurons in the brain and spinal cord, leading to muscle weakness, loss of motor skills and, in advanced stages, the inability to perform vital functions such as breathing and swallowing. The cause of the disease remains unclear and is often associated with a complex interaction between genetic (mutations in SOD1, C9orf72, TARDBP, FUS) and environmental (toxic exposures, trauma and nutritional factors) factors. The global prevalence is estimated at 1.5 to 3 cases per 100,000 population.



The quality of life in patients with ALS is profoundly influenced by the way daily care is managed, symptom management, emotional support and the patient's active involvement in decision-making. Recent studies in different European countries show that quality of life does not depend only on the physical aspects of the disease, but also on psychosocial factors, family support and the quality of the patient-nurse relationship.

Amyotrophic Lateral Sclerosis (ALS) Clinic

The onset of ALS can be so subtle that symptoms are often overlooked. Early symptoms include brief jerks (myoclonus), abdominal pain, or a certain stiffness of the muscles.
Symptoms of ALS often start mildly and may be overlooked at first. They can vary from person to person, but include:

• Weakness in a limb (arm, hand, leg) that gradually gets worse.
• Difficulty climbing stairs, walking, or clumsiness.
• Muscle tremors or cramps.
• Slow or slurred speech.
• Difficulty swallowing, leading to coughing or choking.
• Weight loss.
• Severe fatigue.
• Sometimes, inappropriate emotional outbursts (crying or laughing for no reason).

As the disease progresses, symptoms become more severe and include:
• Shortness of breath or trouble breathing.
• Inability to stand or walk independently.
• Serious difficulty chewing and eating.

Forms of Amyotrophic Lateral Sclerosis (ALS)

Amyotrophic Lateral Sclerosis has several types that are distinguished based on the site of onset of symptoms, the speed of progression and the pattern of spread.

Spinal ALS (Classic ALS): Begins with weakness of the muscles of the upper and lower limbs. Usually the hands and feet are affected with a distal onset. It begins with muscle weakness, atrophy, fasciculations and spasticity. The spread usually comes towards the brain and the muscles of breathing. This type makes up the largest number of patients with ALS, about 70-80% of cases.

Bulbar ALS: Begins with problems with speech, swallowing and breathing. Usually the cranial nerves (brain bulb) are affected and begins with dysarthria, dysphagia, sialorrhea (flow of saliva), involuntary emotions (laughter and crying for no reason). This type of ALS usually affects 20-25% of cases and has a rapid progression and poor prognosis.

Respiratory ALS which begins with respiratory weakness and weakness of the respiratory muscles. It is very rare and requires early non-invasive or invasive ventilation.

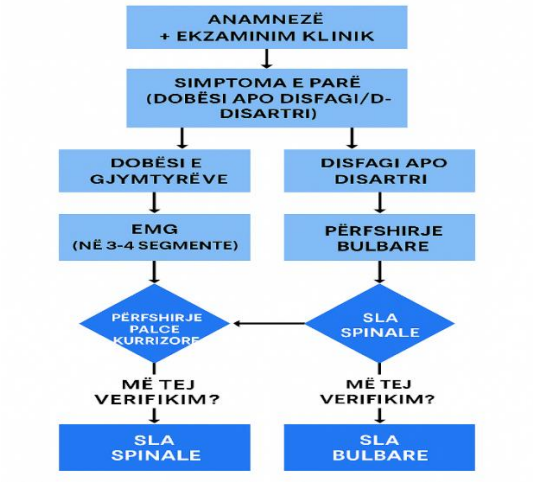
Flail Arm ALS which begins with progressive weakness and atrophy of both arms, without immediate involvement of the legs or breathing. The arms and shoulders are usually affected and has a slower progression than the other forms.

Flail Leg ALS which begins with weakness in the legs that then affects both lower limbs. Progression can be slow but is progressive. Generally, bulbar functions are preserved for a long time.

Frontotemporal ALS which is usually also associated with frontotemporal dementia (FTD). It begins with behavioral changes, language disorders, poor decision-making and apathy. Usually as a form it has a poor prognosis due to cognitive involvement.

*Familial ALS (*FALS): this form of ALS usually has a genetic basis and appears in more than one family member. It accounts for about 5-10% of cases and belongs to common mutations such as C9orf72, SOD1, TARDBP, FUS.

Sporadic ALS which has no family history, with unknown causes, probably multifactorial (genetic and environmental). It accounts for 90-95% of cases.



The role of nursing care and the multidisciplinary approach

Incorporating an integrated palliative approach from diagnosis helps to improve QoL, control symptoms and reduce burden on caregivers. Care in multidisciplinary centers is associated with improved QoL and longer maintenance of function also reduces hospitalizations. Assistance with assistive devices such as non-invasive ventilation, PEG, communication aids and adaptation of physical activity increase autonomy and QoL although the improvement is perceived as too modest due to rapid progression,

Psychosocial interventions and specialized nursing care

A recent study (January 2024) on psychosocial interventions finds that psychological treatments/scal type counseling and personalized support in nursing care improve the coping skills of patients and caregivers. Nurses who use structured approaches such as the Roper-Logan-Tierney Model (Focused on activities of daily living) develop care that supports the functional independence of the patient.
Structured and multidisciplinary nursing care is fundamental in maintaining quality of life for patients with ALS and their caregivers. The use of standardized QoL instruments, the initiation of palliative care at diagnosis, and interventions that support device administration and symptom management are well supported by the international literature. A 2020 meta-analysis based on several studies identified that multidisciplinary care significantly increases survival (+ 142 days) compared to standard neurological care, while improving overall mental QoL outcomes.

Nursing Approach	QoL benefit
Psychological Support	Reduces anxiety/depression, maintains QoL
Functional Monitoring ALSFRS-R	Helps identify and prevent falls
Assistive Devices (NIV, PEG)	Improves survival rate and maintains QoL
Early Palliative Care	Symptom control and respect for patient preferences
Support for Caregivers	Reduces emotional burden and maintains family QoL

CONCLUSIONS

Quality of life in patients with ALS is significantly affected by disease progression, especially in motor, respiratory and social aspects. Multidisciplinary nursing care has a key role in supporting patients and their families, improving physical function, psychological well-being. The most effective nursing care strategies include systematic monitoring of vital parameters, management of respiratory and nutritional symptoms, health education and prevention of pressure ulcers.

REFERENCE

Ortega-Hombrados L, Molina-Torres G, Galán-Mercant A, Sánchez-Guerrero E, González-Sánchez M, Ruiz-Muñoz M. Systematic Review of Therapeutic Physical Exercise in Patients with Amyotrophic Lateral Sclerosis over Time. Int J Environ Res Public Health. 2021 Jan 26;18(3):1074. doi: 10.3390/ijerph18031074. PMID: 33530383; PMCID: PMC7908444.

Mercadante S, Al-Husinat L. Palliative Care in Amyotrophic Lateral Sclerosis. J Pain Symptom Manage. 2023 Oct;66(4):e485-e499. doi: 10.1016/j.jpainsymman.2023.06.029. Epub 2023 Jun 26. PMID: 37380145.

Liu S, Sun X, Ren Q, Chen Y, Dai T, Yang Y, Gong G, Li W, Zhao Y, Meng X, Lin P, Yan C. Glymphatic dysfunction in patients with early-stage amyotrophic lateral sclerosis. Brain. 2024 Jan 4;147(1):100-108. doi: 10.1093/brain/awad274. PMID: 37584389.

Hamad AA, Alkhawaldeh IM, Nashwan AJ, Meshref M, Imam Y. Tofersen for SOD1 amyotrophic lateral sclerosis: a systematic review and meta-analysis. Neurol Sci. 2025 May;46(5):1977-1985. doi: 10.1007/s10072-025-07994-2. Epub 2025 Jan 17. PMID: 39820998; PMCID: PMC12003547.

Tülek Z, Özakgül A, Alankaya N, Dik A, Kaya A, Ünalan PC, Özaydin AN, İdrisoğlu HA. Care burden and related factors among informal caregivers of patients with amyotrophic lateral sclerosis. Amyotroph Lateral Scler Frontotemporal Degener. 2023 Feb;24(1-2):125-132. doi: 10.1080/21678421.2022.2079993. Epub 2022 Jun 2. PMID: 35652417.

Legal and Field Practices in Combating Illegal Wildlife Trade: The Case of Türkiye

ÇAĞDAN UYAR *[1]

Abstract: In this study, firstly, the international importance of illegal wildlife trade within the framework of the CITES Convention and its place in Türkiye are explained. Then, the relationship between the concepts of seize, forfeit, and confiscate in the national legislation, and the authorization left by CITES to the national law on this issue was evaluated. The enforcement authorities in this field in Türkiye and especially the role of the customs administration are detailed, and data on smuggling for the last six years are visualized with creating heat map. Detection densities at border gates, seizure reporting problems and data gaps are discussed. Problems such as lack of specialized personnel, inadequacies in species identification and data deficiencies still exist in the implementation of CITES. This study aims to fill an important gap in terms of making these deficiencies visible, presenting the situation on the ground based on concrete data and developing recommendations for policy makers. This study emphasizes that the effectiveness of scientific authorities and enforcement authorities is of vital importance for global biodiversity. In this regard, the coordinated work of enforcement authorities with scientific authorities in customs applications emerges as a factor that improves speed and economy. This study examined illegal wildlife species seized at Turkish border crossings between 2019 and 2025 and determined that most seizures occurred at Istanbul Airport, Habur Border Gate, and Sarp Border Gate. It was determined that 46 of the 103 seizures that occurred during the six-year period involved species subject to CITES. In most of these cases, customs officers' reports were found to be inconsistent and incomplete. In customs practices, inter-agency communication is lacking in the initial stages; accurate identification of species and correct shipping procedures are essential, and effective monitoring of the legal process is crucial. The map generated for this study shows wildlife trafficking activity across Türkiye, based on recorded incidents at airports, border gates, ports, and specific cities. The wildlife population in Türkiye, as in many countries around the world, is facing a growing decline. To prevent this situation, international efforts and national practices must be continuously reviewed and improved, and current studies should be taken into consideration by the authorities.

Keywords: CITES structural analysis, illegal wildlife trade, border checkpoint practices, legal adequacy, biodiversity conservation, seizure procedures.

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1. INTRODUCTION

Türkiye has a strategic importance as a transit point between Asia, Europe and Africa due to its geopolitical location. This makes Türkiye a transit country for wildlife trafficking. Examples caught at customs gates are concrete indicators of this importance. The main purpose of this study is to make a situation assessment based on the data of the inspections carried out at customs between the years 2019-2025.

Developing countries of Asia, Africa and Latin America are a network of wildlife producers. North America, Japan, Europe and other rich, industrialized countries are called wildlife consumers. Producer countries can earn large sums of money as the market value of their wildlife species increases as they become rarer (Inskipp and Wells, 2019).

According to UNEP's 2016 report "The rise of environmental crime", wildlife crime is increasing at an astonishing rate. The report reveals that this field of crime has diversified to become the 4th largest crime sector in the world within a few decades and has grown 2-3 times faster than the global economy. INTERPOL and UNEP estimate that USD 91-258 billion worth of natural resources are stolen by criminals annually. According to official sources from CITES and EUROPOL, illegal wildlife trade is estimated at around USD 25 billion per year (Uyar, 2022; UNEP-INTERPOL, 2022). Effective enforcement of the CITES Convention at customs is crucial to prevent the illegal trade of endangered species. Customs inspections ensure the verification of permits and documentation, helping to stop smuggling and false declarations. In this way, biodiversity is protected, and international trade is maintained on sustainable grounds.

According to current data from General Directorate of Nature Conservation and National Parks (NCNP), there are currently 785 wild animals in Türkiye. 650 animal species are under protection, including 123 of 154 mammals, 386 of 490 birds and 141 of 141 reptiles (NCNP, 2023). In coordination with the CITES Convention, there are 11 rescue and rehabilitation centers across Türkiye (Figure 1). Türkiye has 11.466 natural species, 3.649 endemic species (31.82% endemic species ratio), 171 alien species and 70 agricultural species, totaling 11.707 flora. Hybrids are not included in this total (Güner et al., 2012; Wildlife Rescue, 2022).

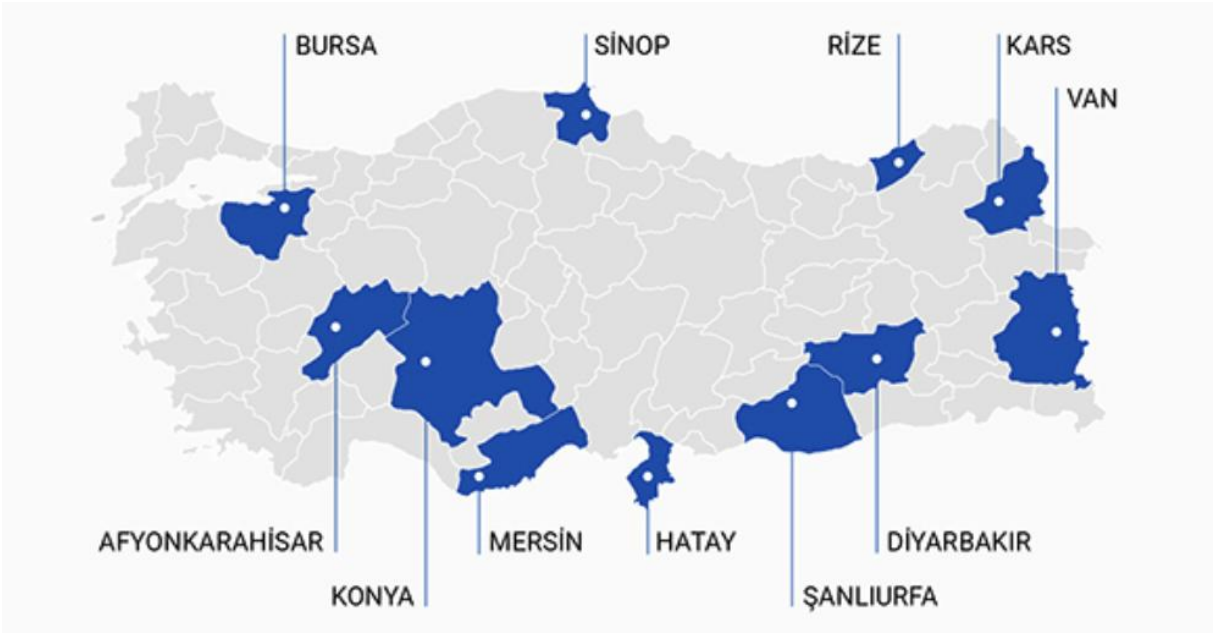

Figure 1. Rescue and rehabilitation centers across Türkiye (Wildlife Rescue, 2022).

Treatment and care of wild animals provided by veterinarians at these centers are released back into the wild following observation and evaluation. In this context, in 2022, the General Directorate of NCNP, affiliated with the Ministry of Agriculture and Forestry, treated 11.377 wild animals at 11 rehabilitation centers (province names) established to support wildlife, enabling them to return to their natural habitats. In 2024, 400 birds, including owls, red hawks, forest owls, eagles, and partridges, were treated at the center and released into the wild. The Ministry of Agriculture and Forestry is working to expand these centers throughout Türkiye (Wildlife Rescue, 2022; Rehabilitation, 2024).

According to Muloin (1998), Tapper (2006), UNWTO (2022), and Uyar (2022) benefits of wildlife development are as follows:

- Biodiversity: In nature, different species are connected through various food webs. The disappearance of one species could influence several others down the line.
- Agriculture: Promoting wildlife conservation could help secure future food supplies.
- Scientific Research: There may be many undiscovered plants and animals in the wild. Fifty percent of the drugs available in the United States were originally developed from microbial organisms, plants, and animals.
- Economics of Eco-Services: Ecosystem activities have an effect on the quantity and quality of fresh water accessible to humans.
- Ecotourism: Enjoying African ecosystems has been a tremendous stimulus for economies within Africa.
- Environmental Indicators: Various animals can serve as indicators for other environmental problems is one of the rarely discussed benefits of wildlife conservation. The loss of peregrine falcons and bald eagles was one of the factors that alerted scientists to the toxicity of DDT, unnoticed for longer in a less diverse ecosystem.
- Education: Studying animals and their habitats can be a valuable learning experience for students of all ages.
- Psychological Benefits: Ecotourists experience a tremendous sense of wonder, contentment, and fulfillment from their wildlife encounters.

Due to these vital benefits, it is crucial to prevent the intentional or unintentional overexploitation of plant and animal species (including live specimens or their parts) under CITES. Indeed Buckley (2012) states that the impact of rare animals used as souvenirs remains one of the least studied areas of research into sustainable tourism. Despite Buckley's correct assessment and approach, these effects are still not fully explored today.

1.1. The socio-economic value of wildlife and monitoring illegal trade

According to the information from UNEP (2019) issued brochure, it is stated that, over the 10 million CITES trade transactions reported by Parties in the last decade, 78% involve fauna (animals), and 22% flora (plants). When examining the literature and official documents, it has been determined that the species most frequently caught illegally are flora. The most often smuggled species include birds, insects, reptiles, plants, mollusks and amphibians. Insects are employed in the cuisine, pharmaceutical, cosmetic, and dyeing industries as colorants, as well as in resistance tests against environmental stressors such extreme heat, cold, or radiation. Collectors can purchase butterflies. Birds are collected and utilized for scientific research. In the textile, cosmetic, and medical industries, reptiles are utilized for their eggs, skin,

and poison. Mollusks and amphibians are kept as pets or utilized in the culinary, cosmetic, and decoration industries (UNODC, 2011; Nellemann, C., 2012; OECD. Publishing. 2012; Erol, 2014; Birben ve Gençay, 2019).

Turkish customs records mention CITES, but some reports are generally incomplete and questionable in terms of species. It has been determined that the reports lack sufficient species data or, even if the data is available in the records, it does not indicate whether the species is CITES-listed. Tourism officials, collectors, museum directors, international scientific researchers, pet shops, and officials using plant and animal parts in clothing, medicine, and cosmetic products should pay attention to whether these species are endangered and whether they are imported into the country with a CITES certificate.

In addition to these data from the Turkish Ministry of Trade, when the illegal wildlife trade attempts identified by the Ministry of Agriculture and Forestry based on its inspections and reports are taken into account, it is evident that there has been a significant increase in this area in recent years. CITES is not just a trade convention; it should also consider the circulation of many natural resources around the world and their impact on ecological processes. The international ICCWC consortium (CITES, INTERPOL, UNODC, WCO, the World Bank) is working diligently and implementing projects to examine the reasons driving wildlife trade underground. In addition, the role of the ICCWC consortium in providing deterrence is crucial, and INTERPOL is one of the highly effective organizations supporting this through periodic regional operations.

The text of the CITES Convention consists of 25 articles and 3 appendices. Each party has liability to designate a management authority, a scientific authority and an enforcement authority, and to notify these authorities to the secretariat based in Switzerland (Uyar, 2023; CITES, 2024).

CITES works by subjecting the international trade of specimens of selected species to certain controls. The import, export, re-export and possession of species covered by the Convention are processed through a permitting and certification system. These authorities are responsible for ensuring that trade flows properly.

The main objectives of the Convention (CITES, 2024):

- Monitoring and, where necessary, stopping international trade in endangered or potentially endangered species,
- Preventing the exploitation of the ecological balance through international trade,
- Assisting the parties to ensure the sustainable use of their biological resources.

The effectiveness of international conventions for the effective protection of wildlife can be measured in various ways. The success of conservation and sustainability efforts based on legal norms can be measured by parameters such as the prevention of illegal activities and the reduction in the number of endangered species in wildlife resources.

This study examined official announcements of the illegal wildlife trade reports from the Ministry of Trade in Türkiye based on customs gate controls conducted between 2019 and 2025 (Ministry of Trade, 2024). The official announcements on wildlife trafficking under investigation presented the recorded incident data, and it was possible to examine the scope of the report in terms of reporting technique.

2. MATERIAL AND METHOD

Specifically, in order to investigate the adequacy of reports on wild animal and plant smuggling held over a 6-year period, all official announcements by the Turkish Ministry of Trade were examined and compiled into a table in MS Excel 2021 (Ministry of Trade, 2024). The columns in this table consist of border gate, geographic coordinates for each location (latitude and longitude), country of origin and destination, species seized, date and time, nationality of the person, how it was discovered, whether it was in scope of CITES, legal sanction process, and seizure data.

It was observed that no detailed research had been conducted for Türkiye on this subject previously. Therefore, to identify the intensity of illegal activities at border crossings, a heat map was created using the geographic coordinates where illegal activities were detected. The R programming language was used to generate these data.

As data source; a manually compiled dataset containing 33 key locations (airports, borders, ports, and cities) where wildlife trafficking incidents were reported. Value shows the relative intensity of trafficking activity (higher value = more cases). Administrative province boundaries for Türkiye were obtained using the Natural Earth dataset via the rnaturalearth package. Provinces are shown as polygons with grey borders. Points represent locations of recorded wildlife trafficking incidents. Size corresponds to the number of incidents (value). Color uses a gradient from light red (#FFCCCC) to dark red (#990000) to reflect intensity. The heat map was generated using ggplot2 for plotting and theming. Spatial features were managed with sf (simple features). Data for boundaries was retrieved via rnaturalearth and rnaturalearthdata. “ggplot2” is used for map plotting and styling, “sf” is used for spatial data handling and plotting, “rnaturalearth” is used for for retrieving country and province borders, rnaturalearthdata is used for Natural Earth base data.

