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ORIGINAL PAPER

Integrating Circular Economy Principles into Strategic Urban Planning for Sustainable Built Environment Development

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Abstract

It is widely acknowledged that the circular economy (CE) is a valuable tool for achieving strategic urban planning and implementing the principles of sustainable development. In recent years, a notable increase in scientific studies on CE, which is vital to the environmental and socio-economic developments of the urban environment. The purpose of the research is to investigate the significance of integrating circular economy (CE) principles into strategic urban planning and sustainable development of the built environment in Southwestern Nigeria. By examining the environmental, economic, and demographic impacts of CE practices, this research addresses the knowledge gap in understanding how it can be effectively applied to enhance sustainability in urban environments, particularly within the context of a developing region like Southwestern Nigeria. The study objectives were to: (i) identify factors influencing strategic urban planning, and (ii) examine circular economy indices for enhancing the urban environment in Nigeria. The results revealed significant relationships between various predictors of environmental issues and the circular economy on the sustainable environment. Notably, strong and significant correlations were found between environmental issues induced by environmental change, contributing to greenhouse gas emissions and altering natural landscapes ($\beta=0.411$, $p=0.001$), and between Circular Economy (CE) indices and a sustainable urban environment ($\beta=0.577$, $p=0.001$). This emphasises how crucial the integration of circular economy principles is in promoting a sustainable built environment through effective government policies, community engagement, and innovative approaches. The study advocates strategically incorporating these strategies into governmental decisions and development initiatives to achieve a sustainable urban environment.

Highlights

- The study demonstrates the significance of integrating circular economy (CE) principles into strategic urban planning
- Circular economy (CE), which is vital to the environmental and socio-economic developments of a sustainable built environment
- The circular economy (CE) can be enhanced through effective government policies, community engagement, and innovative approaches
- Strategic urban planning plays a crucial role in climate adaptation and achieving a sustainable built environment

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Keywords Circular economy · Strategic urban planning · Environmental sustainability · Technological innovations · Nigeria

Introduction

The circular economy (CE) offers a transformative framework for advancing sustainability, particularly within urban environments. By promoting the efficient use of resources through reuse, recycling, and minimized consumption, it supports long-term environmental and economic resilience [10, 52, 92]. Recent studies [52, 87] underscore the significant potential of it to address sustainability challenges associated with the built environment, which remains a major contributor to environmental degradation. Despite its promise, the integration of CE into this sector is hindered by factors such as the slow renewal of building stock, urban density, and complex environmental impacts across a structure's life cycle. Recognising these dynamics is essential for aligning circular strategies with sustainable development goals. The integration of Circular Economy (CE) principles into urban planning is emerging as a crucial paradigm shift from the dominant linear economic model. It offers a systemic approach aimed at regenerative design, resource efficiency, and waste minimisation [12, 44, 54]. Yet, its application in urban contexts, particularly in developing nations like Nigeria, presents significant tensions between conceptual ideals and practical implementation.

A notable African example of circular economy (CE) integration is the Lagos State Circular Economy Hotspot Initiative, which aims to embed circular practices within urban management systems. Programs led by the Lagos State Government, such as plastic waste recycling, composting, and material recovery, are implemented in collaboration with stakeholders like the Lagos State Waste Management Authority (LAWMA). Educational efforts through the LAWMA Academy and Extended Producer Responsibility (EPR) schemes incentivise community participation in recycling and resource recovery. These initiatives demonstrate how its principles can inform urban transformation and strategic planning in rapidly urbanising Nigerian cities. Incorporating its strategies, such as resource efficiency, material reuse, and waste minimisation, into urban development plans supports the transition toward sustainable, low-carbon cities. This is particularly vital in the context of the Global South, where urban growth often outpaces infrastructure development. However, as Ahmed et al. [10] highlight, regulatory and social barriers continue to hinder effective CE implementation in plastic waste management across emerging economies.

While the contextualization of CE in Nigeria's strategic urban planning is promising, practical challenges remain. These include fragmented policies, limited institutional capacity, and insufficient integration of regenerative design approaches. Nevertheless, as cities face mounting pressures from population growth and environmental degradation, they offer a critical pathway for aligning urban development with sustainability goals [54, 97]. Cities are central to material consumption, built environment development, and waste generation, making them strategic entry points for interventions [24, 70, 87]. In Nigeria, as a global South, however, fragmented governance structures, infrastructural deficits, and limited technical expertise hinder the systematic integration of its principles into urban planning. Although some municipalities express sustainability ambitions, these are seldom underpinned by measurable indicators or cross-sectoral strategies necessary for long-term impact [88, 108].