In this regard, it is important to be well aware of the power of CITES scientific authorities and to follow potential ways of improvement in order to interpret field applications in terms of legal liabilities. This is because when an illegal species is seen at border gates, whether it falls under CITES is clarified by obtaining the opinion of the scientific authority. The institutional structure of the scientific authorities of the 185 countries that are members of the Convention was also examined, and the situation in Türkiye was evaluated on this matter (CITES, 2024).

➢ An understanding of the CITES authorities of Türkiye, which are responsible for monitoring these illegal activities and related matters, ensures a clear understanding of their working organization and division of responsibility. Türkiye's CITES structure is as follows (CITES, 2024):

Management Authorities

Lead Management Authority: Ministry of Agriculture and Forestry.
Head Office (Coordination): General Directorate of Nature Conservation and National Parks.
Regional Departments: Nature Conservation and National Parks (NCNP) *Ankara, Istanbul, Izmir and Antalya Departments* for birds, mammals other than marine mammals, reptiles, amphibians and arthropods.

Other Management Authorities
General Directorate of Forestry: Timber species and other forest products.
General Directorate of Plant Production: Live plants.
General Directorate of Fisheries and Aquaculture: Aquatic animal species.

Scientific Authority
TÜBİTAK (Scientific and Technological Research Council of Türkiye)

Enforcement Authorities
Ministry of Trade (General Directorate of Customs, General Directorate of Imports)
Ministry of the Interior (General Directorate of Security - Department of Anti-Smuggling and Organized Crime, Gendarmerie General Command - Department of Public Security, Coast Guard Command). *The General Directorate of Imports of the Ministry of Trade publishes the CITES Communiqué every three years.*

The main task of the customs authority is to control the legal and illegal trade in endangered animal and plant species and products made from them. The ministry data from the last six years has been examined, particularly regarding the monitoring and intervention of illegal activities within the scope of the duties of enforcement authorities, which are CITES implementing institutions. Based on the results obtained after this examination, the points that need to be developed are listed in the conclusions section.

3. RESULTS

Following the institutional analysis of the scientific authorities of 185 countries that are of great importance at customs; this section provides a general international assessment under the heading “CITES species in smuggling reports,” followed by data on the numerical situation in Türkiye. The current status of legal regulations in Türkiye for the legal stage of the seizure process is explained. Seizure and confiscation policies are explained in terms of how the forfeiture heading in the agreement is adapted to Türkiye. Illegal wildlife trade data is quantified and explained by displaying it on heat map.

According to CITES database, it has been determined that the highest scientific authority comes from 62 parties within the ministry institutions. It is also known that management authorities are mostly selected from ministerial institutions. This number is followed by uncategorized government institutions with 56 parties. Other science authorities are: zoo, office, school, laboratory, private sector, veterinary service, conservation office, NGO, agency. It is also determined that the scientific authority of 31 countries consists of universities. Among the Scientific Authorities of all CITES parties; 62 are ministries, 31 are universities and 6 are both universities and ministries. When we look at the number of scientific authorities, the majority of which are ministries according to the data of all members. Scientific authority is TÜBİTAK in Türkiye, and preparing Conference and Parties (CoP) reports, annual trade reports while helping management authority for effective conservation of wildlife (numbers are generated from CITES, 2024 by author).

3.1. CITES Species in Smuggling Reports

It is useful to look at recent research that can help you understand the literature on this subject in greater depth. There is a great deal of research not specific to CITES but aimed at improving the economic and logistical aspects of commercial flows. These studies should be evaluated separately in terms of how endangered species can be identified at border

crossings and subjected to rescue and rehabilitation, legal, and other procedures (Polemis and Tsionas, 2016; Shahrokhi Shahraki and Bachmann, 2018; Capello et al., 2018).

Wildlife originating from the American continent is a low priority for everyone except relevant specialized agencies, both in the United States and in other countries in the Western Hemisphere. Unlike narcotics, illegal wildlife trafficking is also monitored by a small and specialized agency; general border guards are only lightly trained and moderately motivated to detect such shipments. The process is slow but certain. Wildlife sources from other continents are generally prioritized (Uyar, 2023). Despite these claims about the importance of the illegal wildlife trade, there is very little systematic academic research on this trade. This study relies largely on reports from federal investigations, individual cases, and other government studies, journalists' books, and a few interviews with experienced government researchers. Therefore, its limitations are the scope of the government's knowledge about the trade (Reuter and O'Regan, 2017).

Studies examining the economic effects of increasing the number of customs officers at 17 major land border crossings and 4 international airports in the US have revealed what factors affect waiting times at customs. Adding one additional customs officer to the staff resulted in a reduction in waiting times ranging from 8% to 100%. It was determined that this contributed $64.8 million annually to the US GDP and generated 1.084 new jobs (Roberts et al., 2014; Avetisyan et al., 2015). Today, however, FWS officials have stated that the length of the waiting period is not significant when deciding whether a species is subject to investigation and whether it is subject to CITES. However, the situation is different for live wild animals, which are sent to zoos designated as rehabilitation centers after undergoing health checks (Uyar, 2023).

In this research, data from the last 6 years of work carried out by CITES enforcement authorities together with customs personnel at customs were examined. According to the Ministry of Trade's data, CITES species were identified in 46 of the 103 seizures made in the last 6 years, while the species were not specified in 56 seizures. No legal action was taken in 1 seizure because a non-CITES species was identified. Seizure and legal proceedings were initiated in all other cases.

3.2. National Legislation on CITES

Under Article 90 of the Turkish Constitution, the CITES Convention is a convention guaranteed by Turkish law. The provisions of this Convention cannot be brought to the Constitutional Court and no lawsuit can be filed for its annulment. After being signed by Türkiye and published in the Official Gazette, the CITES Convention has the force of law and contains binding provisions for administrative and judicial bodies. The existence of an implementing regulation serves as a guide for the implementation of liabilities and is based on the Convention, which has the force of law (Uyar, 2022; Uyar and Elvan, 2024).

There is no CITES training program for prosecutors and judges working in units dealing with investigations and prosecutions related to the CITES Convention. In cases of seizure, confiscation, and administrative sanctions, the staff of the Provincial Directorate of NCNP prepare and provide information notes to judicial officials on matters brought before the court, and also explain the procedures, application, and scope of the legislation verbally. According to Turkish legislation, confiscation with internal compensation is a type of sanction applied only to native species. If the species is native, compensation penalties are applied in addition to administrative fines.

In the translation of the agreement text published in the Official Gazette, the term "confiscation" has been translated as "müsadere," but another equivalent of this word is "seizure," and in Turkish law, seizure and confiscation are different criminal procedure law practices. The Management Authority's practice is not a "confiscation" requiring a court decision, but is in fact legally a "seizure" (Uyar, 2023).

3.2.1. *Seizure and Confiscation Policies*

According to international practice, the procedures for processing identified CITES species are carried out through two separate methods: "seizure" and "forfeiture," either by court order or as evidence for a court order. In CITES Convention, these procedures are generally referred to as "confiscation"; the two terms used can be summarized as follows:

Seizure: Based on probable cause that a crime has been committed, the government may seize evidence as part of its investigation. The seized evidence will be used to prove the elements of the crime.
Forfeiture: During a criminal investigation, the government will request the confiscation (forfeiture) of evidence upon confirmation of the crime. Some criminal laws have established provisions for seizure. If a person is acquitted or no charges are brought, the seized evidence is returned to its owner.

For CITES species, public forfeiture is commonly initiated by member countries (in cases where no criminal complaint has been filed). The public forfeiture process is carried out in accordance with the laws. In short, the government follows the guidelines set forth by the law to seize assets instead of pursuing criminal charges.

Any party with an interest in the goods may file a written objection to the seizure with the court.

The Turkish text of the Agreement published in the Official Gazette regulates “confiscation” procedures for customs processes, not “seizure.” The CITES Implementation Regulation regulates ‘’seizure’’ procedures, not “confiscation” (Uyar, 2023).

Assuming that every country has adequate deterrent legal infrastructure and monitoring mechanisms, it is still surprising to see and report that trade moves underground at the first opportunity (Zhang et al., 2008).

3.3. Türkiye Ministry of Trade’s Trafficking Records

Following meetings with the four CITES regional offices in Türkiye, it was determined that İstanbul is the province with the highest volume of wildlife trade by air, land, and sea. In this regard, it can also be said that İstanbul has a very high volume of wildlife permit/document flow.

Furthermore, an examination of Ministry of Trade data reveals that over the past six years, illegal wildlife activities were most frequently detected at Istanbul Airport, Habur Border Gate, and Sarp Border Gate. Almost all of these activities were detected while attempting to enter Turkish territory. During this process, the aforementioned unregistered items were confiscated and administrative fines were imposed.

The contents of the reports of 103 cases obtained from the official website of the Ministry of Trade over the approximately 6-year period from January 2019 to September 2024 primarily include: date, time, place of origin, destination at the time of capture, customs gate, nationality of the person captured, species captured, method of seizure, whether the species are covered by CITES, whether they were live or dead, and whether they involved legal proceedings and seizure. 46 of the seized species were in the CITES category. Almost all of the records for these cases contain investigation data.

The intensity of illegal wildlife trafficking cases seized in Türkiye, based on border gates, is presented with an intensity map. The map visualizes wildlife trafficking activity across Türkiye between 2019–2025, based on recorded incidents at airports, border gates, ports, and specific cities (Figure 2).

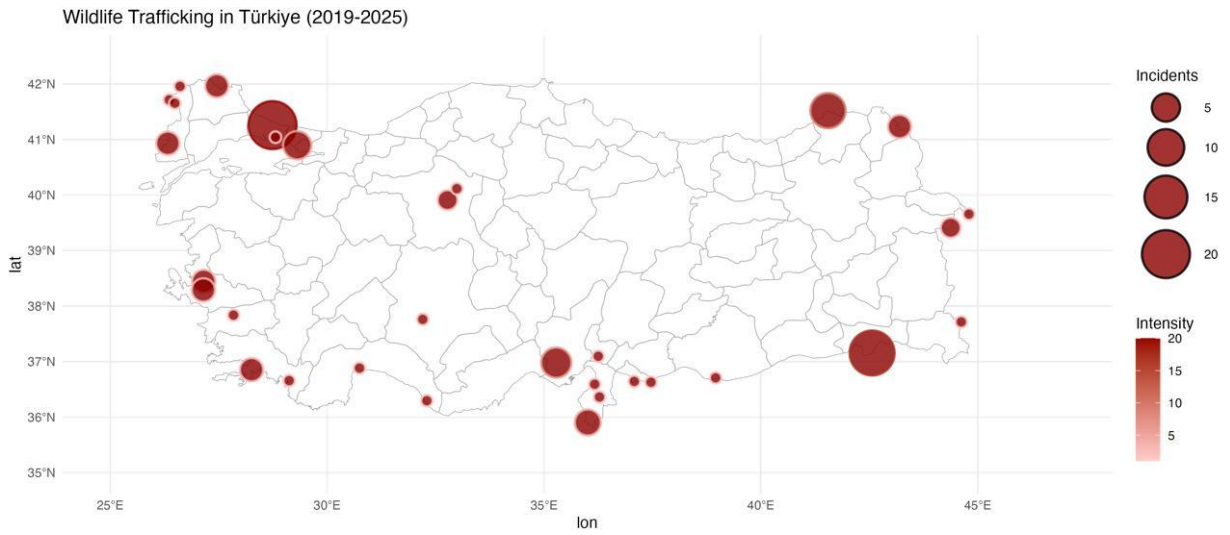

Figure 2. Wildlife trafficking incidents’ intensity in Türkiye.

This map presents a spatial distribution of wildlife trafficking incidents detected across Türkiye between 2019 and 2025. Each plotted point represents a confirmed location where wildlife or wildlife-derived products were seized, intercepted, or reported. The data includes a variety of entry and exit points such as international airports (e.g., Istanbul Airport, Sabiha Gökçen Airport, Adnan Menderes Airport), land border crossings (e.g., Habur, Sarp, Kapıkule), maritime ports (e.g., İskenderun Limakport, Fethiye, Marmaris), and specific cities or customs warehouses where trafficking activity was recorded.

The intensity of activity at each location is expressed by a quantitative value, representing either the number of seizures or the relative frequency of detected cases. Higher values indicate more prominent trafficking hotspots. By visualizing these data points over the provincial borders of Türkiye, the map helps to identify key trafficking routes, high-risk border gates, and major transportation hubs that serve as gateways for illegal wildlife trade. This map supports further monitoring, risk assessment, and prioritization of enforcement efforts, allowing authorities, researchers, and conservation organizations to better understand the geographical patterns of wildlife trafficking and to allocate resources effectively

4. DISCUSSION AND CONCLUSIONS

Due to the research findings the discussion of perspectives is as follows:

Approach 1 (Implementation conflict): Conflicts of interest and differences between rich and poor countries make it difficult to implement wildlife conservation conventions. Countries tend to avoid assuming their share of responsibility. The question of who should share the burden and in what proportions in solving environmental problems, especially those of a global nature, is also a source of controversy between developed and underdeveloped countries.
Those who argue that the main pollution is caused by industrial enterprises in industrialized countries argue that it would be more in line with the principles of equity for them to bear the costs of preventing and eliminating pollution (Polluter Pays Principle in interntional law).

Approach 2 (Awareness policy): For an environmental law to be effective at the international level, first of all, environmental values must be recognized internationally as a common asset of all societies. All societies should be made aware of the catastrophic consequences that await humanity in the event of the destruction of these values. These efforts will increase environmental awareness in society (Non timber forest products, importance of ecological balance, benefits of nature etc.).
Approach 3 (Categorizing): Recognizing that many societies depend on wildlife trade (wildlife producer countries and consumer countries), solutions need to take into account the type of use and social scale, distinguishing between essential and 'luxury' or non-essential uses of wildlife.

Approach 4 (Alerting tradors): CITES has set its strategic objectives for 2021-2030 and has asked parties to recognize illegal trade as a serious crime. Today, traders still rarely provide evidence of the sustainability of captured animals, and the responsibility for this is often placed on any regulator that does not have sufficient assessment capacity. The identities of those who provide information on illegal activities, known as whistleblowers, should be kept confidential for deterrence purposes.

Approach 5 (Incentives): The vast majority of protected species are found in developing countries, where conservation mechanisms are not sufficiently and effectively utilized. A certain segment of society in these countries earn income from protected species and their by-products. For these reasons, it has become clear that trying to improve CITES incentive capacities will be effective. This is because it is known that studies and research have shown that trade tends to continue illegally when there is administrative pressure. Balancing initiatives and proposals to ensure that trade is sustainable and that many people are not deprived of economic gains is likely to be successful.

According to a comprehensive study conducted in Hungary, there have been developments in awareness and methodology regarding reporting and record-keeping at customs. In this research, customs officials record which types of goods are most frequently involved in smuggling using statistical tables. Seizure statistics for the 2015–2019 period were kept and analyzed separately. These records also reveal the routes of smuggling (air, land, mail) and the concealment methods used. This study has revealed some shortcomings. It is noted that there are no officials specializing in nature conservation at customs, and that records are often kept only at the level of “type of crime” and “product seized.” In most cases, the records were closed because the perpetrators were unaware that the species were protected. This highlights the lack of adequate training and information. This situation is unfortunately the same in Türkiye. As a proposed solution, specially trained personnel should be assigned for more systematic reporting. In smuggling cases, not only the products but also the relationships and network structures of the perpetrators should be reported. It is emphasized that inspections, records, and reporting must be integrated with international databases (e.g., CITES, Interpol, Europol). In summary, this recent study was conducted through customs reporting and record-keeping, seizure statistics, case-based records, and surveys. However, due to a lack of expertise and fragmented legislation, records are often inadequate. A stronger standard reporting system and regular record-keeping are recommended (Zsigmond and Kovács, 2021).

It is obvious that a world standard should be set for determining whether wildlife flora and fauna elements are CITES species at customs as soon as possible. While determining this standard, it should be taken into account that customs inspection officers and customs officials most frequently make species determinations by consulting their own Scientific Authority. The time it takes for scientific authority decisions to be reflected in the bureaucratic process, the variable methods of accessing instant data and the lack of sufficient staff trained in species identification prolong customs processes and put species identification at risk.

The convention, has its roots a history of nearly 60 years. However, since then, even in countries with the lowest crime rates, it is still seen that there is illicit wildlife trade at a level that affects the world's biodiversity. One of the main reasons for this increase is the race to obtain economic returns and patents for useful species. When examined by species in Türkiye, it can be said that the health sector is the top priority. The large number of medicinal leeches caught in Türkiye can be explained in this way. The ministry says that goldfinches and leeches are the most commonly seized species. The main reason for this is that leeches are used in alternative medicine, while goldfinches are sought after for their unique appearance and commercial value. It is obvious that improvements will be made with the motto of "*Conscious Society and Decisive Authorities*". Societies must be convinced that protection is more cost effective and beneficial. Because people are unaware, they may purchase souvenirs made from parts of endangered species at tourist destinations. Sometimes even the sellers are unaware of this situation. Or there may be countries that continue to trade for economic gain without knowing what kind of disasters illegal wildlife trade can cause for our environment. One of the most pressing issues is that plant and animal species transported to new countries as a result of illegal trade can spread as invasive alien species in their new habitats, causing rapid economic decline in both urban and rural green spaces.

Conclusions of the Results are as follows:

- Even if the customs inspection period is extended, there are countries known to provide effective protection with a small team. This once again highlights the importance of personnel who have a good understanding of the subject and can effectively communicate with relevant institutions.
- Biosmuggling, which causes deterioration of the natural balance, decrease in the richness of endemic species and unauthorized use of natural resources, should be prevented and the personnel and local people should be well trained in its detection and cases should be recorded properly. In this regard, cooperation with scientific authorities should be carried out. Regional and international coordination, through early detection systems and Controls, is essential to prevent bio-smuggling.
- More units that control and monitor illicit trade must be established. In this regard, protecting the anonymity of those who report smuggling would be a suggestion that facilitates a solution. The existing capacity of the relevant state institutions should be strengthened, new structures should be established and relevant experts should be assigned to these units.
- National legislation, policies and legal sanctions should be strong in order to control wildlife trafficking and reduce the damage. When formulating national policies and initiatives, policy makers might use international forestry statistics as a reference. But it is noted that inadequate data and monitoring weaknesses exist in many countries when it comes to assessment of flora and fauna.
- The provisions of the CITES Convention should be effectively implemented. Customs and enforcement officers should be well-trained and their labor rights should be improved in each country. It is very important that experts trained in CITES be employed at border crossings and that these experts maintain close communication with scientific authorities. Training packages should be developed for CITES implementation at border controls, and the effective implementation of digitalization must be ensured. Scientific events should be organized about the activities of scientific authorities and more staff should be employed in this field.
- It is important for the future of mankind to be careful about the excessive and uncontrolled use of wild animals and plants. Social participation in decision-making, research/development dimension and resource utilization dimension of forest villagers, as well as the integration of wildlife in decision-making processes will ensure full protection.
- The number of scientific authorities such as universities, institutes and laboratories should be increased in parties. Especially by these scientific organizations, both live flora and fauna transportation processes (IATA procedures) should be followed strictly in customs processes. Countries that regularly report trafficking have received awards. The lack of a university unit or other academic office in the scientific authorities affects the accuracy of decision-making on this issue.
- The issue of which other crimes these cases are associated with and what sanctions are subsequently applied is not available in existing databases. It is believed that making this information accessible would have a deterrent effect. In this regard, enforcement authorities should cooperate with other institutions to identify the criminal networks involved.

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REFERENCES
Avetisyan, M., Heatwole, N., Rose, A., & Roberts, B. (2015). Competitiveness and macroeconomic impacts of reduced wait times at US land freight border crossings. Transportation Research Part A: Policy and Practice, 78, 84-101.

Buckley, R., Cater, C., Linsheng, Z., and Chen, T. (2008). Shengtai luyou: Cross-cultural comparison in ecotourism. Annals of Tourism Research, 35 (4), 945–968.

Capello, R., Caragliu, A., & Fratesi, U. (2018). Measuring border effects in European cross-border regions. Regional Studies, 52(7), 986-996.

CITES (2024). CITES Convention Secretariat official website. https://cites.org/eng (accessed: 10 September 2025).

Güner, A., Aslan, S., Ekim, T., Vural, M., & Babaç, M. T. (2012). Türkiye bitkileri listesi. Damarlı Bitkiler, Nezahat Gökyiğit Botanik Bahçesi ve Flora Araştırmaları Derneği Yayını, 262.

INTERPOL. (2022). The Rise of Environmental Crime Report. https://www.interpol.int/Crimes/Environmental-crime/Wildlife-crime (accessed: 14.09.2025).

Ministry of Trade, 2024. Announcements. https://ticaret.gov.tr/duyurular (accessed: 14 December 2024).

Muloin, S. (1998). Wildlife tourism: The psychological benefits of whale watching. Pacific Tourism Review, 2 (3–4), 199–213.

NCNP (2023). Doğa Koruma ve Milli Parklar Genel Müdürlüğü biyoçeşitlilik resmi istatistikleri. https://www.tarimorman.gov.tr/DKMP/Menu/20/Biyocesitlilik-Istatistikleri (accessed: 12 September 2025).

Polemis, M. L., & Tsionas, M. G. (2016). The impact of transport infrastructure on economic growth: Evidence from the European Union. Energy Economics, 56, 384-388.

Rehabilitation (2024). Yaban Hayvanı Kurtarma ve Rehabilitasyon Merkezi Şifa Dağıtmaya Devam Ediyor https://bolge3.tarimorman.gov.tr/Haber/386/Yaban-Hayvani-Kurtarma-Ve-Rehabilitasyon-Merkezi-Sifa-Dagitmaya-Devam-Ediyor (accessed: 10 September 2025).

Reuter, P., & O'Regan, D. (2017). Smuggling wildlife in the Americas: scale, methods, and links to other organised crimes. Global Crime, 18(2), 77-99. DOI: 10.1080/17440572.2016.1179633

Roberts, B., Rose, A., Heatwole, N., Wei, D., Avetisyan, M., Chan, O., & Maya, I. (2014). The impact on the US economy of changes in wait times at ports of entry. Transport Policy, 35, 162-175. DOI: 10.1016/j.tranpol.2014.05.010

Shahrokhi Shahraki, H., & Bachmann, C. (2018). Designing computable general equilibrium models for transportation applications. Transport Reviews, 38(6), 737–764. https://doi.org/10.1080/01441647.2018.1426651. Transport Reviews, 38(4), 456-478.

Tapper, R. (2006). Wildlife watching and tourism: a study on the benefits and risks of a fast growing tourism activity and its impacts on species. UNEP/Earthprint.

UNEP. (2019). the Swiss Federal Food Safety and Veterinary Office (Swiss CITES Management Authority) Designed and printed at United Nations, Geneva – 1903324 (E) – March 2019 – 4.000 – UNEP/CITES/2019/1.

UNWTO. (2022). the United Nations World Tourism Organization, official website, https://www.unwto.org/asia/unwto-chimelong-why-wildlife (accessed: 24 July 2052).

Uyar, Ç. (2022). CITES convention impacts on the tourism in Türkiye. Humanities studies, (13), 120-130. [Alternate version: Кагдан, У. (2022). ВПЛИВ КОНВЕНЦІЇ CITES НА ТУРИЗМ У ТУРЦІЇ. Humanities Studies, (13 (90)), 120-130] DOI: 10.26661/hst-2022-13-90-14

Uyar, Ç. (2023). Legal analysis of international CITES convention in terms of Sustainable forestry (in Turkish). PhD Dissertation no. 811240. İstanbul University-Cerrahpaşa, İstanbul.

Uyar, Ç., & Elvan, O. D. (2024). Legal analysis of the CITES convention in terms of Turkish administrative and judicial processes. International Environmental Agreements: Politics, Law and Economics, 24(4), 515-538. DOI: 10.1007/s10784-024-09650-0

Wildlife Rescue (2022). Yaban hayatının devamlılığı için yaz-kış görevdeler. Anadolu Agency. https://www.aa.com.tr/tr/yasam/yaban-hayatinin-devamliligi-icin-yaz-kis-gorevdeler/2702011 (accessed: 12 September 2025).

Zhang, L., Hua, N., & Sun, S. (2008). Wildlife trade, consumption and conservation awareness in southwest China. Biodiversity and conservation, 17(6), 1493-1516.

Zsigmond, Cs., Kovács, D. (2021). Experiences of the Hungarian customs authority in international illegal wildlife trafficking. DRC Sustainable Future, 2(1): 54-60; DOI: 10.37281/DRCSF/2.1.6.

Determination of the Chemical Profile of *Petroselinum crispum* Seed Essential Oil by GC-MS

OSMAN-BODUR*[1], TANER-ERKAYMAZ[1]

Abstract: Petroselinum crispum is an aromatic and medicinal plant of the Apiaceae family, valued for its essential oils that contribute both to its distinctive aroma and its potential therapeutic properties. The present study aimed to characterize the chemical composition of parsley seed essential oil using Gas Chromatography–Mass Spectrometry (GC-MS). The analysis identified a total of 33 compounds, representing 100% of the oil. The essential oil composition was dominated by monoterpene hydrocarbons and phenylpropanoid derivatives. The major constituents were α-pinene (20.87%), β-pinene (16.80%), p-mentha-1,5,8-triene (18.09%), β-phellandrene (10.02%), and myristicin (9.35%). Other notable components included 1-allyl-2,3,4,5-tetramethoxybenzene (4.84%), α-myrcene (3.86%), p,α-dimethylstyrene (3.72%), α-terpinolene (3.02%), and bicyclo[4.4.0]dec-5-ene-1-acetic acid (3.05%). Minor constituents (<1%) such as apiole, elemicin, carotol, and several sesquiterpenes (germacrene-D, trans-caryophyllene, α-elemene) were also detected. The predominance of monoterpenes, particularly α-pinene and β-pinene, is consistent with the fresh, resinous aroma of parsley essential oil and suggests possible antimicrobial and anti-inflammatory activities, as supported by literature. Phenylpropanoids such as myristicin and 1-allyl-2,3,4,5-tetramethoxybenzene, although present at lower concentrations than the pinenes, are pharmacologically significant due to their antioxidant and bioactive potential. The presence of compounds like p-mentha-1,5,8-triene and β-phellandrene contributes to the distinctive sensory qualities of parsley oil, while trace sesquiterpenes provide additional chemical diversity. In conclusion, the GC-MS analysis revealed that parsley seed essential oil is rich in monoterpene hydrocarbons and bioactive phenylpropanoids, highlighting its potential applications in the food, cosmetic, and pharmaceutical industries. The high proportion of α- and β-pinene combined with the notable presence of myristicin suggests multifunctional bioactivity. Further studies are required to evaluate the biological effects of this essential oil to support its industrial and therapeutic applications.

Keywords: *Petroselinum crispum*, GC-MS, essential oil, chemical composition.

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1. INTRODUCTION

Petroselinum crispum (parsley), a characteristic member of the Apiaceae family, has long attracted attention in the food, cosmetic, and phytotherapeutic industries due to the aromatic and pharmacological potential of its essential oils. The seed essential oil, in particular, is rich in monoterpene hydrocarbons (e.g., α-pinene, β-pinene, β-phellandrene, p-mentha-1,5,8-triene) and phenylpropanoids (e.g., myristicin, apiole, elemicin). Its composition is strongly influenced by genotype, plant organ, phenological stage, cultivation conditions, extraction technique, and geographical origin. Recent GC–MS analyses have revealed that seed oils often display chemotypes dominated by 1,3,8-p-menthatriene, β-phellandrene, apiole, and myristicin, whereas leaf and stem oils are generally apiole-rich (Herrera-Calderon et al., 2023; Franciscato et al., 2022). This variation underscores the need for well-characterized compositional data to support product standardization and targeted biological evaluation (Ganea et al., 2024).



Figure 1. *Petroselinum crispum* seeds

Gas chromatography–mass spectrometry (GC–MS) is regarded as the gold standard for elucidating the essential profiles of aromatic plants, enabling both quality control and mechanistic hypotheses of biological activity (Hamedi et al., 2019). For example, a Peruvian study of parsley seed oil identified 33–47 constituents, with major components such as 1,3,8-p-menthatriene (~22–23%), β-phellandrene (~15%), and apiole (~22%) (Herrera-Calderon et al., 2023). Similarly, analyses of leaf oils have confirmed high levels of apiole and myristicin, with substantial contributions from α/β-pinene

and terpinolene (Franciscato et al., 2022; Nouioura et al., 2024). These findings demonstrate that plant part, extraction conditions, and origin are key determinants of chemical composition (Ganea et al., 2024).

The biological potential of parsley essential oil is largely attributed to its monoterpenes and phenylpropanoids. Several reviews and comparative studies have reported that α- and β-pinene exhibit antimicrobial activity through membrane-disrupting mechanisms, while myristicin and apiole possess antioxidant and anti-inflammatory activities (Angane et al., 2022; Götz et al., 2022). Nevertheless, the alkylbenzene class (myristicin, elemicin, apiole) also raises safety concerns, particularly in relation to metabolism and dose-dependent toxicology (Götz et al., 2022). A recent toxicological review highlighted the importance of evaluating the biotransformation pathways of these compounds to establish safe limits for use (Götz et al., 2022).

Experimental studies have further confirmed the antimicrobial efficacy of parsley essential oil against foodborne pathogens. For instance, organically cultivated parsley oil rich in apiole (~62%) and myristicin (~9%) showed significant inhibitory activity against Staphylococcus aureus and S. epidermidis (Franciscato et al., 2022). Similarly, Galgano et al. (2022) demonstrated antibacterial effects of spice oils, including parsley, against Gram-positive and Gram-negative bacteria. These findings suggest that the composition–activity relationship requires systematic investigation.

From an industrial perspective, chemotypes dominated by monoterpenes contribute a fresh, resinous aroma and are valued as flavoring and masking agents, whereas phenylpropanoid-rich oils provide antioxidant and preservative functions. A recent food application study confirmed that parsley essential oil could enhance oxidative stability and reduce microbial spoilage, indicating its potential as a natural preservative (Vitalini et al., 2022). Nevertheless, sensory thresholds, dosing, and regulatory compliance remain challenges that depend heavily on the chemical profile.

At the mechanistic level, new evidence continues to emerge. For example, apiole has been shown to selectively inhibit human CYP1A enzymes, highlighting the potential risk of herb–drug interactions (Espinosa-Aguirre et al., 2024). In addition, integrative analyses combining ATR-FTIR, DSC, and GC–MS have been applied to parsley oil for rapid fingerprinting and authentication, offering a practical approach to quality assurance (Kobacy et al., 2025).

In this context, the present study aims to provide a detailed GC–MS characterization of P. crispum seed essential oil, focusing on the predominance of α-pinene, β-pinene, p-mentha-1,5,8-triene, β-phellandrene, and myristicin, and to compare this profile with previously reported chemotypes. Emphasis on seed material allows us to highlight differences in the monoterpene/phenylpropanoid balance relative to aerial part oils, with potential implications for antimicrobial and anti-inflammatory activity. Moreover, the detection of trace compounds such as apiole, elemicin, carotol, germacrene-D, trans-caryophyllene, and α-elemene provides additional insight into the sensory and pharmacological contributions of minor constituents. Ultimately, establishing a comprehensive GC–MS profile will be critical for product standardization, biological testing, safety evaluation, and regulatory alignment in both industrial and therapeutic applications.

2. MATERIAL AND METHOD

2.1. Plant material

Petroselinum crispum seeds were sourced from Manolya Doğal ve Aromatik Ürün.Gıda San.ve Tic.Ltd.Şti., a company producing oil in Isparta. Reference sample is available at the Natural Products Application and Research Center of Süleyman Demirel University, where the analysis was conducted.

2.2. GC–MS Analysis

Analysis of the essential oil compounds in *Bellis perennis* oil samples was performed using a GC-MS instrument. 50 µL of the obtained the essential oil sample was taken and diluted with 10 mL of n-hexane solvent. After the mixture was homogenized by vortexing for 3 minutes, a 1/40 dilution was made with acetone in a 2 mL volumetric flask and injected into the GC-MS instrument.

2.3. Identification of Compounds

Essential oils compounds were identified by computer search using their mass spectra either with known components (Adams, 1989), or by comparison of received chemical substances mass-spectrum which are in essential oils composition and according to mass-spectrum library (Wiley, 2007).

3. RESULTS

3.1. GC–MS Analysis Chromatogram

The analysis of the essential components of the samples was performed using gas chromatography-mass spectrometry (GC-MS). The spectra corresponding to sample are presented in Figure 2.

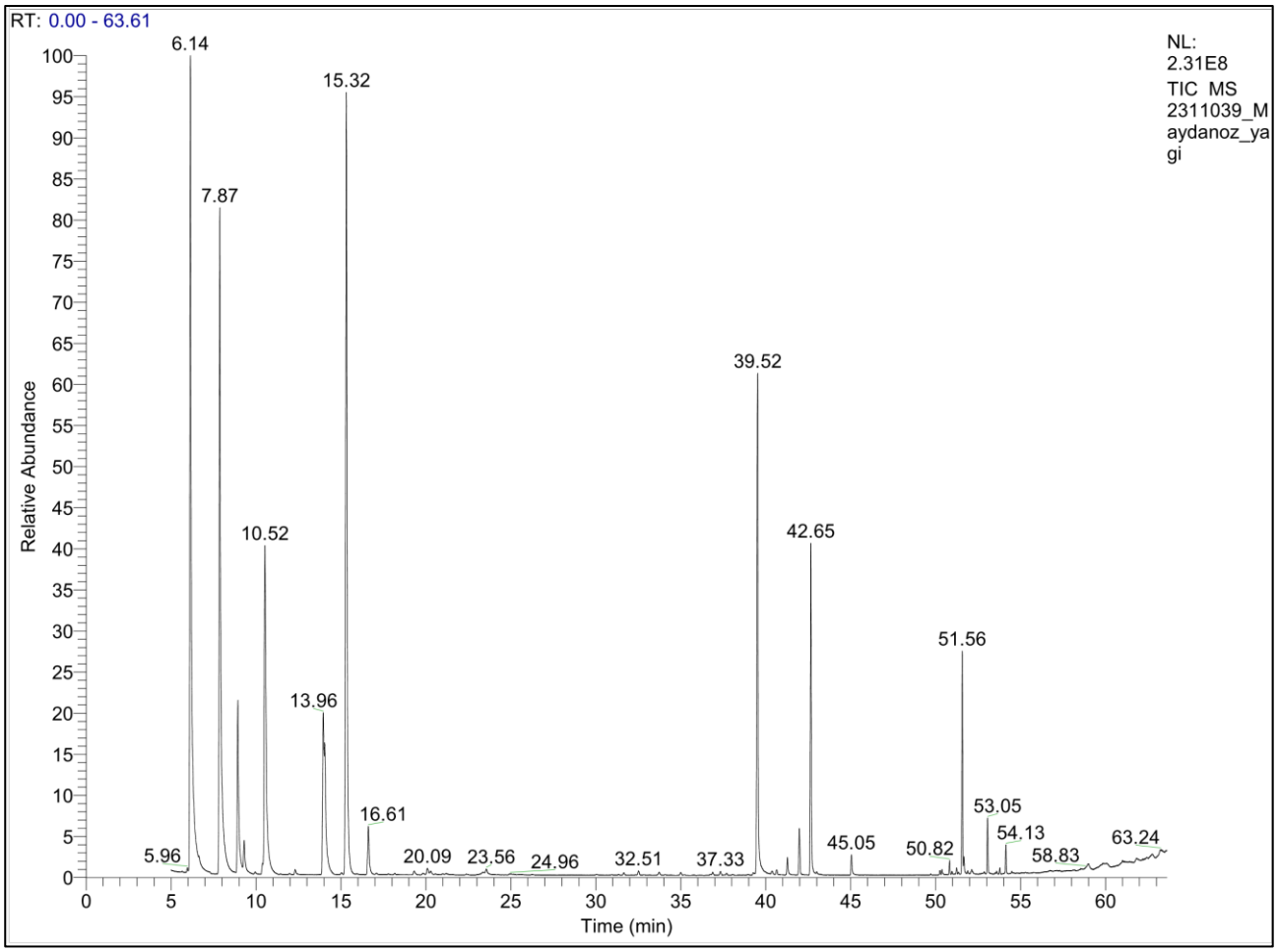

Figure 2. GC-MS chromatogram of *petroselinum crispum* seed

The percentage values of the essential components, as observed in the spectra, are presented in Table 1. The major constituents were α-pinene (20.87%), β-pinene (16.80%), p-mentha-1,5,8-triene (18.09%), β-phellandrene (10.02%), and myristicin (9.35%). Other notable components included 1-allyl-2,3,4,5-tetramethoxybenzene (4.84%), α-myrcene (3.86%), p,α-dimethylstyrene (3.72%), α-terpinolene (3.02%), and bicyclo[4.4.0]dec-5-ene-1-acetic acid (3.05%). Minor constituents (<1%) such as apiole, elemicin, carotol, and several sesquiterpenes (germacrene-D, trans-caryophyllene, α-elemene) were also detected.

Table 1. Percentage values of *petroselinum crispum* seeds essential oils obtained by GC-MS

No	Identified Compounds	% Amount	Measurement Limit	Unit
1	α-Thujene	0.04	0.01%	% (Peak rate)
2	α-Pinene	20.87	0.01%	% (Peak rate)
3	ß-Pinene	16.80	0.01%	% (Peak rate)
4	α-Myrcene	3.86	0.01%	% (Peak rate)
5	I-Phellandrene	0.81	0.01%	% (Peak rate)
6	α-Terpinene	0.05	0.01%	% (Peak rate)
7	p-Cymene	0.16	0.01%	% (Peak rate)
8	ß-Phellandrene	10.02	0.01%	% (Peak rate)
9	Delta-3-carene	0.03	0.01%	% (Peak rate)
10	ç-Terpinene	0.12	0.01%	% (Peak rate)
11	α-Terpinolene	3.02	0.01%	% (Peak rate)
12	p,α-Dimethylstyrene	3.72	0.01%	% (Peak rate)
13	p-Mentha-1,5,8-triene	18.09	0.01%	% (Peak rate)
14	(2-Methylprop-1-enyl)-cyclohexa-1,3-diene	1.15	0.01%	% (Peak rate)
15	6-Isopropenyl-3-methoxymethoxy-3-methyl-cyclohexene	0.03	0.01%	% (Peak rate)
16	6-Butyl-1,4-cycloheptadiene	0.03	0.01%	% (Peak rate)
17	4-Terpineol	0.09	0.01%	% (Peak rate)
18	p-Cymen-α-ol	0.15	0.01%	% (Peak rate)
19	Linalyl propionate	0.09	0.01%	% (Peak rate)
20	Selina-3,7(11)-diene	0.06	0.01%	% (Peak rate)
21	α-Elemene	0.09	0.01%	% (Peak rate)
22	trans-Caryophyllene	0.07	0.01%	% (Peak rate)
23	ç-Elemene	0.06	0.01%	% (Peak rate)
24	trans-α-Farnesene	0.06	0.01%	% (Peak rate)
25	Germacrene-D	0.08	0.01%	% (Peak rate)
26	Myristicin	9.35	0.01%	% (Peak rate)
27	Elemicin	0.29	0.01%	% (Peak rate)
28	Carotol	0.76	0.01%	% (Peak rate)
29	1-Allyl-2,3,4,5-tetra methoxybenzene	4.84	0.01%	% (Peak rate)
30	Apiole	0.33	0.01%	% (Peak rate)
31	m-tolyl-Dimethylacetaldehyde	0.16	0.01%	% (Peak rate)
32	Bicyclo[4.4.0]dec-5-ene-1-acetic acid	3.05	0.01%	% (Peak rate)
33	α-Benzyl-N-methyl-α-phenethylamine	0.37	0.01%	% (Peak rate)
34	Other Compounds	1.32	0.01%	% (Peak rate)
	Total	**100.00**		

4. DISCUSSION AND CONCLUSIONS

The GC-MS analysis of Petroselinum crispum seed essential oil revealed a complex chemical profile dominated by monoterpene hydrocarbons and phenylpropanoid derivatives. The major constituents were identified as α-pinene (20.87%), β-pinene (16.80%), p-mentha-1,5,8-triene (18.09%), β-phellandrene (10.02%), and myristicin (9.35%).

The high proportion of α- and β-pinene is noteworthy, as these monoterpenes are widely recognized for their antimicrobial, anti-inflammatory, and antioxidant properties. Their predominance contributes not only to the characteristic resinous and fresh aroma of parsley oil but also to its pharmacological potential. Similarly, the substantial presence of myristicin (9.35%) and 1-allyl-2,3,4,5-tetramethoxybenzene (4.84%) highlights the importance of phenylpropanoids, which are known to possess bioactive effects such as antioxidant, insecticidal, and neuroprotective activities.

The detection of minor constituents, including apiole, elemicin, carotol, and sesquiterpenes such as germacrene-D and trans-caryophyllene, provides additional chemical diversity. Although present in trace amounts, these compounds may exert synergistic effects with the dominant constituents, enhancing the overall biological activity of the oil.

From an industrial perspective, the predominance of monoterpenes and bioactive phenylpropanoids indicates that P. crispum seed essential oil could be valuable for applications in the food, cosmetic, and pharmaceutical industries. Its potential as a natural flavoring and preservative is supported by its antimicrobial activity, while its antioxidant and anti-inflammatory properties suggest possible use in therapeutic formulations.

In conclusion, this study provides a detailed chemical characterization of Petroselinum crispum seed essential oil from Isparta, Türkiye. The results confirm that the oil is rich in monoterpene hydrocarbons, particularly α-pinene and β-pinene, along with pharmacologically relevant phenylpropanoids such as myristicin. These findings highlight the multifunctional bioactivity of parsley seed essential oil and reinforce its potential for industrial and medicinal applications. Future studies should focus on in vitro and in vivo evaluations of its biological effects, as well as standardization efforts to support its incorporation into commercial products.

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REFERENCES

Adams, R.P. (1989). Identification of essential oils by ion trap mass spectroscopy. Academic Press, New York, USA.

Angane, M., Swift, S., Huang, K., Butts, C. A., & Quek, S. Y. (2022). Essential Oils and Their Major Components: An Updated Review on Antimicrobial Activities, Mechanism of Action and Their Potential Application in the Food Industry. *Foods*, *11*(3), 464. https://doi.org/10.3390/foods11030464.