Urban planning in Nigeria often remains reactive and politically driven, contrasting with the proactive and systems-oriented approach of CE, which promotes closed-loop resource flows and adaptive infrastructure planning. The European Commission [39] emphasises that its successful integration in urban systems depends on the use of quantifiable indicators to evaluate resource efficiency, material flows, and environmental outcomes. Yet, Nigerian urban plans rarely apply such metrics, resulting in weak monitoring and limited capacity for course correction. Without operational indicators, urban planners and policymakers face challenges in aligning their strategies with broader development goals. As Geng et al. [43] and Völker et al. [102] suggest, the adoption of their metrics enhances transparency, facilitates policy evaluation, and fosters stakeholder engagement. In the Nigerian context, however, its implementation is hampered by inconsistent professional understanding and inadequate institutional frameworks to support evidence-based sustainability planning.

According to CE frameworks, cities where material consumption, the built environment, and waste generation intersect present key opportunities for circular interventions [24, 70, 87]. However, Nigeria's urban development is hindered by fragmented governance structures, weak technical capacity, and insufficient infrastructure. These constraints limit the alignment of urban planning processes with its principles. While some municipalities express sustainability intentions, they often lack measurable indicators and cross-sectoral strategies required for effective CE integration [88, 108]. Strategic urban planning in Nigeria remains reactive and politically driven, contrasting with the long-term systemic thinking required by it, which advocates for closed-loop systems and adaptive infrastructures. The European Commission [39] emphasises the importance of applying its indicators, such as material flow analysis, resource efficiency metrics, and environmental impact assessments, to guide urban policy. Yet, such metrics are scarcely employed in Nigeria, resulting in minimal monitoring and evaluation.

For CE strategies to align with broader developmental goals, measurable indicators must become operational. Geng et al. [43] and Völker et al. [102] highlight that integrating its metrics into decision-making enhances transparency, fosters institutional trust, and facilitates corporate alignment with sustainability objectives. In Nigeria, inconsistent professional understanding and weak institutional frameworks obstruct its implementation and undermine data-driven urban transformation. There remains an urgent need to embed its principles not only in policy documents but also through pilot projects and feedback systems. This includes mainstreaming the related infrastructure, such as green buildings, decentralised waste systems, and resource recovery zones, into zoning laws, urban plans, and environmental assessments. Embedding the principle into national frameworks, such as Nigeria's National Urban Development Policy or Lagos State Development Plan, could provide foundational guidance for implementation.

Notable pilot projects in Nigeria, such as the SUNREF programme (funded by the French Development Agency), have demonstrated the feasibility of CE in urban settings. These initiatives, operating mainly in Lagos and Abuja, have implemented energy-efficient retrofits and sustainable building practices. In Ogun State, community plastic recycling hubs harness low-tech innovations and informal labour, showcasing the circular reuse of materials. Similarly, the Lagos State Circular Economy Hotspot Initiative, led by the Lagos State Government and the Lagos State Waste Management Authority (LAWMA), promotes plastic recycling, composting, and materials recovery. Despite these efforts, academic incorporation of CE in urban planning remains limited [13, 14, 24].

Scholars have proposed embedding CE into zoning, land-use regulations, and environmental impact assessments to enable systemic change [70, 88]. However, Nigerian urban planning continues to be short-term and politically reactive. The persistent gap between CE's conceptual foundation and its real-world application in Nigeria is largely attributable to systemic planning inertia, fragmented governance structures, and limited stakeholder engagement. Bridging this divide is essential for transforming CE from an aspirational model into a functional planning instrument. To bridge this gap, there is a need for context-sensitive CE strategies that incorporate both top-level frameworks and localised experimentation. Embedding CE metrics into existing instruments like the National Urban Development Policy or Lagos State Development Plan could anchor its transitions in measurable, scalable actions. Effective integration of its into strategic urban planning is vital for achieving sustainable, future-ready Nigerian cities [103]. Accordingly, this research seeks to bridge the gap by applying its principles within Nigeria's urban context to promote a resilient and environmentally responsible built environment. This study explores the factors shaping strategic urban planning and assesses the integration of circular economy (CE) indices as tools for enhancing environmental sustainability within Nigeria's urban environments. The dual objectives of the research are:

- To identify critical factors influencing strategic urban planning in Nigeria; and
- To examine how circular economy indices can contribute to the sustainability and resilience of urban areas.

From these objectives, the study proposes two central hypotheses:

- Hypothesis 1: There is a significant relationship between the drivers of strategic urban planning and the effectiveness of addressing environmental challenges and promoting sustainability in Nigeria's urban environment.
- Hypothesis 2: The implementation of circular economy indices significantly enhances the sustainability and resilience of Nigeria's urban environment.

As urbanisation intensifies, especially in developing countries, the integration of circular economy principles into urban planning emerges as a transformative pathway toward sustainable development. Circular economy approaches such as resource efficiency, waste minimisation, regenerative material cycles, and renewable energy utilisation are increasingly recognised for their potential to reshape urban growth patterns and reduce ecological impacts. Through renewable energy adoption, green construction, and designs for longevity, it can bolster the built environment's resilience to climate disruptions [15, 109, 111]. Çalıkoğlu et al. [24] reinforce that it enhances biodiversity, climate outcomes, and resource efficiency.

This research investigates how CE frameworks can be systematically embedded within the strategic planning and development of the built environment in Nigeria. It underscores the importance of tailoring its strategies to local socio-economic and environmental contexts to maximise effectiveness. By addressing the unique constraints and opportunities present in Nigeria, the study provides empirical insights and policy-relevant recommendations for CE-based urban sustainability. Furthermore, the research bridges the gap between global circular economy strategies and the practical realities of urban planning in develop-

ing nations. It highlights how locally grounded its applications, such as sustainable construction practices, decentralised waste management, and adaptive reuse of materials, can drive environmental, economic, and social resilience. The originality of this study lies in its synthesis of empirical findings, regional adaptation, and policy innovation, offering a robust framework for advancing circular economy principles in Nigeria's urban future.

Review of Literature

Environmental Challenges and Sustainable Development

The growing urgency of environmental crises, rising global temperatures, sea-level rise, biodiversity loss, desertification, and urban vulnerability has sparked a global rethinking of how cities are planned and built [98, 105]. In the Global South, particularly in Nigeria, the intersection of environmental degradation and urban expansion has created a complex terrain where traditional planning approaches are proving inadequate [5, 74].

Nigeria's emission profile reflects this challenge: fossil fuel combustion alone accounts for over 60% of the country's greenhouse gas (GHG) emissions, while agriculture, land use change, and waste contribute the rest [40, 97]. Without systemic shifts, emissions are projected to rise by over 30% by 2030. This reinforces the urgent need to transition from reactive environmental management to strategic, future-facing urban planning rooted in sustainability.

Recent literature highlights the promise of strategic urban planning as a tool for integrating resilience into the built environment. However, the conversation is no longer just about better infrastructure or land use; it is increasingly about embedding Circular Economy (CE) principles into planning frameworks [88, 110]. It moves beyond linear development models to emphasise resource circularity, waste minimisation, and design for regeneration ideas that align well with sustainability objectives, yet raise unresolved tensions in both theory and practice. A growing body of scholarship debates whether it should be framed primarily as a technological solution driven by smart systems, material innovation, and industrial symbiosis or as a structural transformation requiring policy realignment, equity frameworks, and behavioural shifts [9, 55]. Moreover, while top-down CE initiatives often dominate, grassroots and community-led practices increasingly challenge centralised planning paradigms, calling attention to issues of local knowledge, social justice, and economic inclusion [101].

In the Nigerian context, CE discourse remains emergent. Most policy and academic efforts are focused on waste management or renewable energy, with less attention given to how their frameworks can be structurally integrated into spatial and infrastructural planning [6, 24]. As such, this study contributes by exploring how its indices can be strategically embedded within urban planning practices to simultaneously tackle environmental degradation, economic inefficiencies, and social inequities. Rather than treating CE as a one-size-fits-all model, this research embraces the complexity of adapting global CE concepts to local realities. It critically engages with debates between technological optimism versus socio-political restructuring, and centralised planning versus decentralised adaptation, positioning urban Nigeria as a compelling case for the nuanced, context-aware implementation.

Environmental degradation in Nigeria and broader Sub-Saharan Africa has emerged as both a symptom and a catalyst of rapid urbanisation, economic expansion, and popula-

tion growth. As infrastructural development accelerates, environmental externalities, particularly air pollution, have intensified. For instance, Nigeria recorded a PM2.5 level of 21.40 μg/m^3 in 2019, ranking 39th globally and nearing pollution levels in industrialised nations like South Africa and Saudi Arabia [11]. These environmental risks, compounded by climate-induced phenomena such as heatwaves, erratic rainfall, and rising sea levels, are not merely ecological concerns,they constitute profound public health and development challenges [97, 114].

Scholars have linked these disruptions to worsening food insecurity, heightened water stress, and rising malnutrition, with projections indicating that climate-related malnutrition in Sub-Saharan Africa may increase by 25–90% by 2050 [112, 113]. The literature consistently identifies a growing burden of infectious diseases exacerbated by changing climatic conditions, thus highlighting a crucial interface between environmental sustainability and human health. While many studies offer descriptive accounts of pollution and vulnerability, a notable gap persists in terms of synthesising actionable responses rooted in systems thinking and the circular economy. Some scholars advocate for nature-based solutions such as ecosystem restoration and green infrastructure to mitigate urban ecological stress, aligning with the bottom-up sustainability paradigm (see Fig. 1). There is a conceptual divergence between technocratic and community-driven approaches to sustainability. By positioning ecosystem services as central to circular planning, it underscores how cities in Nigeria and other sub-Saharan regions can transition from extractive and linear models to regenerative, low-carbon, and resilient urban systems. Others call for robust top-down policy integration that combines environmental governance with public health imperatives. However, tensions remain unresolved in the literature.