Espinosa-Aguirre, J.J., Camacho-Carranza, R., Hernández-Ojeda, S.L., Cárdenas-Ávila, R. I., Santes-Palacios, R. (2024). Apiole, an important constituent of parsley, is a mixed-type inhibitor of the CYP1A subfamily. Mutation Research - Fundamental and Molecular Mechanisms of Mutagenesis. 829, 111881. https://doi.org/10.1016/j.mrfmmm.2024.111881.

Franciscato, L. M. S., Mendes, S. S., Frederico, C., Gonçalves, J. E., Faria, M. G. I., Gazim, Z. C., & Ruiz, S. P. (2022). Parsley (*Petroselinum crispum*): Chemical composition and antibacterial activity of essential oil from organic cultivation against foodborne pathogens. *Australian Journal of Crop Science, 16*(5), 605–611. https://doi.org/10.21475/ajcs.22.16.05.p3585.

Galgano, M., Capozza, P., Pellegrini, F., Cordisco, M., Sposato, A., Sblano, S., Camero, M., Lanave, G., Fracchiolla, G., Corrente, M., Cirone, F., Trotta, A., Tempesta, M., Buonavoglia, D., & Pratelli, A. (2022). Antimicrobial Activity of Essential Oils Evaluated In Vitro against *Escherichia coli* and *Staphylococcus aureus*. *Antibiotics*, *11*(7), 979. https://doi.org/10.3390/antibiotics11070979.

Ganea, M., Vicaș, L. G., Gligor, O., Sarac, I., Onisan, E., Nagy, C., Moisa, C., & Ghitea, T. C. (2024). Exploring the Therapeutic Efficacy of Parsley (*Petroselinum crispum* Mill.) as a Functional Food: Implications in Immunological Tolerability, Reduction of Muscle Cramps, and Treatment of Dermatitis. *Molecules*, *29*(3), 608. https://doi.org/10.3390/molecules29030608.

Götz, M. E., Sachse, B., Schäfer, B., & Eisenreich, A. (2022). Myristicin and Elemicin: Potentially Toxic Alkenylbenzenes in Food. *Foods*, *11*(13), 1988. https://doi.org/10.3390/foods11131988.

Hamedi, A., Pasdaran, A., Pasdaran, A. (2019). Antimicrobial Activity and Analysis of the Essential Oils of Selected Endemic Edible Apiaceae Plants Root from Caspian Hyrcanian Region (*Elaeosticta glaucescens; Malabaila secacul; Caucalis platycarpos* and *Eryngium caucasicum*). Pharmaceutical Sciences. 25. 138-144. https://doi.org/10.15171/PS.2019.21.

Herrera-Calderon, O., Saleh, A. M., Mahmood, A. A. R., Khalaf, M. A., Calva, J., Loyola-Gonzales, E., Tataje-Napuri, F. E., Chávez, H., Almeida-Galindo, J. S., Chavez-Espinoza, J. H., & Pari-Olarte, J. B. (2023). The Essential Oil of *Petroselinum crispum* (Mill) Fuss Seeds from Peru: Phytotoxic Activity and In Silico Evaluation on the Target Enzyme of the Glyphosate Herbicide. *Plants*, *12*(12), 2288. https://doi.org/10.3390/plants12122288.

Kobacy, W., Gong, X., Elshamandy, N. K. F., Zahran, H., Osman, A. I., Rashwan, A. K. (2025). ATR-FTIR, DSC, GC–MS of garlic (*Allium sativum*), parsley (*Petroselinum crispum*), and thyme (*Thymus vulgaris*) essential oils and their synergistic effects on antioxidant and antimicrobial properties. Food Bioscience. 71. 107262. https://doi.org/10.1016/j.fbio.2025.107262.

Nouioura, G., Fadili, M. E., Hachlafi, N. E., Abuelizz, H. A., Elidrissi, A. E., Ferioun, M., Soulo, N., Er-rahman, S., Lyoussi, B., Derwich, D. (2024). *Petroselinum crispum L.*, essential oil as promising source of bioactive compounds, antioxidant, antimicrobial activities: In vitro and in silico predictions. Heliyon, 10(8), e29520.

Vitalini, S., Nalbone, L., Bernardi, C., Iriti, M., Costa, R., Cicero, N., … Vallone, L. (2022). Ginger and parsley essential oils: chemical composition, antimicrobial activity, and evaluation of their application in cheese preservation. *Natural Product Research*, *37*(16), 2742–2747. https://doi.org/10.1080/14786419.2022.2125965.

Wiley, (2007). Registry, 8th ed. with NIST 05 MS Spectra, Revision 2005 D.06.00. s.l. Agilent Technologies.

Compliance of Isparta-Origin Lavender Oils (*Lavandula angustifolia* Mill.) with ISO 3515 and Their Impact on Sleep Health

OSMAN-BODUR*[1], TANER-ERKAYMAZ[1]

Abstract: Currently, sleep disorders are among the most common health problems. There is a growing demand for natural products to improve sleep quality, and among these, lavender oil is one of the most preferred essential oils. In this study, ten randomly selected lavender oil samples commercially available in Isparta Province were collected and evaluated for quality by analyzing their density, optical rotation, refractive index, and volatile compound composition according to the ISO 3515 standard. The density measurements for samples 2 and 5 were found to be 0.898 g/cm³ and 0.899 g/cm³, respectively, while their refractive index values were determined as 1.4510 and 1.4520. Additionally, the optical rotation measurements for samples 2, 5, and 7 were -5.11°, -5.19°, and -5.58°, respectively, all of which were observed to fall outside the reference ranges specified by the standard. According to the analysis of volatile compounds, the camphor content in samples 2 and 5 was identified as 1.56% and 2.55%, respectively, and the lavandulyl acetate content in sample 7 was found to be 8.13%, both exceeding the limits outlined in the ISO 3515 standard. Based on these results, it was concluded that the analyzed samples did not fully meet the standard parameters, suggesting that the therapeutic efficacy of these marketed products may be reduced or ineffective. With this study, it was aimed to draw attention to the importance of considering quality standards in product selection when sleep support is desired to be provided using lavender oil.

Keywords: Lavender oil, Sleep disorders, GC/MS Analysis, ISO Standard.

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1. INTRODUCTION

Sleep is a fundamental biological process essential for physical, cognitive, and emotional well-being. However, factors associated with modern lifestyles, such as increased stress, demanding work schedules, and extensive use of technology, have contributed to a decline in sleep quality. As a result, sleep disorders have become one of the most prevalent health issues worldwide (Morin and Benca, 2012). Millions of individuals worldwide experience difficulties in falling asleep, frequent nighttime awakenings, and feelings of insufficient rest. Chronic sleep disturbances are associated with an increased risk of developing serious health conditions, including cardiovascular diseases, diabetes, depression, and anxiety (Medic et al., 2017).

Although pharmacological treatments are commonly used in the management of sleep disorders, concerns regarding adverse effects and the risk of dependency associated with long-term use have led individuals to seek safer and more natural alternatives (Sateia et al., 2017). Aromatherapy practices, particularly the use of essential oils, hold a significant place among these natural alternatives. Aromatherapy is a complementary therapy that aims to promote physical and psychological well-being through the inhalation or topical application of essential oils extracted from plants (Lee et al., 2012).

Lavender oil (Lavandula angustifolia Mill.) stands out as one of the most commonly used essential oils in aromatherapy. Due to its key components, such as linalool and linalyl acetate, lavender oil exhibits sedative, anxiolytic, and antidepressant effects, making it a popular choice in interventions aimed at improving sleep quality (Cavanagh and Wilkinson, 2002; Koulivand et al., 2013). Systematic reviews and clinical studies have shown that lavender oil aromatherapy may be effective in treating sleep disorders related to insomnia, stress, and anxiety (Saud et al., 2022). However, the chemical composition of essential oils is influenced by various factors such as the method of production, geographical origin, and harvest time, leading to quality variations among products available in the market. In order for lavender oil to be effectively used for sleep support, it is essential that the products meet certain quality standards. The ISO 3515 standard defines quality criteria for lavender oil, including parameters such as density, optical rotation, refractive index, and volatile compound composition.

Essential oils are complex mixtures derived from natural sources, which elicit various physiological effects on the human body depending on their chemical composition. In complementary medicine practices such as phytotherapy and aromatherapy, the use of essential oils with known chemical compositions is crucial for achieving the desired therapeutic effect. Due to the lack of standardization, pharmacopoeias and standards like ISO are often referred to in order to assess the therapeutic usability of essential oils. This study aims to analyze the physical and chemical properties

of commercially available lavender oil (Lavandula angustifolia Mill.) samples in Isparta, in accordance with the ISO 3515 standard, and conduct a quality assessment. Through the evaluation of parameters such as density, refractive index, optical rotation, and volatile compound analysis, this study seeks to determine the current status of quality control for lavender oil products offered to consumers and highlight the importance of quality standards in ensuring proper product selection by consumers.

2. MATERIAL AND METHOD

A total of 10 lavender oil samples from different brands available for sale were randomly sourced from various retail locations. The samples were randomly numbered from 1 to 10 (Figure 1).



Figure 1. Lavender oil samples sourced from the market

2.1. Density Measurement

The density measurement was determined according to ISO 279 outlined in the standard.

2.2. Optical Rotation Measurement

The optical rotation measurement was determined according to ISO 592 specified in the standard.

2.3. Refractive Index Measurement

The refractive index value was determined according to ISO 280 outlined in the standard.

2.4. GC–MS Analysis

Analysis of the essential oil compounds in lavender oil samples was performed using a GC-MS instrument. 50 µL of the obtained the essential oil sample was taken and diluted with 10 mL of n-hexane solvent. After the mixture was homogenized by vortexing for 3 minutes, a 1/40 dilution was made with acetone in a 2 mL volumetric flask and injected into the GC-MS instrument.

Analyses were carried out with Thermo Scientific Trace 1300 GC gas chromatograph instrument, Thermo Scientific-ISQ7000 single quadrupole mass spectrometer detector (Thermo Fisher Scientific Inc. Waltham, Massachusetts, USA) system. Chromatographic evaluations were made using Xcalibur software. TraceGOLD TG-624SilMS GC (Thermo Fisher Scientific Inc. Waltham, Massachusetts, USA) column was used as the analytical column for chromatographic separation. The inlet temperature of the instrument was 250 °C. The injection volume was 2 µL. 1/5 split ratio was used. Helium gas was used as the carrier gas and the gas flow was 1.5 mL/min. The oven temperature was programmed from 35 °C (2 min.) to 100 °C at a rate of 2 °C /min., then from 100 °C (1 min.) to 250 °C at a rate of 5 °C/min. The detector temperature was 280 °C.

3. RESULTS

3.1. Density

The data for the density measurements of 10 samples are presented in Table 1. The obtained values were evaluated in consideration of the density range specified in the ISO 3515 standard (0.878-0.892 g/cm³). It was observed that samples 2 and 5 fell outside the specified reference range.

3.2. Optical Rotation

The data for the optical rotation measurements of 10 samples are presented in Table 1. The obtained values were evaluated based on the optical rotation range specified in the ISO 3515 standard (-12.5° to -6.0°). It was observed that samples 2, 5, and 7 fell outside the specified reference range.

3.3. Refractive Index

The data for the refractive index measurements of 10 samples are presented in Table 1. The obtained values were evaluated in consideration of the refractive index range specified in the ISO 3515 standard (1.4550 – 1.4660). It was observed that samples 2 and 5 fell outside the specified reference range.

Table 1. The analysis data of the physical parameters of the samples

Sample No	Density (g/cm^3)	Refractive Index	Optical Rotation (°)
1	0,881	1,4570	-8,62
2*	**0,898**	**1,4510**	**-5,11**
3	0,879	1,4560	-6,98
4	0,883	1,4570	-8,44
5*	**0,899**	**1,4520**	**-5,19**
6	0,880	1,4570	-8,46
7	0,882	1,4570	**-5,58**
8	0,883	1,4570	-8,61
9	0,887	1,4570	-8,55
10	0,881	1,4560	-7,43

*: Outside the reference value range

3.4. GC–MS Analysis

The analysis of the volatile components of the samples was performed using gas chromatography-mass spectrometry (GC-MS). The spectra corresponding to samples 1-5 are presented in Figure 2, and the spectra corresponding to samples 6-10 are presented in Figure 3.

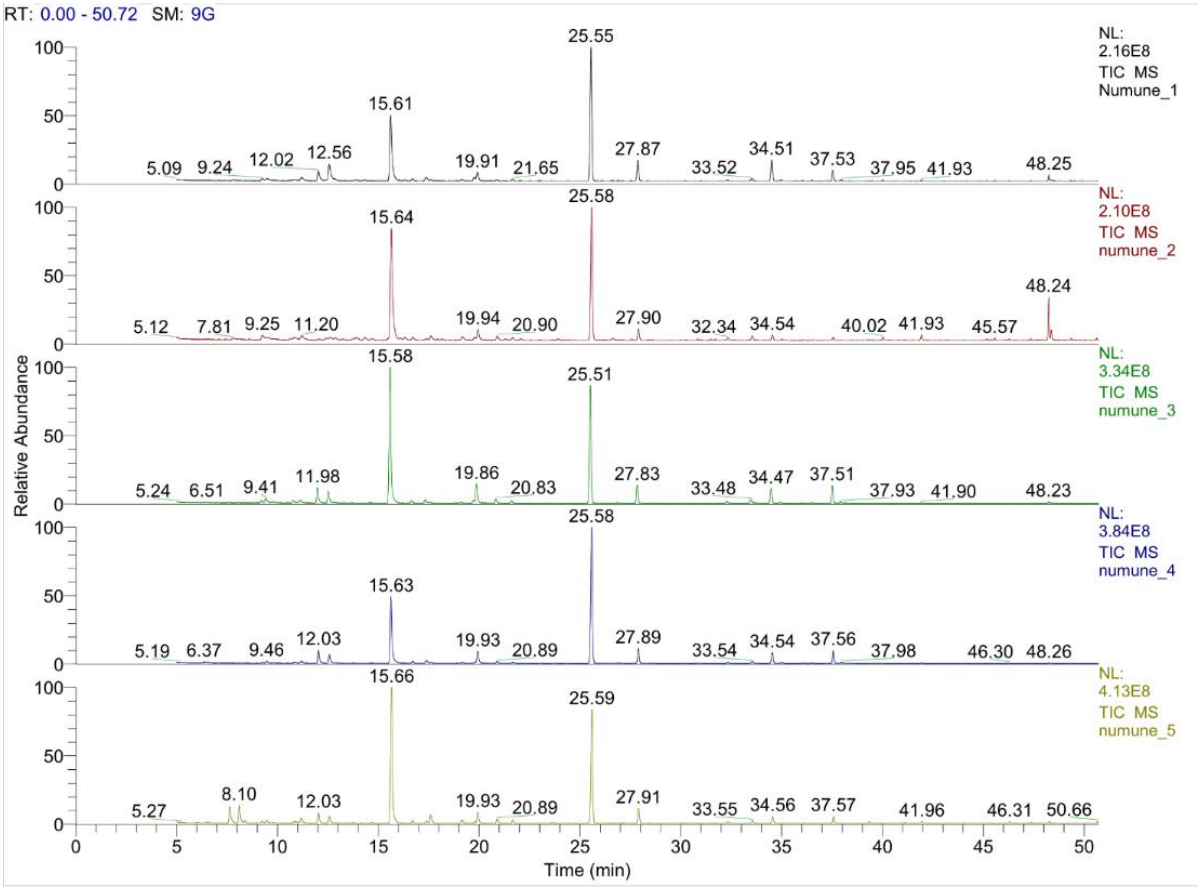

Figure 2. GC-MS spectrum of samples 1-5

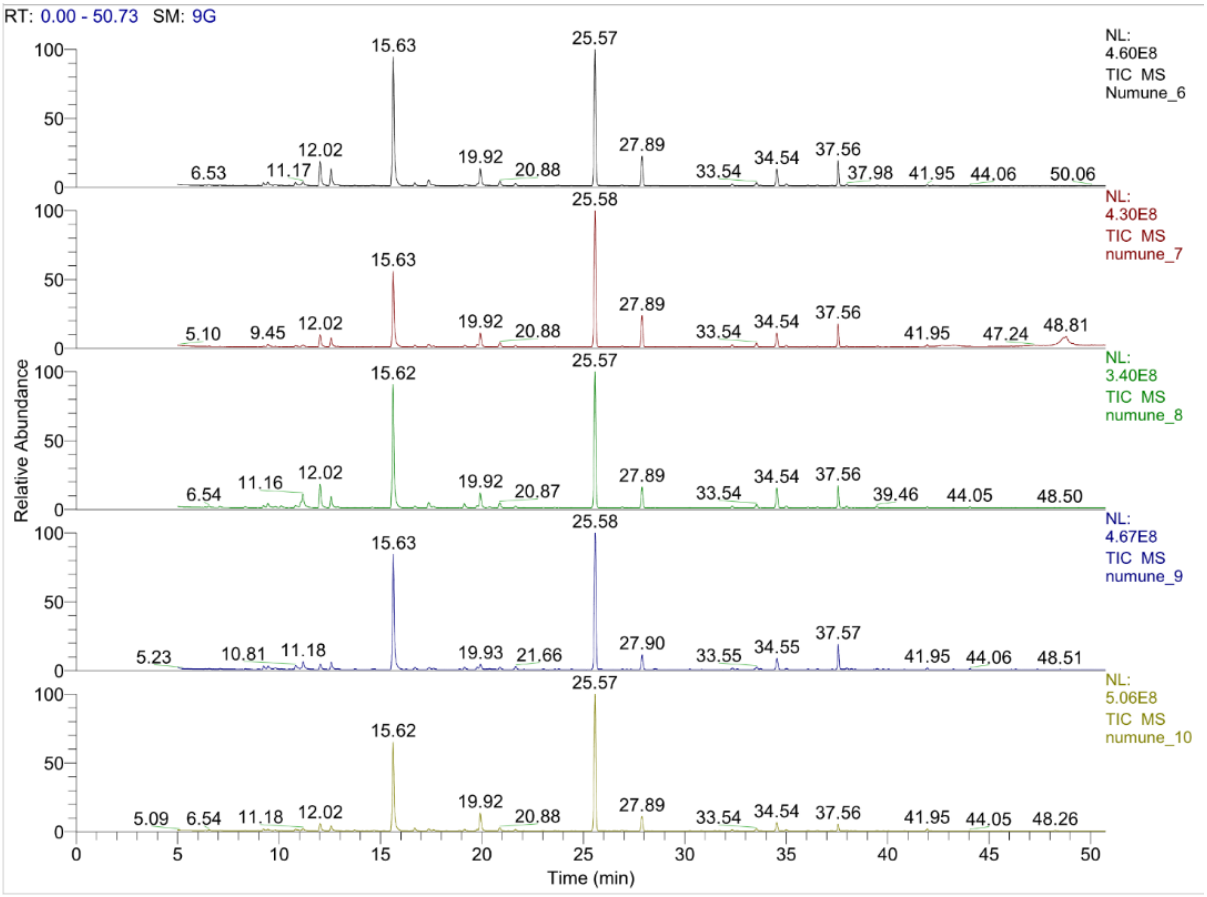

Figure 3. GC-MS spectrum of samples 6-10

The percentage values of the volatile components, as observed in the spectra, are presented in Table 2. The obtained values were evaluated based on the threshold values for the compounds ((E)-β-Ocimene, (Z)-β-Ocimene, 1,8-Cineole, 3-Octanone, Camphor, Lavandulol, Lavandulyl acetate, Limonene, Linalool, Linalyl acetate, Terpinen-4-ol, α-Terpineol, and β-Phellandrene) specified in the ISO 3515 standard.

Table 2. Percentage values of the lavender essential oils obtained by GC-MS

Compound	Sample No										ISO 3515 (%)
	1	2	3	4	5	6	7	8	9	10	
(E)-β-Ocimene	3,46	0,49	2,91	2,93	1,93	3,72	2,60	2,62	1,90	1,57	0,0-6,0
(Z)-β-Ocimene	6,06	0,29	3,81	4,21	2,78	5,28	3,40	5,21	1,26	2,20	0,0-10,0
1,8-Cineole	1,33	1,26	0,69	0,55	1,59	1,11	0,46	2,53	2,25	0,72	0,0-3,0
3-Octanone	0,71	0,67	0,61	0,19	0,46	0,58	0,09	0,41	0,84	0,52	0,0-5,0
Camphor	0,21	**1,56***	0,09	0,13	**2,55***	0,09	0,17	0,19	0,22	0,28	0,0-1,5
Lavandulol	0,92	0,49	0,49	0,23	0,29	0,30	0,57	0,40	0,54	0,25	0,0-3,0
Lavandulyl acetate	5,40	2,78	0,03	4,50	3,56	5,92	**8,13***	4,20	3,64	4,03	0,0-8,0
Limonene	0,04	0,04	0,08	0,14	0,17	0,11	0,06	0,37	0,14	0,05	0,0-1,0
Linalool	24,24	38,36	38,11	24,26	39,26	31,45	23,50	29,70	33,38	29,99	20,0-45,0
Linalyl acetate	35,49	33,06	30,31	43,23	29,82	28,81	37,61	29,30	35,57	41,25	25,0-47,0
Terpinen-4-ol	2,57	2,99	5,02	3,81	2,79	4,21	4,01	3,38	1,37	5,84	0,0-8,0
α-Terpineol	0,35	1,06	1,01	0,57	1,16	0,95	1,20	1,10	0,58	0,96	0,0-2,0
β-Phellandrene	0,02	tr	tr	0,03	tr	0,02	0,04	0,22	0,09	tr	0,0-1,0

tr: trace (< 0.01)
*: Outside the reference value range

When the data provided in the table is examined, the camphor compound in samples 2 and 5 was found to be 1.56% and 2.55%, respectively. The reference range for the camphor compound, as specified in the ISO 3515 standard, is 0.0-1.5%. It was observed that the obtained values fall outside the reference range. Furthermore, in sample 7, the lavandulyl acetate compound was found to be 8.13%, which exceeds the reference range of 0.0-8.0% specified in the ISO 3515 standard.