On one hand, proponents of technological optimism stress innovation, clean energy transitions, and smart urbanism as pathways to resilience. On the other hand, critics highlight the structural barriers of economic inequality, policy inertia, and poor enforcement that undermine sustainability efforts in African cities. Effective CE adoption must, therefore, navigate these dualities by combining long-term structural reforms with context-sensitive, grassroots innovations. Thus, the discourse on environmental change and sustainability in African contexts must evolve from passive documentation to proactive integration. This includes synthesising interdisciplinary strategies, confronting political and economic asymmetries, and embedding its practices within socio-ecological resilience frameworks. Table 1 summarises relevant literature contributions across these themes.

Bridging Circular Economy Theories and Strategic Urban Planning Implementation in Nigeria

The Circular Economy (CE) has emerged as a transformative paradigm in sustainable urban development, gaining traction among policymakers, scholars, and practitioners in the built environment [97, 111]. Unlike traditional linear models, it promotes a systemic and regenerative approach by focusing on three actionable pillars: minimising waste and pollution, maximising resource reuse, and restoring natural systems [10, 33]. The EMF's circular cities framework operationalises these principles through measurable indicators such as material flow efficiency, waste diversion rates, and ecosystem health metrics, providing a blueprint adaptable to urban contexts globally [34, 35, 86]. This framework also highlights the impor-

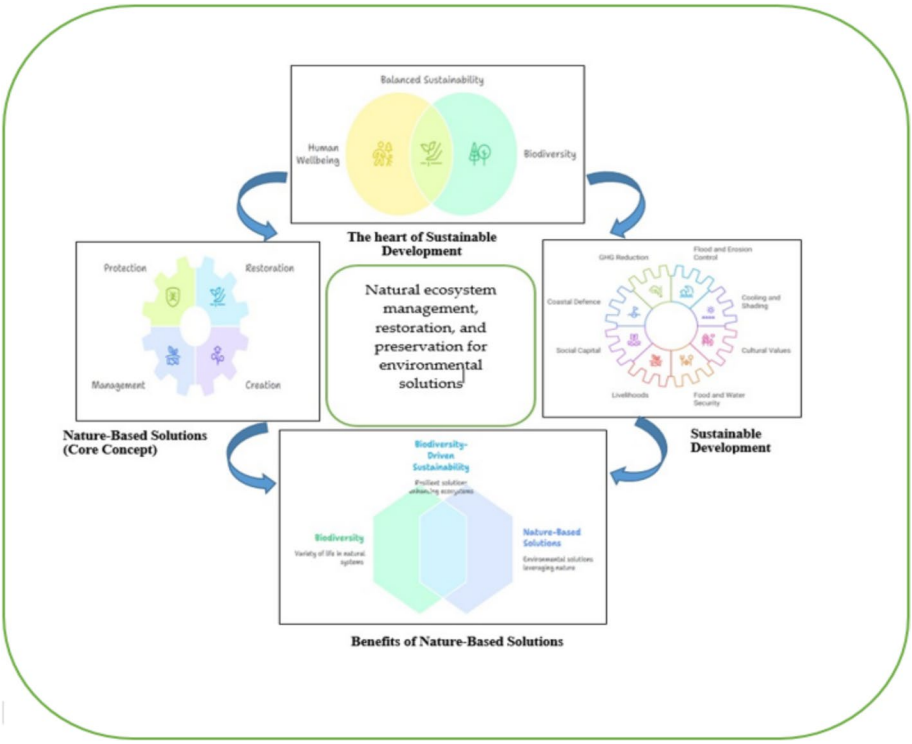


Fig. 1 Nature-based solutions (NbS) for urban environmental resilience within a circular economy framework. Source: Adapted from Seddon [93]

tance of multi-level governance, cross-sector collaboration, and innovation diffusion factors critical to embedding CE into urban planning practice.

Policy adoption across diverse geopolitical settings, including Germany's 1996 Closed Substance Cycle and Waste Management Act, Japan's 2002 Basic Law for a Recycling-Based Society, China's 2009 Circular Economy Promotion Law, and the European Union's 2015 Circular Economy Strategy, illustrates how CE principles translate into concrete legislative instruments [38, 64, 72, 95]. These policies incorporate measurable targets such as recycling quotas, resource productivity benchmarks, and lifecycle assessments, providing practical metrics for evaluation. However, the transferability of these models to Nigeria requires contextual adaptation to address fragmented urban governance, infrastructural deficits, and limited technical capacity. Thus, this study refines the CE framework (Fig. 2) by integrating localised indicators of material efficiency, waste management efficacy, and environmental resilience relevant to Nigeria's urban realities. This tailored framework guides empirical analysis, linking theoretical constructs with operational metrics to assess the effectiveness of strategic urban planning in advancing sustainable, circular cities.

A core debate within CE scholarship revolves around technological optimism versus systemic reform. Proponents of CE argue that technological innovations such as decentralised waste systems and green infrastructure can help cities transition toward sustainability [10, 97]. However, critics highlight the limitations of techno-centric solutions without struc-

Table 1 Summary of literature on environmental challenges, circular economy, and sustainability strategies in Sub-Saharan Africa

Indicators/focus area	Author(s)	Key findings	CE/sustainability ımplications
Climate-induced health challenges	Lloyd et al. [112]; Serdeczny et al. [113]	Projected rise in malnutrition and disease due to temperature increase, poor sanitation, and extreme weather events in SSA	Necessitates climate-resilient health systems and sustainable water/sanitation strategies
Environmental vulnerability and degradation	van Hooidonk et al. [114]; Anthun et al. [20]	Sea-level rise, flooding, droughts, and extreme heat pose risks to environmental sustainability and human development	Encourages the adoption of adaptive infrastructure and nature-based solutions within circular planning frameworks
Environmental health and waterborne diseases	Levy et al. [115]; Gundry and Conroy [49]	Poor water quality leads to gastrointestinal and vector-borne diseases, especially in low-income communities	Reinforces the need for closed-loop water management systems in urban and rural design
Climate change and food security	Foley et al. [41], Godfray et al. [47], Swarnakar and Khalfan [97]	Food systems are threatened by environmental stressors, reducing yields and intensifying malnutrition risks	Supports regenerative agriculture, climate-smart farming, and circular bioeconomy practices
Urban air pollution and emissions	Air Quality in Nigeria [11]; Legg [61]; Kilungo et al. [116]; Rahman and Duraman [88]	Nigeria ranks 39th globally in PM2.5 levels; emissions from vehicles, generators, and factories are growing threats	Urges transition to low-emission transportation, green energy, and CE-driven industrial ecosystems
Environmental problems and economic stability	Costanza et al. [117]; Pel et al. [87]	Environmental degradation increases economic costs and undermines development gains	Emphasises the need for eco-efficiency, carbon pricing, and green economy transitions
Urbanisation impacts on ecosystems and infrastructure	Egbe [118]; Onwuanyi and Ndinwa [84]; Roe [90]	Urban sprawl degrades ecosystems, disrupts infrastructure, and fuels inequality	Promotes compact urban design, ecosystem restoration, and CE-based land-use planning
Public health and weak infrastructure	Swarnakar and Khalfan [97]	Inadequate infrastructure increases vulnerability to pollution-related diseases in urban Africa	Advocates for CE-health integrated design in the built environment
Nature-based solutions and regenerative design	CE Practitioners (2018–2024)	Use of wetlands, green roofs, urban forests, and permeable surfaces to improve sustainability and environmental resilience	Aligns with CE's closed-loop systems, reducing waste, regenerating resources, and enhancing ecological performance
Global environmental change and sustainability policy	van Hooidonk et al. [114]; Anthun et al. [20]	Global consensus on sustainable pathways calls for adaptive governance and multi-scalar coordination	Strengthens institutional frameworks for CE implementation and monitoring

CE circular economy, *SSA* Sub-Saharan Africa, *IPCC* ıntergovernmental panel on climate change, *NEST* Nigerian environmental study/action team

tural shifts in governance, policy integration, and social equity [102, 108]. These tensions are especially pronounced in cities like Lagos and Port Harcourt, where fragmented urban governance and infrastructural deficits undermine long-term CE planning. Another unresolved tension is the top-down versus grassroots CE implementation. While international frameworks such as UNEP's Urban CE model advocate lifecycle thinking, stakeholder participation, and inclusive urban governance [99], local institutional inertia often limits adaptation. In Nigeria, it remains inconsistently interpreted, with little alignment between

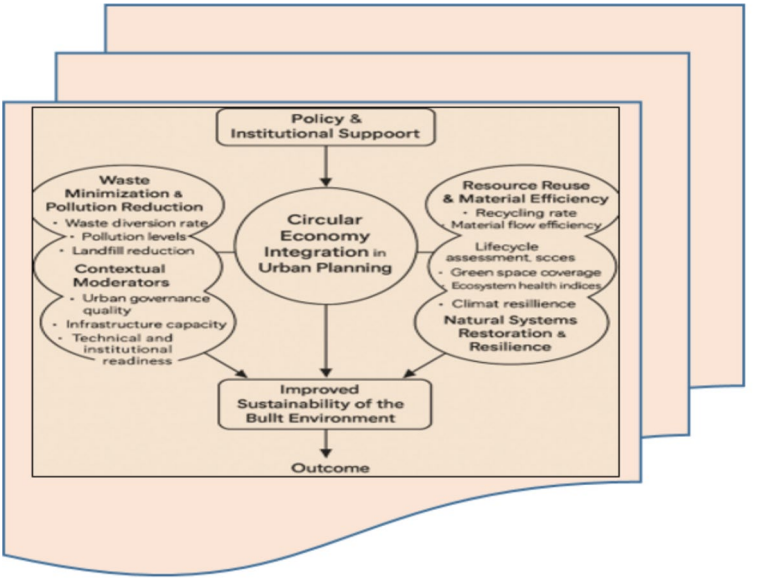


Fig. 2 Conceptual model description: circular economy in urban planning

strategic urban goals and measurable CE indicators [39]. The absence of robust metrics for monitoring material flows and environmental impact hampers meaningful progress. Table 2 summarises key variables and indicators essential for implementing the circular economy (CE) in urban planning. It highlights core pillars like waste reduction, material efficiency, and ecosystem resilience, while considering governance, infrastructure, and institutional readiness as moderators. Policies and measurable outcomes guide sustainable transformation in the built environment.