4. DISCUSSION AND CONCLUSIONS

In this study, ten lavender oil samples (Lavandula angustifolia Mill.) sold in Isparta were analyzed physically and chemically in accordance with the ISO 3515 standard. The density measurements indicated that samples 2 and 5 were outside the reference range, suggesting the presence of substances other than pure lavender oil or the use of non-standard methods during the production process of these samples.

When optical rotation values were examined, measurements outside the ISO 3515 reference range were obtained for samples 2, 5, and 7, indicating that the purity of the compounds in these samples may have been compromised.

Refractive index measurements also revealed that samples 2 and 5 were outside the reference limit values. This discrepancy in the refractive index supports the notion that the physical purity and chemical composition of the oils in these samples differ from those of standardized products.

The results of the volatile compound analysis revealed that the high camphor content in samples 2 and 5, and the 8.13% lavandulyl acetate content in sample 7, which exceeds the standard limit of 8.0%, may alter the characteristic soft and relaxing aromatic profile of lavender oil, potentially diminishing its therapeutic effects.

These findings indicate that some lavender oil products on the market may have a low potential to provide the expected aromatherapeutic effects, particularly in improving sleep quality. The results highlight the importance of subjecting essential oils to effective quality control tests and standardization before being marketed.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Cavanagh, H. M., & Wilkinson, J. M. (2002). Biological activities of lavender essential oil. Phytotherapy Research, 16(4), 301–308. https://doi.org/10.1002/ptr.1103

Koulivand, P. H., Khaleghi Ghadiri, M., & Gorji, A. (2013). Lavender and the nervous system. Evidence-Based Complementary and Alternative Medicine, 2013, Article 681304. https://doi.org/10.1155/2013/681304

Lee, M. S., Choi, J., Posadzki, P., & Ernst, E. (2012). Aromatherapy for health care: An overview of systematic reviews. Maturitas, 71(3), 257–260. https://doi.org/10.1016/j.maturitas.2011.12.018

Medic, G., Wille, M., & Hemels, M. E. (2017). Short- and long-term health consequences of sleep disruption. Nature and Science of Sleep, 9, 151–161. https://doi.org/10.2147/NSS.S134864

Morin, C. M., & Benca, R. (2012). Chronic insomnia. Lancet, 379(9821), 1129–1141. https://doi.org/10.1016/S0140-6736(11)60750-2

Sateia, M. J., Buysse, D. J., Krystal, A. D., Neubauer, D. N., & Heald, J. L. (2017). Clinical practice guideline for the pharmacologic treatment of chronic insomnia in adults: An American Academy of Sleep Medicine clinical practice guideline. Journal of Clinical Sleep Medicine, 13(2), 307–349. https://doi.org/10.5664/jcsm.6470

Saud, N. H., Arsyad, A., Usman, A. N., Rafiah, S., Ahmad, M., & Tamar, M. (2022). The effectiveness of aromatherapies with lavender and cinnamon essential oils on prostaglandin E2 levels in adolescent girls with primary dysmenorrhea. International Journal of Health Sciences, 6(S1), 12636–12644.

The Effect of Different Extraction Methods on Phenolic Content in Pomegranate Juice Production

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Abstract: In this study, the effects of three different methods on the extraction of phenolic compounds were investigated in the process of obtaining pomegranate extract required for pomegranate juice production. In all methods, 100 mL Water was used for extraction of phenolic compounds from 25 g pomegranate fruit and used ultra-turrax homogenization–assisted extraction for 1 minute at the begining. We studied by ultra-turrax homogenization as conventional method (5, 10, 15 and 20 minutes); ultrasound-assisted extraction (60, 80 and 100% amplitude; 5, 10, 15 and 20 min); ASE (Accelerated Solvent Extraction) (5, 10, 15 and 20 min). The phenolic compounds in the pomegranate extract samples were analysed by UHPLC-MS/MS. Punicalagin A, punicalagin B and ellagic acid compounds were detected in high amounts in the obtained pomegranate extracts. These three phenolic compounds were determined as 2297,5 mg/kg, 3545,1 mg/kg and 1231,4 mg/kg by the conventional method, were determined as 3082,6 mg/kg, 5087,9 mg/kg and 1427,1 mg/kg by ultrasound-assisted extraction, were determined also as 3173,5 mg/kg, 5138,4 mg/kg and 1638,2 mg/kg by ASE. According to these results, it can be said that ASE and ultrasound-assisted extraction provide significant advantages in terms of the amount of phenolic compounds in pomegranate juice. Additionally, it was concluded that the durations applied in the extraction methods did not significantly affect the results.

Keywords: Pomegranate juice, phenolic compounds, ASE extraction, ultrasound-assisted extraction, Ultra-Turrax homogenization

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1. INTRODUCTION

The pomegranate (Punica granatum) is a juicy, sweet-tart fruit from the pomegranate family that grows in the Mediterranean climate. Its high antioxidant content strengthens the immune system, supports cardiovascular health, and contains nutrients such as vitamins C, K, and folic acid. Its health benefits are well-known and it is widely used in traditional medicine. Pomegranate is a symbol of health, abundance since ancient times and a fruit rich in vitamins (C, K), minerals (potassium, magnesium), and dietary fiber (Benedetti, et al., 2023).



Figure 1. *Pomegranate and juice*

Pomegranate (Punica granatum L.) is historically recognized as a functional food and medicinal plant, rich in polyphenolic compounds. The fruit, a large berry known as a balausta, contains a diverse array of bioactive constituents, including high concentrations of tannins, anthocyanins, and flavonols. Global interest in pomegranate has surged in recent decades due to accumulating scientific evidence pointing toward its promising therapeutic potential, particularly in mitigating cardiovascular and non-cardiovascular diseases (Heber, 2011).

The phytochemical richness of pomegranate is indisputable, encompassing approximately 124 distinct phytochemicals that often work synergistically to exert potent antioxidant and anti-inflammatory effects (Saparbekova et al., 2022). However, the translation of this high in vitro activity into consistent clinical efficacy faces a significant pharmacological hurdle: the limited oral bioavailability of its primary native compounds.

Pomegranate polyphenols are complex secondary metabolites, chemically characterized by at least two phenyl rings and one or more hydroxyl groups. They can be broadly classified into three major groups: hydrolyzable tannins (specifically ellagitannins), flavonoids (including anthocyanins and catechins), and flavonols.

Phenolic compounds are a diverse group of naturally occurring molecules found in plants, characterized by an aromatic ring with one or more hydroxyl (-OH) groups (Sood and Gupta, 2015). They are secondary metabolites with vital functions in plants, such as contributing to cell wall formation and providing defense. Rich sources include fruits, vegetables, grains, and roots. Classified into major groups like flavonoids (e.g., anthocyanins, flavonols) and non-flavonoids (e.g., phenolic acids, tannins, stilbenes), they possess significant health-protective properties, including antioxidant and anti-inflammatory effects.

Core Structure: An aromatic ring with at least one hydroxyl group (a phenol unit).
Diversity: They can be simple phenols, phenolic acids, or more complex structures like flavonoids and lignans.
Bioactivity: Their structural variations give them a wide range of biological activities, most notably antioxidant properties.

Antioxidant Power: Phenolic compounds are the most abundant antioxidants in the human diet, helping to scavenge free radicals and protect cells from oxidative stress (Demir et al., 2019).
Anti-inflammatory Effects: They have been shown to possess anti-inflammatory properties.
Other Benefits: They also have potential anticancer and other therapeutic activities.

2. MATERIAL AND METHOD

2.1. Fruit material

Pomegranate (Punica granatum L.) fruits were sourced from Botanic Park of Süleyman Demirel University in Isparta. Reference samples are available at the Natural Products Application and Research Center of Süleyman Demirel University, where the analysis was conducted.

2.2. Three Different Methods on The Extraction of Phenolic Compounds

In this study, the effects of three different methods on the extraction of phenolic compounds were investigated in the process of obtaining pomegranate extract required for pomegranate juice production. Extractions were carried out at ambient temperature without applying heat due to the decomposition of phenolic compounds at high temperatures (Uca and Gulec, 2024) (Kashyap et al., 2021).

Ultra-turrax homogenization as conventional method
Ultrasound-assisted extraction
ASE (Accelerated Solvent Extraction)

2.3. LC–MS/MS Analysis

The phenolic compounds in the pomegranate extract samples were analysed by UHPLC-MS/MS. The homogenised 1.0 g sample was extracted with 1 ml methanol/acetonitrile (50/50) solution containing 0.1% (v/v) formic acid (Khoddami et al., 2013). The mixture was vortex mixed for 5 minutes and centrifuged at 4000 rpm at 4 ºC for 15 minutes. The supernatant obtained after centrifugation was passed through a 0.2 µm PTFE membrane filter and injected into the UHPLC-MS/MS instrument. The total analysis time was 7 minutes. The analysis and determination of the amount of phenolic compounds was performed using the Thermo Scientific Ultimate 3000 UPLC, Thermo Scientific- TSQ Fortis (Thermo Fisher Scientific Inc. Waltham, Massachussetts, USA) system. The chromatographic analyses were carried out using Xcalibur software. The analytical column used for chromatographic separation was a Hypersil Gold RP C18 (1.9µm), 50x2.1 mm, (Thermo Fisher Scientific Inc. Waltham, Massachussetts, USA) UHPLC column.

3. RESULTS

3.1. The Effects of Three Different Methods on The Extraction of Phenolic Compounds

The effects of three different methods on the extraction of phenolic compounds were investigated in the process of obtaining pomegranate extract required for pomegranate juice production. In all methods, 100 mL Water was used for extraction of phenolic compounds from 25 g pomegranate fruit and used ultra-turrax homogenization–assisted extraction for 1 minute at the begining (Amyrgialaki et al., 2014). We studied by ultra-turrax homogenization as conventional method (5, 10, 15 and 20 minutes); ultrasound-assisted extraction (60, 80 and 100% amplitude; 5, 10, 15 and 20 min); ASE (Accelerated Solvent Extraction) (5, 10, 15 and 20 min). The phenolic compounds in the pomegranate extract samples were analysed by UHPLC-MS/MS (Singh, et al., 2014).

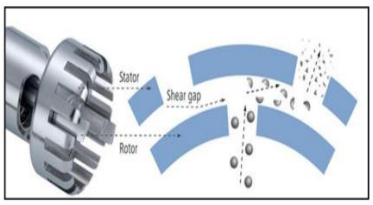

Figure 2. *Ultra-turrax homogenization*

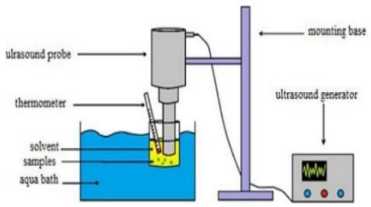

Figure 3. *Ultrasound-assisted*

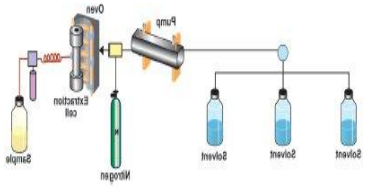

Figure 4. *Accelerated Solvent Extraction*

3.2. Results of LC–MS/MS Analysis

The mobile phases used for the analysis consisted of two variants: organic and inorganic based. Mobile phase A consisted of a 95:5 mixture of water and acetonitrile containing 0.1 % formic acid and 4 mM ammonium formate. Mobile phase B was prepared by mixing acetonitrile and water in a ratio of 95:5 with the addition of 0.1 % formic acid and 4 mM ammonium formate. Mobile phase gradient flow of LC-MS/MS was given in Table 1.
Two different solutions of the mobile phase were prepared and the phenolic compounds were analysed by applying a gradient flow programme of the analytical column (organic and inorganic based). The mass detector of the system is a triple quadrupole spectrometer and works with a combination of three consecutive quadrupoles. The ionisation technique used is called soft ionisation and is generally based on the principle of conservation of the main mass of the analyte (Kafkas et al., 2018). It generally works on the basis of positive ionisation by adding a proton to the main mass (M+1) or negative ionisation by removing a proton from the main mass (M-1). Analytical purity standards of phenolic compounds of known concentration were analysed and the data obtained with the device were compared with the analytical results of the samples. Quantitative results were obtained by comparing the data obtained with the instrument. Retention times and LOD-LOQ values of phenolic compounds were given in Table 2. MS/MS mass transitions of phenolic compounds were given in Table 3.



Figure 5. *LC-MS/MS System*

Table 1. Mobile Phase Gradient Flow of LC-MS/MS

Time	Flow (mL/min)	Mobil Fhase A	Mobil Fhase B
0,0	0,300	100%	0%
2,0	0,300	100%	0%
3,0	0,300	50%	50%
3,5	0,300	0%	100%
5,0	0,300	0%	100%
6,5	0,300	100%	0%
7	Stop flow	100%	0%

Table 2. Retention Times and LOD-LOQ Values of Phenolic Compounds

Compoud Name	Retention Time (min)	Average of Repeatability at 1 mg/Kg)	SD	% RSD	LOD	LOQ
p-coumaric acid	0,81	0,91	0,04	4,36	0,12	0,39
cyanidin	0,89	0,89	0,04	4,66	0,12	0,41
quercetin	0,96	0,88	0,05	5,20	0,14	0,46
ferulic acid	1,25	0,88	0,05	5,16	0,14	0,45
fumaric acid	1,33	0,88	0,05	5,97	0,16	0,53
rosmarinic acid	1,57	0,88	0,04	4,13	0,11	0,37
cyanidin-3-O-glucoside	3,42	0,90	0,04	4,32	0,12	0,39
punicalin	3,74	0,90	0,04	4,53	0,12	0,41

delphinidin-3-O-glucoside	3,89	0,90	0,04	4,28	0,12	0,38
granatin	3,96	0,88	0,01	1,38	0,04	0,12
pellargonidin	4,11	0,88	0,03	3,44	0,09	0,30
ellagic acid	4,36	0,90	0,04	4,32	0,12	0,39
gallic acid	4,82	0,90	0,04	4,58	0,12	0,41
punicalagin B	5,11	0,90	0,03	3,47	0,09	0,31
punicalagin A	5,71	0,89	0,05	5,44	0,15	0,49

Table 3. MS/MS Mass Transitions of Phenolic Compounds

Compound	Retention Time (min)	RT Window (min)	Polarity	Precursor (m/z)	Products (m/z)	Collision Energy (V)	Min Dwell Time (ms)
p-coumaric acid	3.5	7	Negative	163	119.1	35	27.998
cyanidin	3.5	7	Positive	287.1	137.2 / 213	30	27.998
fumaric acid	3.5	7	Negative	115.2	71.1 / 114.1	25	27.998
delphinidin	3.5	7	Positive	303.1	137.1 / 229	30	27.998
rosmarinic acid	3.5	7	Negative	359.1	133 / 135	25	27.998
cyanidin-3-O-glucoside	3.5	7	Negative	484.1	137.2 / 213	35	27.998
punicalin	3.5	7	Negative	781.1	601 / 301	35	27.998
delphinidin-3-O-glucoside	3.5	7	Positive	782.1	165	25	27.998
granatin	3.5	7	Positive	784.5	601 / 301	25	27.998
pellargonidin	3.5	7	Positive	271	149 / 215	35	27.998
ellagic acid	3.5	7	Negative	301.1	229 / 257	35	27.998
quercetin	3.5	7	Negative	301	41 / 65	25	27.998
ferulic acid	3.5	7	Negative	193	134 / 178	25	27.998
gallic acid	3.5	7	Negative	169	125	35	27.998
punicalagin B	3.5	7	Negative	1083.1	601 / 781	25	27.998
punicalagin A	3.5	7	Negative	1083.1	181	25	27.998

4. DISCUSSION AND CONCLUSIONS

Hydro Pomegranate (Punica granatum L.) is a potent source of polyphenols, dominated by ellagitannins, most notably punicalagin. Punicalagin A, punicalagin B and ellagic acid compounds were detected in high amounts in the obtained pomegranate extracts. These three phenolic compounds were determined as 2297,5 mg/kg, 3545,1 mg/kg and 1231,4 mg/kg by the conventional method, were determined as 3082,6 mg/kg, 5087,9 mg/kg and 1427,1 mg/kg by ultrasound-assisted extraction, were determined also as 3173,5 mg/kg, 5138,4 mg/kg and 1638,2 mg/kg by ASE. According to these results, it can be said that ASE and ultrasound-assisted extraction provide significant advantages in terms of the amount of phenolic compounds in pomegranate juice. Additionally, it was concluded that the durations applied in the extraction methods did not significantly affect the results. The results of phenolic compounds were given in Table 4.

Table 4. The results of Phenolic Compounds

Compound	Ultra-turrax	Ultrasound-assisted	ASE
p-coumaric acid	N.D.	N.D.	N.D.
cyanidin	236,7	228,2	276,8
fumaric acid	246,5	251,5	304,3
delphinidin	72,1	83,2	94,3
rosmarinic acid	N.D.	N.D.	N.D.
cyanidin-3-O-glucoside	177,3	189,4	189,3
punicalin	481,6	455,8	510,6
delphinidin-3-O-glucoside	204,7	171,3	341,8
granatin	184,7	183,3	214,5
pellargonidin	256,8	276,3	280,4
ellagic acid	1231,4	1427,1	1638,2
quercetin	N.D.	N.D.	N.D.
ferulic acid	43,8	58,2	66,3
gallic acid	177,8	186,7	188,8
punicalagin B	3545,1	5087,9	5138,4
punicalagin A	2297,5	3082,6	3173,5
Sum	9156,0	11681,5	12417,2

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REFERENCES

Benedetti G. , Zabini F., Tagliavento L., Meneguzzo F., Calderone V., and Testai L. An Overview of the Health Benefits, (2023). Extraction Methods and Improving the Properties of Pomegranate. MDPI, https://www.mdpi.com/2076-3921/12/7/1351

Heber D., (2011). Pomegranate Ellagitannins - Herbal Medicine - NCBI Bookshelf, CRC Press/Taylor & Francis; https://www.ncbi.nlm.nih.gov/books/NBK92772/.

Saparbekova A., Kantureyeva G.O., Kudasova D.E., Konarbayeva Z.K., Latif A., (2022). Potential of phenolic compounds from pomegranate (Punica granatum L.) by-product with significant antioxidant and therapeutic effects: A narrative review.

Uca E., Gulec H.A., (2024). Process Optimization for the Extraction of Phenolic Compounds from Pomegranate Peels: Response Surface Methodology-Desirability Function and Artificial Neural Network-Genetic Algorithm. Akademik Gıda 22(1) (2024) 23-33, DOI: 10.24323/akademik-gida.1460968.

Amyrgialaki, E., Makris, D.P., Mauromoustakos, A., Kefalas, P. (2014). Optimisation of the extraction of pomegranate (Punica granatum) husk phenolics using water/ethanol solvent systems and response surface methodology. Industrial Crops and Products, 59, 216-222.

Singh, M., Jha, A., Kumar, A., Hettiarachchy, N., Rai, A.K., Sharma, D. (2014). Influence of the solvents on the extraction of major phenolic compounds (punicalagin, ellagic acid and gallic acid) and their antioxidant activities in pomegranate aril. Journal of Food Science and Technology, 51(9), 2070-2077.

Sood, A., Gupta, M. (2015). Extraction process optimization for bioactive compounds in pomegranate peel. Food Bioscience, 12, 100-106.

Kashyap, P., Riar, C. S., Jindal, N. (2021). Optimization of ultrasound assisted extraction of polyphenols from Meghalayan cherry fruit (Prunus nepalensis) using response surface methodology (RSM) and artificial neural network (ANN) approach. Journal of Food Measurement and Characterization, 15(1), 119-133.

Demir, T., Akpınar, Ö., Haki, K., Güngör, H. (2019). Nar kabuğundan antimikrobiyal ve antioksidan aktiviteye sahip fenolik bileşiklerin ekstraksiyon koşullarinin optimizasyonu. Gıda, 44 (2), 369-382.

Khoddami A., Meredith A. Wilkes and Roberts T.H., (2013). Techniques for Analysis of Plant Phenolic Compounds. Molecules 2013, 18, 2328-2375; doi:10.3390/molecules18022328.

Kafkas N. E., Kosar M., Öz A.T. and Mitchell A.E., (2018). Advanced Analytical Methods for Phenolics in Fruits. Journal of Food Quality, Online ISSN:1745-4557.