Figure 3 illustrates the dynamics of Circular Economy (CE) adoption and its barriers within the built environment sector. It presents key factors influencing the uptake of CE practices, including systemic challenges such as cultural resistance, regulatory gaps, organisational inertia, and notably, limited public awareness particularly within informal economies. In such contexts, public awareness tends to manifest through grassroots initiatives, informal knowledge sharing, and community-led recycling practices, which often operate outside formal regulatory frameworks. These informal expressions of awareness, while fragmented, contribute to material recovery and reuse but lack the institutional support needed for broader impact. Foundational elements of CE such as resource efficiency, closed-loop systems, and environmental regeneration serve to enhance sustainable resource flows and ecological resilience in urban development. On the other hand, enabling factors such as perceived long-term economic benefits, industry motivations for competitive advantage, and emerging sustainability-oriented regulations support CE integration.

These opposing forces, barriers and enablers highlight the nuanced interplay shaping CE implementation in urban contexts. While the CE framework offers practical and theoretical pathways toward sustainable urban transformation, its successful integration into Nigeria's urban planning system requires more than policy intent. It calls for a deliberate institutional commitment, the development of reliable indicator-based monitoring systems, and targeted

Table 2 Summary of variables and indicators on circular economy in urban planning

Central construct	Operational variables	Indicators
Key Pillars	Waste Minimisation & Pollution Reduction	Waste diversion rate, pollution levels, and landfill reduction
	Resource Reuse & Material Efficiency	Recycling rate, material flow efficiency, lifecycle assessment scores
	Natural Systems Restoration & Resilience	Green space coverage, ecosystem health indices, flood and climate resilience measures
Contextual Moderators	Urban Governance Quality	Transparency index, stakeholder engagement level, and enforcement of urban sustainability policies
	Infrastructure Capacity	Access to basic services, quality of transport and utility infrastructure, smart grid coverage
	Technical and Institutional Readiness	Availability of skilled workforce, research and development investment, innovation adoption rate
Policy & Institutional Support Outcomes	National and local policies, regulations, and incentives serve as enabling mechanisms	Number of CE-related policies, subsidy/incentive availability, compliance enforcement rate
	Enhanced sustainability of the built environment	Environmental footprint reduction, green building certification rate, job creation in green sectors, cost savings from CE adoption

efforts to formalise and elevate public awareness, especially within informal economies, into structured, impactful engagement that aligns with national sustainability goals. Table 3 outlines key CE principles alongside measurable indicators.

Theoretical Framework and Hypothesis Development

This study adopts an integrated theoretical framework that aligns Circular Economy (CE) principles with Sustainable Urban Development (SUD) goals, tailored to the urban realities of Nigeria. The CE approach addresses resource scarcity and waste by promoting closed-loop systems, life-cycle thinking, and regenerative design [32, 44]. Drawing from the Ellen MacArthur Foundation's butterfly diagram, the framework operationalises biological and technical resource cycles, while Doughnut Economics offers socio-ecological boundaries within which cities must function [33, 89]. To ground the framework empirically, it identifies context-relevant levers such as infrastructure gaps, informal economies, and regulatory inefficiencies, converting abstract concepts into actionable variables. Life-cycle assessment, resource efficiency, and systems thinking serve as operative tools to evaluate interlinkages

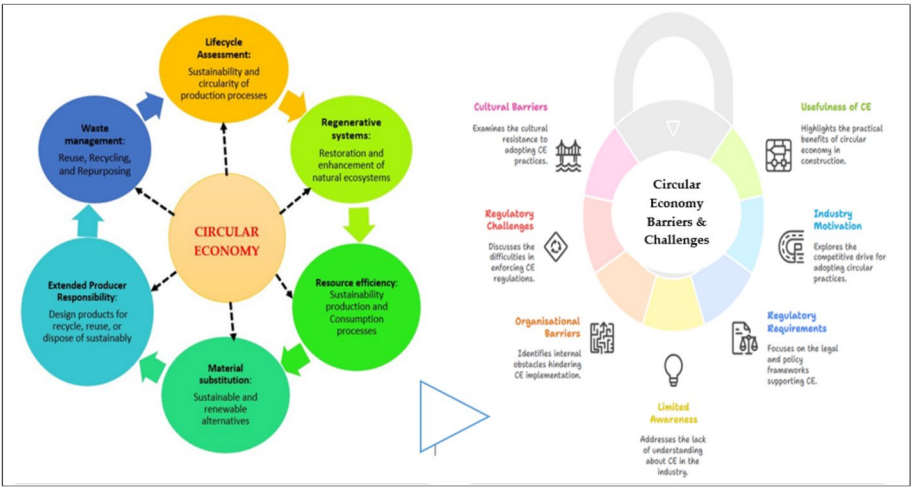


Fig. 3 Promoting circular economy adoption and its barriers in the built environment sector. Source: Adapted from Zaman et al. [107]

across urban production, consumption, and waste flows [66, 88]. Systems thinking, in particular, guides the identification of feedback loops and leverage points, enabling a policy-sensitive roadmap for integrating CE into Nigeria's urban planning strategies [55]. A visual model (see Fig. 4) outlines the interactions among environmental, economic, and social dimensions, showing how CE strategies can enhance urban resilience, reduce waste, and support inclusive growth.

Strategic Urban Planning (SUP), especially sustainability-focused models, emphasise long-term urban viability through resource management, environmental conservation, and equity. Pel et al. [87] propose a systems-based framework using triple-bottom-line principles, integrating material flows, institutional dynamics, and stakeholder strategies. The framework supports Theory of Change (ToC) modelling for planning and evaluating Circular Economy (CE) initiatives. Urban metabolism complements this by viewing cities as living systems, enabling analysis of energy, material, water, and waste flows [12, 53]. This approach helps identify inefficiencies, trace stocks, and design regenerative, resource-efficient systems [106]. By integrating CE and SUP, the study addresses sustainability transitions in rapidly urbanising developing countries, considering socio-economic and cultural contexts. The framework aligns policies, infrastructure, and public engagement for resilient urban development.

Multiple hypotheses were derived from the literature to test factors influencing environmental change and sustainability (Table 4), while Table 5 presents CE principles and their indicators. Figure 5 outlines the conceptual framework, beginning with study objectives such as identifying factors affecting SUP and assessing its indices for urban improvement. It leads to hypothesis testing in two domains, SUP under environmental pressure and CE's role in urban enhancement, culminating in conclusions that demonstrate the interdependence of planning and its strategies.

Table 3 Circular economy principles and their indicators

	Indicators	References
1	**Waste Management**: Waste is seen as a valuable resource in a circular economy. After their life cycle, materials are recovered and recycled, going back into production to make new goods. This minimises the impact on the environment	Di Maio et al. [32]; Stahel [119]; Rahman and Duraman [88]
2	**Resource Efficiency**: Maximising the use of resources throughout the entire production and consumption process is key. This involves using fewer resources, optimising energy and water use, and reducing waste generation, thereby improving overall efficiency and sustainability	Geissdoerfer et al. [44], Carbon Dioxide Information Analysis Centre [25], Chaturvedi et al. [26], Çalıkoğlu et al. [24]
3	**Regenerative Systems**: Circular economy principles emphasise creating systems that regenerate natural ecosystems rather than deplete them. This includes practices like using renewable energy, promoting biodiversity, and ensuring that agricultural and manufacturing processes restore rather than harm the environment	Velenturf and Purnell, [101]. Ahmed et al. [10], Suárez-Eiroa et al. [96], Çalıkoğlu et al. [24]
4	**Lifecycle Assessment (LCA):** The lifecycle assessment (LCA) method is a methodical way to assess a product's environmental effects at every stage of its existence, from the extraction of raw materials to disposal. Since it offers an in-depth comprehension of the sustainability of goods and manufacturing processes, and directs advancements toward more circular practices	Linder et al. [65], Lonca et al. [66], Pel et al. [87]
5	**Extended Producer Responsibility (EPR):** EPR gives producers more control over how items are managed at the end of their useful lives. This principle encourages manufacturers to design products that are easier to recycle, reuse, or dispose of sustainably, incentivising a reduction in waste and environmental impact	Brown et al. [22], Maitre-Ekern [68], Ahmed et al. [10]
6	**Material Substitution**: Material substitution involves replacing non-renewable or harmful materials with sustainable, renewable, or less environmentally damaging alternatives. This principle supports the circular economy by reducing the environmental footprint of products and encouraging the use of materials that can be regenerated or have lower impacts	Geissdoerfer et al. [44], Circular Economy Strategy [27]