Determination of Differences in the Distribution of Polyphenol Compounds in Olive Oils Obtained from Different Regions of Anatolia by LCMSMS

TANER ERKAYMAZ*[1], OSMAN BODUR[1]

Abstract: In this study, we investigated the distribution of polyphenols in olive oils produced from different regions of Anatolia. Olive oil is a fundamental component of the Mediterranean diet, and its beneficial health effects are largely related to its polyphenol content. This study aimed to quantitatively analyze the polyphenol compounds in extra virgin olive oil samples collected from different geographical regions. Twelve extra virgin olive oil samples from the Aegean and Mediterranean regions of Turkey, as well as from the Afrin region of Syria, were analyzed. High-performance liquid chromatography with tandem mass spectrometry (UHPLC-MS/MS) was used to determine the polyphenol compounds. The results showed that the determined polyphenol content varied between 270-850 mg/kg among the samples. The highest polyphenol content was detected in olive oils obtained from the Afrin region, produced by early harvest and cold pressing methods. Concentrations of key polyphenolic compounds such as oleuropein and p-HPEA-EDA showed significant differences depending on the geographical origin of the samples and the production method. According to these results and the information obtained highlight that polyphenol content is an important parameter in the evaluation of olive oil quality and that the effect of production processes on these compounds should be further investigated.

Keywords: Olive oil, polyphenols, UHPLC-MS/MS, phenolic compounds, Ultra-Turrax homogenization

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1. INTRODUCTION

Olive oil is a fundamental component of the Mediterranean diet, and its beneficial health effects are largely related to its polyphenol content. Olive oil is a fatty liquid extracted from the fruit of the olive tree, used extensively in cooking, cosmetics, traditional medicine, and for fuel. It is known for its high content of heart-healthy monounsaturated fatty acids and antioxidants, which are linked to anti-inflammatory benefits and a reduced risk of conditions like heart disease (Foscolou et al., (2018). The highest quality is extra virgin olive oil, made from the first cold pressing, while other grades include virgin, and refined, or "pure," olive oil.

Antioxidants like oleocanthal and oleuropein. These compounds support heart health by regulating cholesterol and blood pressure, aid in bone health, possess anti-inflammatory and antioxidant properties that protect against chronic diseases, and may contribute to a healthy immune system and skin (Flynn et al., 2023).

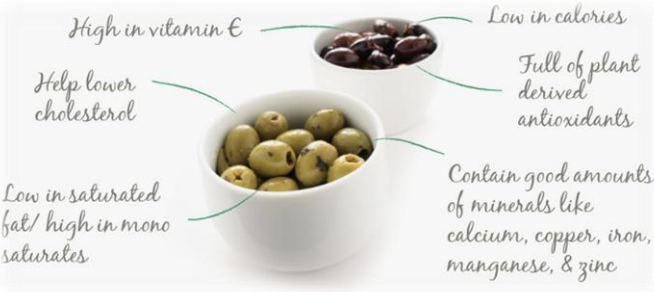

Figure 1. *Benefits of Olive*

Polyphenols also aid digestion, promote satiety for weight management, and may have benefits for brain health and cancer prevention.
Polyphenolic compounds in olives include oleuropein, tyrosol, and hydroxytyrosol, which are powerful antioxidants with anti-inflammatory and other health benefits, and are concentrated in the fruit's skin and around the seed. During processing, oleuropein is hydrolyzed to oleuropein aglycone and then to tyrosol and hydroxytyrosol. These compounds contribute to the bitterness of fresh olives and the health-promoting qualities of extra virgin olive oil (Foscolou et al., (2018).

Major Polyphenols in Olives and Olive Oil
Secoiridoids:
Oleuropein and ligstroside are the most abundant, primarily located in the skin and around the seed.
Hydrolyzed Forms:
During fruit processing, oleuropein and ligstroside are broken down into oleuropein aglycone, ligstroside aglycone, and then further into simpler forms like hydroxytyrosol and tyrosol (Flynn et al., 2023).

Definition of Olive Oil Polyphenols and Their Role in Nutritional BiochemistryI.A. Chemical Composition of Olive Oil and Minor ComponentsExtra virgin olive oil consists primarily of triglycerides (98%), which are composed of glycerol and fatty acids (Bongiorno et al., 2023). The nutritional value, oxidative stability, and therapeutic potential of the oil are hidden in the remaining 2% minor component fraction. These minor components include sterols, hydrocarbons, free fatty acids, volatile components, and phenolic compounds (polyphenols), which are the most critical in terms of nutritional biochemistry. 1Polyphenols are secondary metabolites produced by the olive fruit and are the primary antioxidants responsible for the oxidative stabilisation of olive oil. This stabilisation extends the shelf life of the oil and, when ingested by the human body, plays a critical role in preventing cellular damage through its ability to neutralise free radicals (Türkay et al., 2021). The Relationship Between Polyphenol Concentration and Quality The functional food value of olive oil is directly related to its polyphenol concentration. While polyphenol levels in standard natural virgin olive oils generally range between 100 and 200 mg/kg, oils produced through early harvesting and special processing techniques can reach values of 250 mg/L and above, placing them in the ‘high polyphenol’ category. While traditional quality parameters (e.g., acidity) indicate the degree of oil deterioration, the modern definition of quality focuses on bioactive content. The meticulous production techniques employed to maintain high polyphenol levels (ultra-low temperature cold pressing, early harvesting, rapid processing) also optimise the oil's oxidative stability and, consequently, traditional quality indicators. Therefore, polyphenol content is not only an indicator of health benefits but also a sign of high-level rigour in production and the oil's overall chemical integrity. Oils with high polyphenol content are inherently associated with lower acidity and extended shelf life.
The phenolic compounds found in olive oil are grouped into four main classes based on their chemical structure: simple phenols, secoiridoids, lignans, and flavonoids. It has been determined that these compounds, particularly tyrosol, hydroxytyrosol, and secoiridoid derivatives, constitute 60% to 90% of the total phenolic content. Sekoiridoids are the main phenolic compounds in olive fruit and, after passing into olive oil, are converted into smaller bioactive molecules through enzymatic and hydrolytic processes.

Oleuropein: The main glycoside in olive fruit. It is the primary source of the bitter taste in the oil. Known as a potent antioxidant, it undergoes hydrolysis during olive ripening or pressing to form hydroxytyrosol (Herrera et al., 2014).

Oleocanthal: It is the sole source of the sharp burning sensation felt at the back of the throat, one of the distinctive positive sensory characteristics of olive oil. Its name is derived from Latin roots and means ‘bitter aldehyde’. It has attracted considerable interest in the scientific world due to its anti-inflammatory activity.

Harvest time is a critical factor in maximising polyphenol content. The greener and earlier the olives are harvested, the higher the polyphenol level. As ripening progresses, the amount of phenolic compounds decreases (García et al., 2018).

Olive variety Genetic predisposition directly affects polyphenol accumulation. Varieties such as domat and memecik are known to be rich in bioactive compounds (Lino et al., 2004).

Environmental effects The climate characteristics, soil structure and irrigation conditions of the region where they are grown also affect the chemical composition of olives.

2. MATERIAL AND METHOD

In this study, we investigated the distribution of polyphenols in extra virgin olive oils produced from different regions of Anatolia. This study aimed to quantitatively analyze the polyphenol compounds in extra virgin olive oil samples collected from different geographical regions. Twelve extra virgin olive oil samples from the Aegean and Mediterranean regions of Turkey, as well as from the Afrin region of Syria, were analyzed.

The polyphenolic compounds in the olive oil samples were analysed by UHPLC-MS/MS. 100 mg of the homogenized sample was dissolved in 20 mL of a methanol/acetonitrile (50/50) solution containing 0.1% (v/v) formic acid. The mixture was vortex-mixed for 5 minutes and centrifuged at 4000 rpm at 4°C for 15 minutes. The supernatant obtained after centrifugation was filtered through a 0.2 µm PTFE membrane filter and diluted 10-fold with mobile phase A into a 2 mL vial before being injected into the UHPLC-MS/MS instrument. The total analysis time was 7 minutes.

3. RESULTS

3.1. Results of LC–MS/MS Analysis

The mobile phases used for the analysis consisted of two variants: organic and inorganic based. Mobile phase A consisted of a 95:5 mixture of water and acetonitrile containing 0.1 % formic acid and 4 mM ammonium formate (Suárez et al. 2008). Mobile phase B was prepared by mixing acetonitrile and water in a ratio of 95:5 with the addition of 0.1 % formic acid and 4 mM ammonium formate (Lucci et al., 2017). Mobile phase gradient flow of LC-MS/MS was given in Table 1.

Two different solutions of the mobile phase were prepared and the phenolic compounds were analysed by applying a gradient flow programme of the analytical column (organic and inorganic based). The mass detector of the system is a triple quadrupole spectrometer and works with a combination of three consecutive quadrupoles. The ionisation technique used is called soft ionisation and is generally based on the principle of conservation of the main mass of the analyte. It generally works on the basis of positive ionisation by adding a proton to the main mass (M+1) or negative ionisation by removing a proton from the main mass (M-1) (García et al., 2018). Analytical purity standards of phenolic compounds of known concentration were analysed and the data obtained with the device were compared with the analytical results of the samples. Quantitative results were obtained by comparing the data obtained with the instrument. Retention times and LOD-LOQ values of phenolic compounds were given in Table 2. MS/MS mass transitions of phenolic compounds were given in Table 3.



Figure 6. *LC-MS/MS System*

Table 1. Mobile Phase Gradient Flow of LC-MS/MS

Time	Flow (mL/min)	Mobil Fhase A	Mobil Fhase B
0,0	0,300	100%	0%
3,0	0,300	100%	0%
5,0	0,300	50%	50%
5,5	0,300	0%	100%
8,0	0,300	0%	100%
8,5	0,300	100%	0%
9	Stop flow	100%	0%

Table 2. Retention Times and LOD-LOQ Values of Polyphenolic Compounds

Compoud Name	Retention Time (min)	Average of Repeatability at 5 mg/Kg)	SD	% RSD	LOD	LOQ
oleuropein	1,59	4,52	0,28	5,86	0,84	2,8
p-HPEA-EDA (oleocanthal)	3,45	5,09	0,25	7,17	0,75	2,5
3,4-DHPEA-EDA	4,33	4,63	0,14	8,22	0,42	1,4
p-HPEA-EA (ligstroside aglycon)	5,09	4,74	0,23	6,35	0,69	2,3
3,4-DHPEA-EA (oleuropein aglycon)	6,11	5,14	0,27	5,86	0,81	2,7
3,4-DHPEA (hydroxytyrosol: 3,4- dihydroxyphenylethanol)	6,53	4,59	0,19	7,05	0,57	1,9
p-HPEA (tyrosol: p-hydroxyphenylethanol)	7,16	4,46	0,16	6,13	0,48	1,6

Table 3. MS/MS Mass Transitions of Polyphenolic Compounds

Compound	Retention Time (min)	RT Window (min)	Polarity	Precursor (m/z)	Products (m/z)	Collision Energy (V)	Min Dwell Time (ms)
oleuropein	4.5	9	Negative	539.1	275.1 / 307.1	40	27.998
p-HPEA-EDA	4.5	9	Negative	303.1	59.1 / 285	35	27.998
3,4-DHPEA-EDA	4.5	9	Negative	319.1	56.1 / 69.1	25	27.998
p-HPEA-EA	4.5	9	Negative	361.1	291.1 / 101	35	27.998
3,4-DHPEA-EA	4.5	9	Negative	377.1	275.1 / 95.1	25	27.998
3,4-DHPEA	4.5	9	Negative	195.1	59.1 / 135	35	27.998
p-HPEA	4.5	9	Negative	781.1	601 / 301	35	27.998

This study aimed to quantitatively analyze the polyphenol compounds in extra virgin olive oil samples collected from different geographical regions. Twelve extra virgin olive oil samples from the Aegean and Mediterranean regions of Turkey, as well as from the Afrin region of Syria, were analyzed. Oleuropein, p-HPEA-EDA (oleocanthal) and p-HPEA-EA (ligstroside aglycon) compounds were detected in high amounts in the obtained olive oils. Olive oils collected from Bursa (Gemlik) Balıkesir (Ayvalık), Hatay (Samandağı) region and Afrin region were found to have higher polyphenol compounds. The results of polyphenolic compounds were given in Table 4.

	1	2	3	4	5	6	7	8	9	10	11	12
	Gemlik 1	**Gemlik 2**	**Ayvalık 1**	**Ayvalık 2**	**Aydın 1**	**Aydın 2**	**Serik 1**	**Serik 2**	**Samandağı 1**	**Samandağı 2**	**Afrin 1**	**Afrin 2**
oleuropein	257,9	249,7	270,1	251,2	163,6	187,1	196,5	135,8	243,5	229,3	297,8	295,7
p-HPEA-EDA	37,6	35,6	43,9	49,2	8,3	4,9	5,4	2,1	29,3	27,7	52,2	48,8
3,4-DHPEA-EDA	42,2	40,6	26,2	22,7	24,4	2,7	31,0	25,4	26,8	22,4	59,4	61,0
p-HPEA-EA	43,6	47,1	18,6	14,6	12,3	11,2	8,8	5,8	13,7	13,7	25,1	28,7
3,4-DHPEA-EA	44,6	41,4	61,7	52,8	11,4	8,0	7,7	2,8	17,6	13,2	75,3	83,4
3,4-DHPEA	158,0	167,2	121,5	151,2	117,3	128,6	75,5	91,9	165,1	161,6	216,2	235,5
p-HPEA	33,8	38,4	9,8	26,5	23,7	14,5	8,5	4,8	34,2	28,3	67,5	96,7
Sum	617,6	620,1	551,9	568,3	361,1	357,0	333,4	268,6	530,1	496,2	793,5	849,9

Table 4. The results of Polyphenolic Compounds

4. DISCUSSION AND CONCLUSIONS

Olive oil polyphenols are the key bioactive compounds that determine the value and health potential of natural extra virgin olive oil as a functional food. The chemical structure of these compounds forms the molecular basis for their potent antioxidant, anti-inflammatory and neuroprotective effects. In particular, hydroxytyrosol's ability to cross the blood-brain barrier and oleocanthal's ibuprofen-like anti-inflammatory activity make olive oil important for nervous system health beyond the cardiovascular system.

The production of high-polyphenol olive oil depends on meticulous agricultural and industrial processes, such as early harvesting, pressing at ultra-low temperatures, and rapid processing. The sector should invest in high-resolution instrumental analyses, such as HPLC and LC-MS, which determine the absolute quantity of individual bioactive components, rather than sensory analysis, to meet consumer health expectations and ensure legal compliance. This analytical verification is essential for producers to prove that they meet the 5 mg/20g threshold specified in EU legislation.

The final recommendation for consumers is to adhere to the Mediterranean diet and regularly consume early harvest, cold-pressed, natural extra virgin olive oils that meet EFSA criteria and have their bioactive content labelled with laboratory results, in order to maximise their benefits.

The results showed that the determined polyphenol content varied between 270-850 mg/kg among the samples. The highest polyphenol content was detected in olive oils obtained from the Afrin region, produced by early harvest and cold pressing methods. Concentrations of key polyphenolic compounds such as oleuropein and p-HPEA-EDA showed

significant differences depending on the geographical origin of the samples and the production method. According to these results and the information obtained highlight that polyphenol content is an important parameter in the evaluation of olive oil quality and that the effect of production processes on these compounds should be further investigated.

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REFERENCES

Foscolou A., Critselis E., Panagiotakos D., (2018). Olive oil consumption and human health: A narrative review. Maturitas, Volume 118, December 2018, Pages 60-66.

Flynn M. M., Tierney A. and Itsiopoulos C., (2023). Is Extra Virgin Olive Oil the Critical Ingredient Driving the Health Benefits of a Mediterranean Diet? A Narrative Review.

Bongiorno, D., Di Stefano, V.; Indelicato, S., Avellone, G. and Ceraulo, L., (2023). Bio-phenols determination in olive oils: Recent mass spectrometry approaches. Mass Spectrom. Rev. 42, 1462–1502.

Herrera M. B., Astudillo M. S., Beltrán R. and Sayago A., (2014). Determination of phenolic compounds in olive oil: New method based on liquid–liquid micro extraction and ultra high performance liquid chromatography-triple–quadrupole mass spectrometry. LWT- Food Science and Technology, Volume 57, Issue 1, June 2014, Pages 49-57.

Türkay Ç., Özdikicierler O. and Yemişçioğlu F., (2021). Use of Phenolic Profile and Fatty Acid Composition on Chemometric Discrimination of Turkish Virgin Olive Oils with Geographical Indication. Akademik Gıda 19(2) (2021) 126-136, DOI: 10.24323/akademik-gida.977263.

Lino C., Bongiorno D., Pitonzo R., Indelicato S., Barbera M., Gregorio G. D., Pane D., Avellone G., (2004). Chemical Characterization, Stability and Sensory Evaluation of Sicilian Extra Virgin Olive Oils: Healthiness Evidence at Nose Reach. Foods 2024, 13, 2149.

Suárez M., Macià A., Romero M.P. and Motilva M.J., (2008). Improved liquid chromatography tandem mass spectrometry method for the determination of phenolic compounds in virgin olive oil. Journal of Chromatography A, Volume 1214, Issues 1–2, 19 December 2008, Pages 90-99.

García L. O., Polari J. J., Li X., Bajoub A., Gutiérrez A. F., Wang S. C. and Pancorbo A. C., (2018). Deep insight into the minor fraction of virgin olive oil by using LC-MS and GC-MS multi-class methodologies. Food Chem. 2018 Sep 30:261:184-193. doi: 10.1016/j.foodchem.2018.04.006. Epub 2018 Apr 11.

Lucci, P., Saurina, J. and Núñez, O., (2017). Trends in LC-MS and LC-HRMS analysis and characterization of polyphenols in food. TrAC Trends Anal. Chem. 88, 1–24.

International Olive Council Method. Determination of Free Fatty Acids, Cold Method COI 2017 T.20, Doc. No 34, Rev. 1. Available online: https://www.internationaloliveoil.org/wp-content/uploads/2019/11/COI-T.20-Doc.-No-34-Rev.-1-2017.pdf (accessed on 1 July 2024).

Enhancing Energy Efficiency in Hospital Laundries through Waste Heat Recovery: A Dynamic Simulation and Feasibility Analysis

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Abstract: This study investigates the technical, economic, and environmental feasibility of utilizing high-temperature wastewater generated in hospital laundries for preheating clean water via a plate heat exchanger. A synthetic dataset reflecting variable flow rates and temperatures over a one-year period was developed, and a Python-based dynamic simulation model was constructed. Thermodynamic analyses revealed an annual saving potential of 85,442 kWh of energy, approximately $8,032 in economic benefits, and 40,158 kg CO_2 equivalent emission reductions. With a simple payback period of only 0.45 years, the system proves to be highly attractive from an economic perspective. The findings demonstrate that wastewater heat recovery in hospital laundries offers a sustainable solution for improving energy efficiency, lowering operational costs, and reducing the institutional carbon footprint.

Keywords: Energy efficiency, waste heat recovery, plate heat exchanger, hospital laundry, dynamic simulation, economic feasibility, carbon reduction

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1. INTRODUCTION

Energy consumption and climate change are among the most critical issues on a global scale (Akhmat et al., 2014; Akpan & Akpan, 2012). One of the key steps in reducing these issues and achieving carbon neutrality goals is energy efficiency (Pimenow et al., 2024). Energy efficiency is of critical importance in industrial processes and buildings, both to reduce costs and to increase sustainability (Işık et al., 2024; Zeng et al., 2024). Various service buildings account for a significant share of total energy consumption. Hospitals, in particular, are energy-intensive facilities due to their 24/7 uninterrupted service, intensive use of medical equipment, and hygiene requirements. It is emphasized that the energy intensity of healthcare facilities in Turkey is higher than the European average; therefore, efficiency measures should be prioritized (Bawaneh et al., 2019). Sectoral assessments highlight the high share of the hospital and general healthcare sector in total greenhouse gas emissions (including the managerial/ethical responsibility dimension), making efficiency and renewable integration a strategic imperative (Eckelman et al., 2020).

Although studies on energy efficiency in hospitals have mostly focused on HVAC (Heating, Ventilation, Air Conditioning) systems and lighting, the study analyzed the hospital's energy intensity and found that laundries account for 8-12% of total energy consumption (X. Bai et al., 2024; Chen et al., 2023; Jouhara et al., 2018). In hospitals, central sterilization units and laundries consume large amounts of hot water, resulting in a significant need for heat energy. In a typical industrial laundry, approximately 60-70% of total energy consumption is used for water heating (Chen et al., 2023; Choi et al., 2024) Due to the high hygiene requirements in hospitals, washing machines with higher washing temperatures are preferred.

Laundry process flows (washing → rinsing → spinning/drying → finishing) carry significant waste heat through both gray water (around 60 °C outlet) and exhaust air (dryers/tunnel finishing 80–120 °C). In industrial laundries, preheating fresh air from the drying section using a plate/fin heat exchanger significantly reduces the system's energy consumption; a case study based on actual operating data provides detailed information on the design approach and measurement method (Bobák et al., 2012). In the washing systems commonly preferred in hospitals, wastewater from laundry processes, which has an average temperature of 60-70°C, is discharged into the sewer system, wasting a valuable energy source (Chen et al., 2023; Coskun et al., 2023). This heat source, which is discarded without being recovered, still has usable potential for many low-temperature applications. The main waste heat sources in laundries are hot water from washing machines, hot air from dryers, and condensation heat emitted from steam systems (Choi et al., 2024). Model-based analyses of the potential and economic benefits of wastewater heat recovery in meeting heating/cooling demand at a large city hospital have demonstrated that annual operational savings are possible through HVAC integration based on heat pumps (Sohail et al., 2019). Waste heat recovery systems make it possible to capture this heat and improve energy efficiency. Waste heat recovery stands out as an effective method for reducing energy consumption and lowering the carbon footprint (Akpan & Akpan, 2012). Waste heat recovery technologies have mostly focused on systems such as plate heat exchangers, heat pumps, thermoelectric generators, and organic Rankine cycle systems (T. Bai et al., 2024; Ma et al., 2024).

A study has shown that when waste heat from boilers and gas dryers in commercial laundries is recovered using an integrated WHRS solution, it results in significant reductions in mechanical drying energy costs (Choi et al., 2024). Market application solutions also report that, due to the share of washing water heating in total energy consumption (≈25–40%), it is possible to recover 60–90% of waste water heat, which can reduce the total energy bill by an average of 25% (Laundry Water and Energy Systems | Aquatherm International, n.d.). Numerical modeling and experimental validation studies of HPHEs (ε–NTU-based) demonstrate that this technology is a suitable option for low/medium temperature waste heat applications (Brough et al., 2021).

However, heat exchangers are the preferred choice when there is no need for high temperatures in the process that will use the recovered heat, especially after the recovery process of low-temperature waste heat sources.

The most direct and common method of recovering waste heat is to compare wastewater with clean cold water in a heat exchanger without allowing them to come into contact with each other. This allows the heat in the wastewater to be transferred to the clean water, and the network water can be preheated and used in boilers or other heaters. The performance of different heat exchanger types (plate, shell, and tube) varies significantly in low-temperature applications, and each offers its own unique advantages (Wadekar, 2003). Plate heat exchangers are frequently preferred in waste heat recovery applications due to their advantages such as high efficiency, compact design, and easy maintenance (Abd El-Kawi et al., 2022; Yang et al., 2024). However, contamination can significantly reduce their effectiveness over time. Experimental studies have shown that contamination reduces effectiveness by approximately 18% (Abd El-Kawi et al., 2022). While pipe and tube designs are traditional, they can be enhanced with advanced materials to improve energy efficiency, particularly in industrial cooling (Panchal & Rabas, 1989). Heat pipe heat exchangers are excellent for low-temperature waste heat recovery and provide significant thermal performance improvements when finned designs are used (Seo et al., 2024).

Studies focusing on the Economic and Environmental Feasibility of waste heat recovery indicate that the payback period typically ranges from 2 to 4 years (Nagpal et al., 2021; Sohail et al., 2019) and that CO_2 emissions can be reduced by 10–20% (Bagnasco et al., 2015; Wehbi et al., 2023). A review of the literature reveals that recovering waste heat from wastewater in high-capacity laundries is a proven energy efficiency measure with significant potential. Plate heat exchangers are widely preferred due to their low investment costs and simplicity, while heat pumps offer higher savings rates. However, studies focusing on energy efficiency in hospitals show that there are relatively few studies in the literature on the specific applications of waste heat recovery in hospitals. Examining and researching annual waste heat changes using dynamic modeling methods, thereby presenting a scalable model, will be a guide for managers and engineers in this sector.

Although waste heat recovery is an overlooked area with high potential for increasing the energy efficiency of hospitals, investment costs are low, and payback periods are quite short. In addition, such projects make a concrete contribution to hospitals' sustainability reporting and carbon neutrality goals.

This study aims to fill a gap in the existing literature by focusing on a specific area such as hospital laundries, taking seasonal effects into account through dynamic simulation, and presenting the results in terms of both economic and environmental dimensions. The main objective of this study is to comprehensively analyze the technical feasibility, economic viability, and environmental benefits of recovering thermal energy from wastewater generated by a hospital laundry. In the study, the quantities and temperatures of laundry wastewater over a one-year period were estimated using an average approach, and a dataset was created. The potential energy savings, carbon emission reductions, and economic gains achievable under the projected operating conditions were determined. This research aims to provide a decision support mechanism and a feasibility study example for similar energy recovery projects.

2. MATERIAL AND METHOD

The study was conducted with consideration of the hospital's role as an education and research facility. The hospital has more than 25 different medical departments and polyclinics, including internal medicine, surgery, pediatrics, obstetrics and gynecology, intensive care, emergency services, oncology, cardiology, and orthopedics, and provides an average of 250,000 outpatient services, 15,000 hospitalizations, and 8,000 surgeries per year. It provides 24/7 uninterrupted service with a total of 1,200 staff (doctors, nurses, healthcare technicians, and administrative personnel). The hospital's central laundry has three high-capacity 100 kg industrial washing machines and two 50 kg dryers. Each of these machines consumes approximately 200-300 liters of water per wash cycle and heats this water to 60-70°C using electric resistors. An average of 20-25 wash cycles are performed daily in the laundry room, generating a total of up to 8,000 liters of hot wastewater. Considering the current energy consumption of a typical washing machine, it is stated that approximately 70% of the energy is spent on heating the water (*Laundry Water and Energy Systems | Aquatherm International*, n.d.). This high energy consumption and regular wastewater discharge make laundries ideal candidates for waste heat recovery.

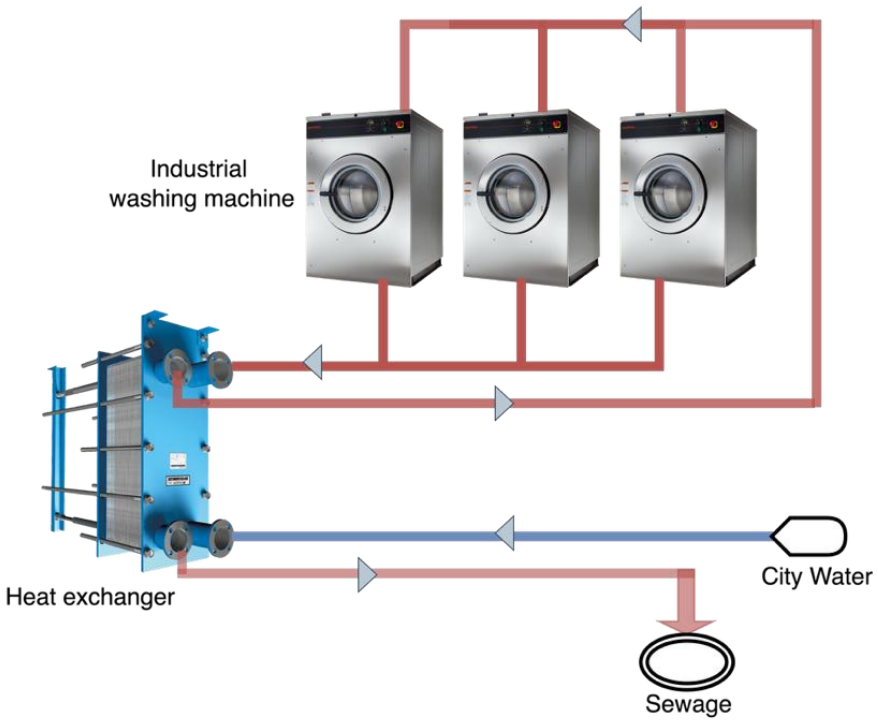

Figure 1. Schematic representation of the proposed system for laundry waste heat recovery

2.1. Creation of the Data Set

In this study, a data set was used that reflects the actual working conditions of the hospital in question but was created with certain assumptions to overcome privacy and data accessibility restrictions. The data set is based on the average daily wastewater volume and temperature values covering a 365-day period. In addition, seasonal variations were modeled to better reflect real working conditions. It was assumed that the water volume increased by 15% in winter due to patient density and blanket/cover usage and decreased by 5% in summer. Wastewater temperature was designed to be higher in winter due to ambient temperature and lower in summer. Random noise has been added to the dataset to achieve a realistic distribution.

2.2. Waste heat recovery

Although various methods exist for recovering waste heat generated in systems, heat exchangers stand out when considering low cost, low maintenance expenses, easy installation, and sustainability. In this study, a counterflow liquid-liquid heat exchanger was chosen to preheat the washing machine's process water using waste laundry water.

To determine the efficiency of a heat exchanger, it is necessary to determine the maximum heat transfer that could theoretically be achieved in an ideal counterflow heat exchanger of infinite length. The maximum heat energy (Q_{max}, kW) that can theoretically be transferred in the heat exchanger is calculated using the following formula (Sekulić & Sha, 2023; Sidebotham, 2015).

$$Q_{max} = C_{min}(T_{h,in} - T_{c,out})$$

$$C_h = \dot{m}_h c_{p,h} \text{ and } C_c = \dot{m}_c c_{p,c}$$

$$C_{min} = \min(C_h, C_c)$$

Here, $\dot{m}_c$ and $\dot{m}_h$ represent the flow rate of the water to be heated and the flow rate of the waste water (kg/s), respectively, while C_p denotes the specific heat capacity of water (4.18 kJ/kg·K). The efficiency (ε) of the heat exchanger is defined as the ratio of the actual heat transfer rate to the maximum heat transfer rate theoretically possible (Ohadi, 1991; Sekulić & Sha, 2023).

$$\varepsilon = \frac{Q_{useful}}{Q_{max}}$$

Here, ε is the efficiency of the heat exchanger. In this study, this efficiency is assumed to be 75% for the plate heat exchanger. This value was selected based on similar applications in the literature and industrial standards. In real systems, heat losses and efficiency limitations exist. Therefore, to determine the useful heat energy gained in practice,

the heat exchanger's efficiency (Q_{useful}, kW) can be used to determine the inlet and outlet temperatures of the fluids using the following equations (Sekulić & Sha, 2023; Sidebotham, 2015).

$$Q_{useful} = C_h\left(T_{h,in} - T_{h,out}\right) = C_c\left(T_{c,out} - T_{c,in}\right)$$

Here, $T_{h,in}$ is the inlet temperature of the high-temperature flow (laundry wastewater) to the heat exchanger, $T_{c,out}$ is the outlet temperature of the low-temperature flow (washing machine process water) from the heat exchanger, $T_{h,out}$ is the outlet temperature of the high-temperature flow (laundry wastewater) from the heat exchanger, and $T_{c,in}$is the inlet temperature of the low-temperature flow (washing machine process water) to the heat exchanger (Sekulić & Sha, 2023).

$$Q_{useful} = UA\Delta T_{LM}$$

Here, U represents the total heat transfer coefficient (W/m²·K), A represents the required total heat transfer area (m²), and ΔT_{LM} represents the Logarithmic Mean Temperature Difference. For counterflow heat exchangers, the Logarithmic Mean Temperature Difference (LMTD) can be written as follows (Ohadi, 1991; Sidebotham, 2015);

$$\theta_1 = T_{h,in} - T_{c,out}$$
$$\theta_2 = T_{h,out} - T_{c,in}$$
$$LM = \frac{\theta_2 - \theta_1}{\log_e \frac{\theta_2}{\theta_1}}$$

The U -value for plate heat exchangers is high due to the plate structure that increases fluid turbulence. In this study, a value of U = 2500 W/m²·K, which is widely accepted in the literature for water-to-water applications, was used (Sekulić & Sha, 2023). The system must be sized according to peak load conditions (maximum flow rate and temperature difference). The calculated $Q_{useful}$and $\Delta LMTD$ values are substituted into the above formula to obtain the required minimum heat transfer area A.

After determining the required minimum heat transfer area, the number and characteristics of the plates must be determined.

$$A = N\ A_{plate}$$

The total number of plates (N) is determined using the formula. Here, A_{plate} is the area of one surface of the plate to be selected. Plates of standard sizes (e.g., 0.3 m², 0.5 m²) are available on the market. In this study, it is assumed that plates with an effective heat transfer area of 0.4 m² are used. The channel spacing between the plates should be optimized according to the fluid flow rate and pressure drop.

2.3. Modeling and Simulation Approach

All engineering equations summarized above were repeatedly solved using Python codes for each day in the 365-day synthetic data set created. This dynamic simulation provided a more realistic picture of system performance under changing conditions throughout the year, rather than a fixed-point design. Savings calculations were performed separately for each day and then aggregated to monthly/annual totals.

2.4. Economic and Environmental Analysis Methodology

After determining the annual energy savings (kWh), monetary savings were calculated assuming a regional average electricity unit price of of $0.094/kWh However, considering the investment cost, heat exchanger, pumps, piping, insulation, and labor costs, the total cost for such a system is estimated to be an average of ~$3,650The following formula is suggested for the simple payback method.

$$\text{Payback Period} = \frac{\text{Initial Cost}}{\text{Average Annual Cash Flow}}$$

2.5. Environmental Analysis

The carbon reduction achieved through energy savings was calculated using the average carbon emission factor of the national electricity grid mix (0.47 kg CO_2e/kWh) for each kWh of electricity saved.

2.6. Software and Libraries Used

All engineering calculations, data analysis, statistical evaluation, and graphical outputs were performed using the Python 3.9 programming language and the NumPy, Pandas, Matplotlib, and Seaborn libraries.

3. RESULTS

Analysis of the data set created shows that the amount of wastewater increased to an average of approximately 9,200 liters/day in the winter months (January, February, December) and decreased to an average of 7,500 liters/day in the summer months (July, August). Wastewater temperature tends to decrease slightly during the summer months due to the effect of ambient temperature. This seasonality directly affects the energy recovery potential. Figure 2 shows the changes in laundry wastewater quantities and temperatures over 365 days (1 year).

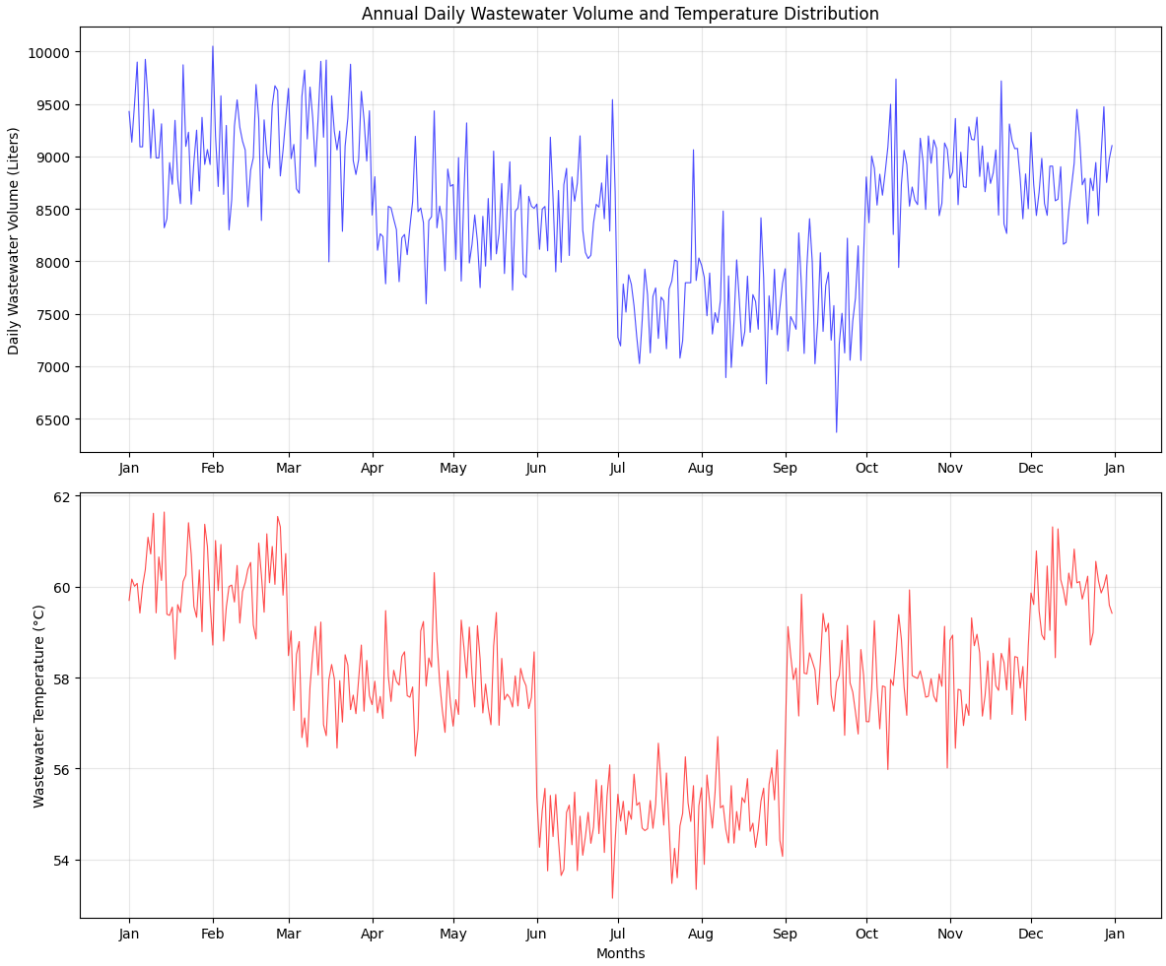

Figure 2. Wastewater volume and temperatures of one year hospital laundry facility

The monthly changes in average wastewater volume and temperature, shown separately for 365 days in Figure 2, are provided in Figure 3.

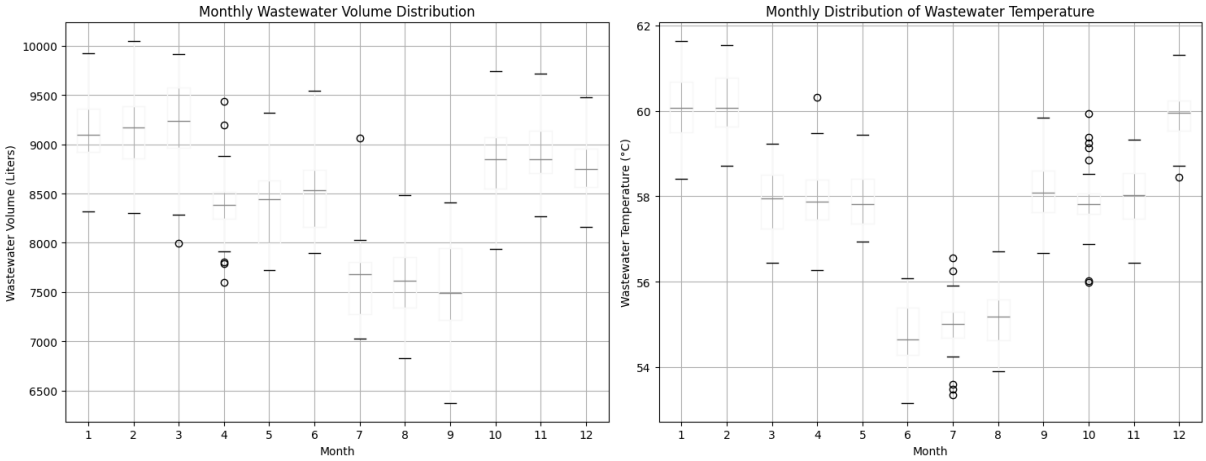

Figure 3. Monthly average laundry wastewater temperatures and quantities for one year

The technical specifications and dimensions of the counterflow plate heat exchanger designed in this study are given in Table 12. The distribution of preheated water temperature after using the heat exchange calculated in the current profile is shown in the figure. Figure 4 shows the monthly average temperature values of the preheated water obtained as a result of recovery with the plate heat exchanger. According to the analysis results, the preheated water temperature varies between 54.7°C and 60.1°C throughout the year. The highest temperature value of 60.1°C is reached in January and February, while the lowest temperature of 54.7°C is observed in June. This distribution is directly related to seasonal changes in wastewater temperature. Wastewater temperature, which is higher in winter (January-March), decreases in summer (June-August), and this situation is directly reflected in the preheated water temperature. The system's ability to provide an average outlet temperature of 55.7°C throughout the year offers significant energy savings potential compared to traditional water heating systems.

Table 1. Heat exchanger specifications designed for waste heat recovery

Basic Design Parameters	
Heat transfer surface area	15 m²
Number of plates	35 quantity (33 heat transfer plates + 2 cover plates)
Plate material	316L stainless steel (1.4404)
Plate thickness	0.5 mm
Plate dimensions	500 mm x 1000 mm (width x length)
Plate type	60° chevron-shaped, high-efficiency model
Maximum working pressure	16 bar
Maximum working temperature	120°C
Flow Channels and Hydraulic Properties	
Distance between channels	3 mm
Equivalent diameter	6.8 mm
Total number of channels	66 (33 channels for each fluid)
Performance Features	
Heat transfer coefficient (U)	2.5 kW/m²°C
Average efficiency	%75-80
NTU (Number of transfer units)	2.1
Capacity ratio (Cmin/Cmax)	0.95-1.0
Heat transfer capacity	350-450 kW (design conditions)
Physical Dimensions and Connections	
Total length	650 mm (plate package + connections)
Width	500 mm
Height	1100 mm
Weight	≈280 kg (filled with water)
Connection diameter	80 mm (entry/exit)
Connection standard	DIN/PN16 flange

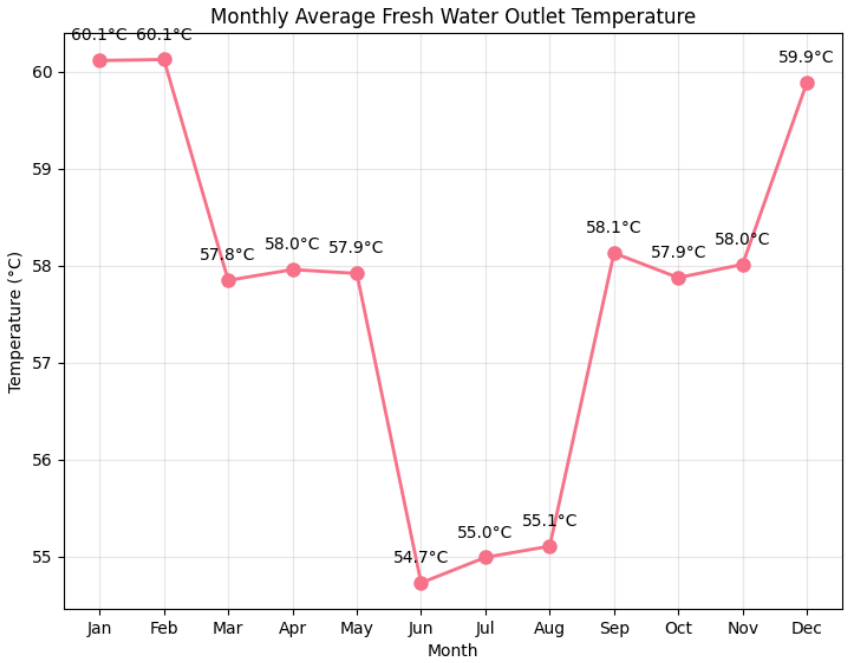

Figure 4. Monthly distribution of preheated water temperatures after the heat exchanger

Figure 5 and Figure 6 shows the results related to energy recovery potential. According to the simulation results, it was determined that a plate heat exchanger system operating at 75% efficiency could save a total of 85,442 kWh of electrical energy per year. This value corresponds to a significant reduction in the laundry's electricity consumption for water heating purposes. When examining the monthly distribution, it was observed that the highest savings were achieved in February with approximately 7,872 kWh, while this value dropped to 6,250 kWh in September. This finding confirms the linear relationship between the amount of wastewater and the energy potential.

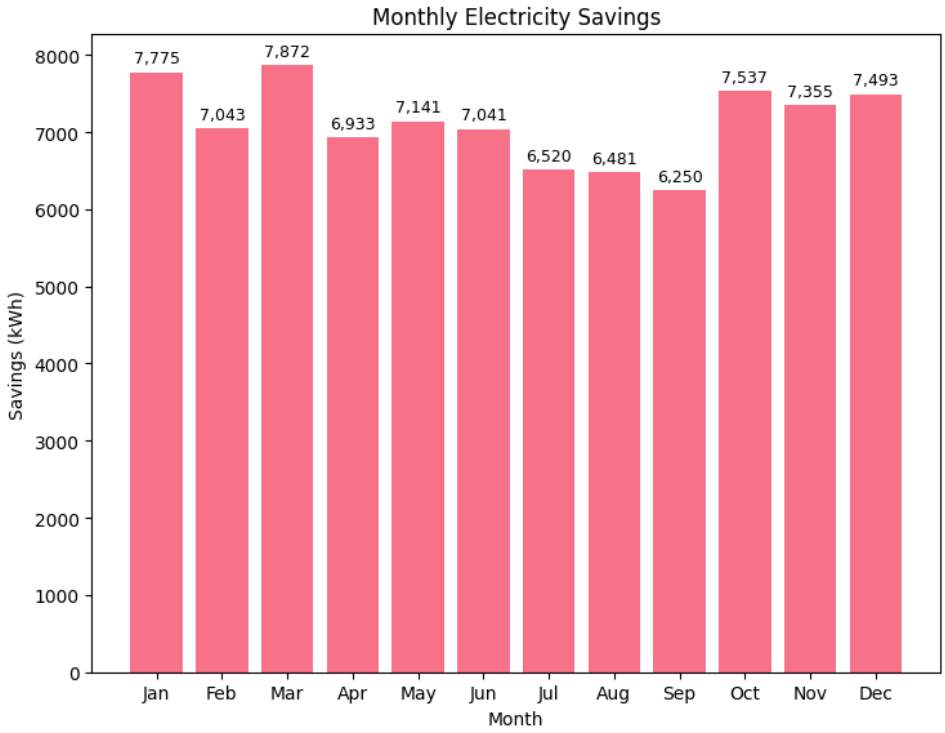

Figure 5. Monthly energy savings amount with waste heat recovery

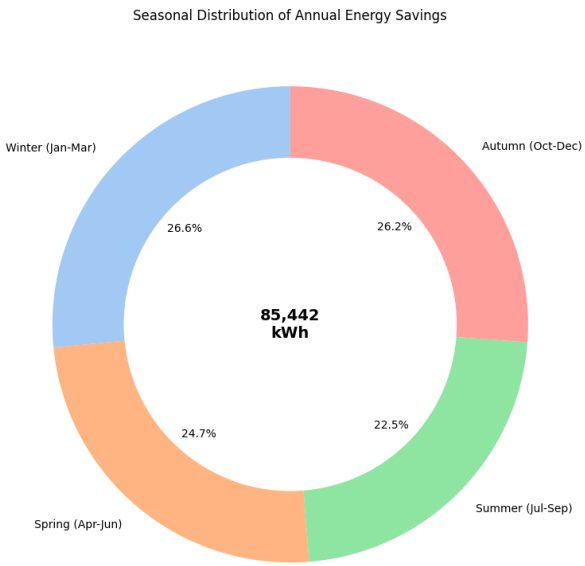

Figure 6. Seasonal energy savings amount with waste heat recovery

Figure 7 shows the economic feasibility results of the system. The energy savings achieved per month, calculated at an electricity price of $0.094/kWh, translate to an annual savings of $8,032 for the business. Assuming that the total cost of the plate heat exchanger, pump, piping, and labor is ~$3,650, the system's simple payback period is calculated to be 0.45 years. This extremely short payback period demonstrates that the project is very attractive from an economic standpoint. Possible increases in energy prices will shorten this period even further.

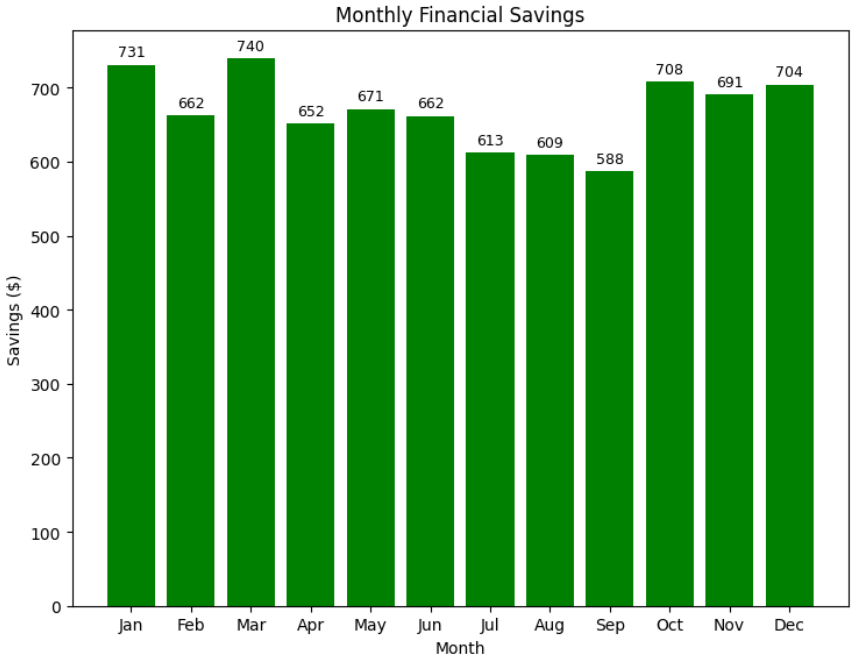

Figure 7. Mounthly financial savings achieved through monthly energy savings

Figure 8 shows the carbon emission reduction achieved to demonstrate the environmental impact of the energy savings achieved. If the project is implemented, it is estimated that 40,158 kg CO2e 58,750 kg (approximately 59 tons) of CO_2 equivalent carbon emissions will be prevented annually. This reduction is equivalent to the amount of carbon that approximately 900 mature trees can absorb in a year or the emissions caused by a 170,000 km car journey. This finding demonstrates that the project will also make a significant contribution to sustainability and corporate social responsibility goals.

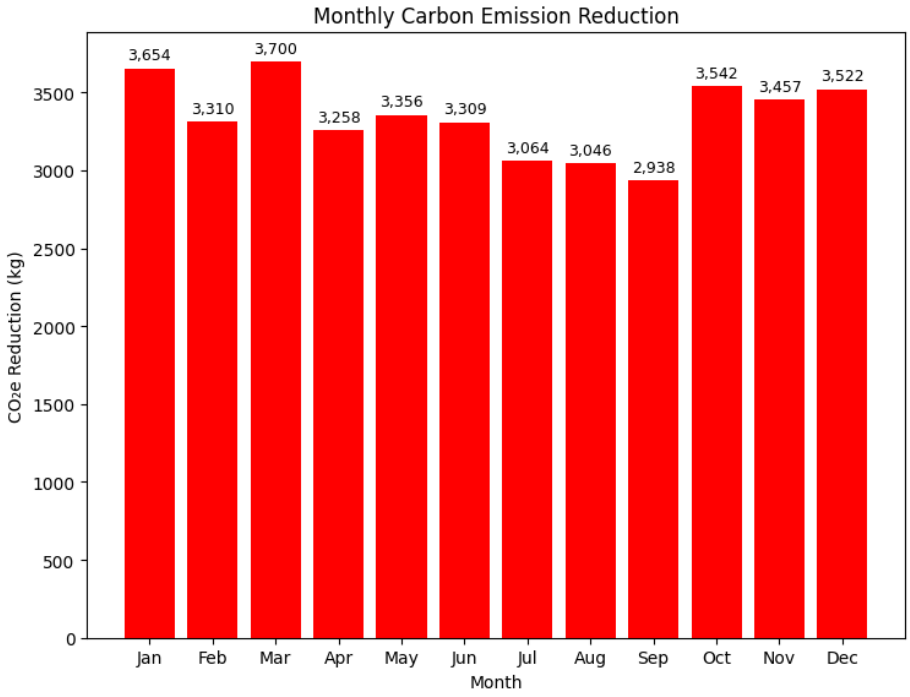

Figure 8. Monthly carbon dioxide emission reduction achieved through monthly energy savings

A qualitative analysis correlating the daily wastewater volume and wastewater temperature with the daily energy savings in a waste heat recovery system (WHRSO) is presented in Figure 9. The x-axis of the graph shows the daily wastewater volume (6500 - 10000 L/day). As the flow rate increases, the total amount of energy that can be recovered also increases linearly. This is directly related to the m (mass) variable in the formula. More wastewater means more thermal energy entering the system and, consequently, more energy that can be recovered. The higher the wastewater temperature, the greater the temperature difference (ΔT), which increases the amount of energy recovered proportionally.

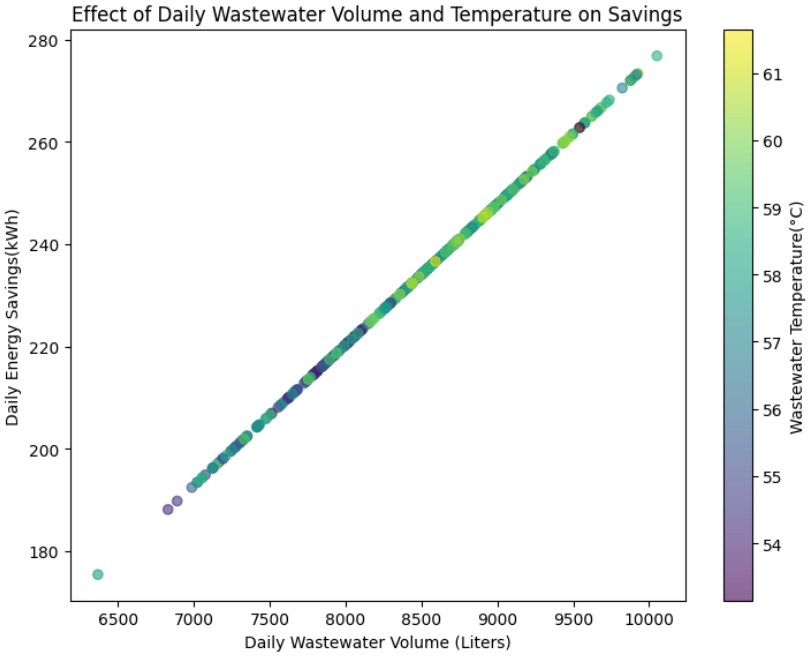

Figure 9. The effect of daily wastewater volume and wastewater temperature on daily energy savings

4. DISCUSSION AND CONCLUSIONS

This study has clearly demonstrated that recovering thermal energy from wastewater in hospital laundries is technically feasible, economically very attractive, and extremely beneficial for the environment. The developed Python model produced realistic results by taking seasonal variability into account and strongly supported the project's feasibility with robust data.

The system should be sized to withstand flow and temperature variations, based on peak loads during winter months. To prevent the accumulation of fibers and particles on the wastewater side, installing a filter at the exchanger inlet is critical for system efficiency and maintenance intervals.

A waste heat recovery system that could be installed in the laundry prevents the direct use of 85,442 kWh of electrical energy for heating per year. This equates to an average saving of 234 kWh/day.
A waste heat recovery system that could be installed in the laundry room prevents the emission of 40,158 kg of CO2e per year, significantly reducing the hospital's carbon footprint. This amount of CO2e saved is equivalent to the carbon amount that approximately 900 mature trees can provide in a year or the emissions caused by a 170,000 km car journey.
The annual savings in energy costs are valued at $8,032. Considering the investment cost (heat exchanger, pump, installation) (approximately $3,650), the system's payback period is estimated to be 0.45 years based on a simple calculation. This period will shorten with increases in energy prices.
A plate heat exchanger should be selected to serve an average daily heat load of 234.1 kWh. Taking into account wastewater flow and temperature variations, the system should be sized to operate at 75.0% efficiency.

Waste heat recovery in hospital laundries is an environmentally friendly and economically viable project that improves energy efficiency. Seasonal data shows that both water consumption and savings are higher during the winter months. This analysis strongly supports the feasibility of the project.
This study can be used as an application guide for hospital administrators and energy managers. The next step is to validate this model and conduct fieldwork by collecting real data at a pilot hospital.
Future studies should compare different types of heat exchangers, include exergy analysis, and perform a life cycle cost analysis (LCCA) of the system. In addition, the potential for reusing waste water not only for its heat but also as grey water can be investigated.

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It should be written as short as possible and expressing the contribution made without giving the number.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: S.A., F.Y.; Investigation: Y.F.; Material and Methodology: S.A., F.Y.; Supervision: S.A., F.Y.; Visualization: S.A., F.Y.; Writing-Original Draft: S.A., F.Y.; Writing-review & Editing: S.A., F.Y.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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REFERENCES

Abd El-Kawi, O. S., Elbakhshawangy, H. F., & Abdelmaksoud, A. (2022). Numerical and Experimental Performance Analysis for Different Types of Heat Exchangers. *Journal of Mechanical, Civil & Industrial Engineering*, *3*(1), 13–27. https://doi.org/10.32996/JMCIE.2022.3.1.3

Akhmat, G., Zaman, K., Shukui, T., & Sajjad, F. (2014). Does energy consumption contribute to climate change? Evidence from major regions of the world. *Renewable and Sustainable Energy Reviews*, *36*, 123–134. https://doi.org/10.1016/J.RSER.2014.04.044

Akpan, U. F., & Akpan, G. E. (2012). The Contribution of Energy Consumption to Climate Change: A Feasible Policy Direction. *International Journal of Energy Economics and Policy*, *2*(1), 21–33. https://dergipark.org.tr/en/pub/ijeeep/issue/31899/350661

Bai, T., Yao, Y., Hu, B., Feng, J., & Jin, Z. (2024). Thermodynamic analysis of exhaust waste heat recovery in a compound open absorption heat pump system. *Applied Thermal Engineering*, *257*, 124387. https://doi.org/10.1016/J.APPLTHERMALENG.2024.124387

Bai, X., Ma, W., Huang, J., Liang, C., & Zhang, X. (2024). Performance assessment and improvement of district cooling system: A case study of enhancing energy efficiency of hospital buildings. *Case Studies in Thermal Engineering*, *56*, 104187. https://doi.org/10.1016/J.CSITE.2024.104187

Bawaneh, K., Nezami, F. G., Rasheduzzaman, M., & Deken, B. (2019). Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States. *Energies 2019, Vol. 12, Page 3775*, *12*(19), 3775. https://doi.org/10.3390/EN12193775

Bobák, P., Pavlas, M., Máša, V., Jegla, Z., & Kšenzuliak, V. (2012). Heat Recovery in Professional Laundry Care Process. *Chemical Engineering Transactions*, *29*, 391–396. https://doi.org/10.3303/CET1229066

Chen, Y., Ozaki, A., Yusuke, A., Choi, Y., & Lee, H. (2023). Numerical modeling of laundry drying in a commercial laundry plant: Incorporating water potential as a driving force for heat and mass transfer. *Journal of Cleaner Production*, *423*, 138735. https://doi.org/10.1016/J.JCLEPRO.2023.138735

Choi, Y., Chen, Y., Ozaki, A., Lee, H., & Arima, Y. (2024). Advancing sustainable laundry practices utilizing waste heat from commercial laundry facilities. *Applied Thermal Engineering*, *247*, 123136. https://doi.org/10.1016/J.APPLTHERMALENG.2024.123136

Coskun, C., Oktay, Z., Özbek, H., Sogut, M. Z., Coskun, C., Oktay, Z., Özbek, · H, & Sogut, M. Z. (2023). *Hospital Energy Analysis in Turkey*. 643–654. https://doi.org/10.1007/978-3-031-30171-1_69

Eckelman, M. J., Huang, K., Lagasse, R., Senay, E., Dubrow, R., & Sherman, J. D. (2020). Health care pollution and public health damage in the united states: An update. *Health Affairs*, *39*(12), 2071–2079. https://doi.org/10.1377/HLTHAFF.2020.01247

Işık, C., Ongan, S., Islam, H., Balsalobre-Lorente, D., & Sharif, A. (2024). ECON-ESG factors on energy efficiency: Fostering sustainable development in ECON-growth-paradox countries. *Gondwana Research*, *135*, 103–115. https://doi.org/10.1016/J.GR.2024.07.020

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. (2018). Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress*, *6*, 268–289. https://doi.org/10.1016/J.TSEP.2018.04.017

Laundry Water and Energy Systems | Aquatherm International. (n.d.). Retrieved September 17, 2025, from https://www.aquatherminternational.com/

Ma, D., Sun, Y., Ma, S., Li, G., Zhou, Z., & Ma, H. (2024). Study on the working medium of high temperature heat pump suitable for industrial waste heat recovery. *Applied Thermal Engineering*, *236*, 121642. https://doi.org/10.1016/J.APPLTHERMALENG.2023.121642

Nagpal, H., Spriet, J., Murali, M. K., & McNabola, A. (2021). Heat Recovery from Wastewater—A Review of Available Resource. *Water 2021, Vol. 13, Page 1274*, *13*(9), 1274. https://doi.org/10.3390/W13091274

Panchal, C., & Rabas, T. (1989). *Energy-efficiency comparison of advanced ammonia heat-exchanger types*.

Pimenow, S., Pimenowa, O., & Prus, P. (2024). Challenges of Artificial Intelligence Development in the Context of Energy Consumption and Impact on Climate Change. *Energies 2024, Vol. 17, Page 5965*, *17*(23), 5965. https://doi.org/10.3390/EN17235965

Seo, J. H., Kang, S., Kim, K., & Lee, J. (2024). Compact heat pipe heat exchanger for waste heat recovery within a low-temperature range. *International Communications in Heat and Mass Transfer*, *155*, 107550. https://doi.org/10.1016/J.ICHEATMASSTRANSFER.2024.107550

Wadekar, V. V. (2003). Plate-Fin Heat Exchangers for Cryogenic Applications with Special Emphasis on Two-Phase Flow. *Low Temperature and Cryogenic Refrigeration*, 435–450. https://doi.org/10.1007/978-94-010-0099-4_25

Wehbi, Z., Taher, R., Faraj, J., Lemenand, T., Mortazavi, M., & Khaled, M. (2023). Waste Water Heat Recovery Systems types and applications: Comprehensive review, critical analysis, and potential recommendations. *Energy Reports*, *9*, 16–33. https://doi.org/10.1016/J.EGYR.2023.05.243

Yang, Q., Tong, S., Tong, Z., Wang, H., & Cao, X. E. (2024). Ash fouling characteristic analysis and prediction for pillow plate heat exchanger in waste heat recovery based on attentive-feature decision algorithm. *Fuel*, *372*, 132133. https://doi.org/10.1016/J.FUEL.2024.132133

Zeng, Q., Destek, M. A., Khan, Z., Badeeb, R. A., & Zhang, C. (2024). Green innovation, foreign investment and carbon emissions: a roadmap to sustainable development via green energy and energy efficiency for BRICS economies. *International Journal of Sustainable Development & World Ecology*, *31*(2), 191–205. https://doi.org/10.1080/13504509.2023.2268569


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