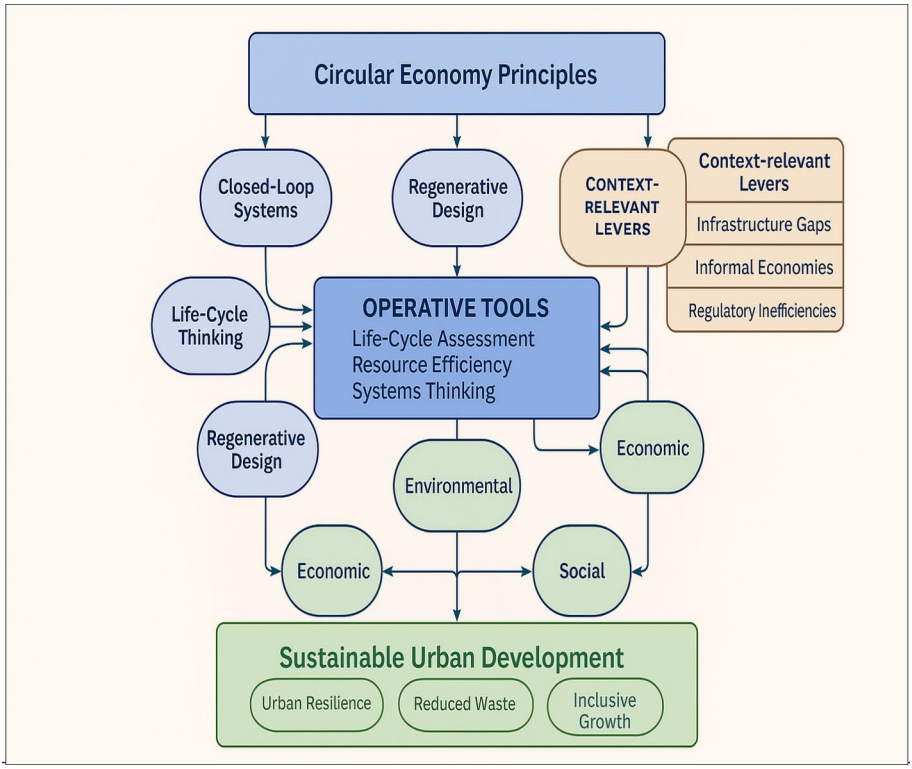


Fig. 4 A visual model illustrating how CE strategies link environmental, economic, and social factors

Method

The Research Study Area

The South-West area of Nigeria, which includes Lagos and Ogun states, was the study's primary emphasis (Fig. 6). According to the 2006 demographic census, the South-West has a landmass of approximately 76,852 km^2 and a population of 27,722,432. The land area covers approximately 166,361 km^2 [73, 77, 122]. A significant portion of Nigeria's land area is characterised by tropical rainforests [8]. Understanding the unique environmental characteristics and socio-economic dynamics of the South-West region is essential for comprehending the complexities of the challenges of the impacts of environmental change and devising effective ameliorating strategies tailored to the local context. The focus on Nigeria's Southwestern zone is particularly crucial in this study due to its status as the most densely populated area in the country. With rapid urbanisation and industrialisation. The study focused on the two states because they are unique among the states in the South West area, having a real-life case study where circular economy (CE) principles are being explored to address mounting challenges in waste management, resource efficiency, and infrastructural resilience. In addition, the two states face specific difficulties relating to the effects of environmental change, urban development, and environmental sustainability. Together, these

Table 4 Hypothesis development on the relationships between environmental challenges and sustainability

Hypotheses	Discussion	Literature
Main Hypothesis H1: Rapid urbanisation and industrial activity in Southwestern Nigeria significantly drive deforestation and greenhouse gas emissions	Urbanisation and deforestation reduce carbon-absorbing trees, while industrial emissions together intensify environmental change and degradation in the affected region	Agboola et al. [7]; Stone et al. [94]
Sub-Hypothesis (H1a): Implementing sustainable urban planning and green infrastructure in the south-western region of Nigeria can effectively enhance the adaptive capacity of urban environments	Sustainable urban planning involves designing cities with environmental resilience in mind, such as reducing carbon footprints, improving energy efficiency, and promoting public transportation	Smith et al. [120]
Sub-Hypothesis (H1b): Biodiversity loss is a major driver of environmental change, resulting in decreased ecosystem resilience and increased vulnerability to environmental changes	Biodiversity is crucial for ecosystem stability and resilience. Loss of species can disrupt ecosystem functions, leading to reduced capacity to adapt to environmental change. Literature suggests that decreased biodiversity impacts ecosystem services, exacerbating environmental change	Ejike-Alieji and Ekpoh [36], Çalıkoğlu et al. [24]
Sub-Hypothesis (H1c): Pollutants in land, air, and water directly impact environmental change, affecting atmospheric and environmental stability	Pollutants such as greenhouse gases and particulate matter have been shown to contribute to environmental change by affecting atmospheric stability and contributing to global warming. Research links pollutants to increased greenhouse gas concentrations and disrupted environmental conditions	Ma et al. [67]; Rahman and Duraman [88]
Sub-Hypothesis(H1d): Environmental problems significantly impact mental health, necessitating interventions for environmental stressors	Environmental stressors, including natural disasters and environmental degradation, have been linked to various mental health issues	Gazarian et al. [42]; Clayton et al. [28]; Environmental Change and Sustainable Urban Development in Africa and Asia [29]

Table 5 Hypotheses development on the assessment of the circular economy principles and their indicators

Hypotheses	Discussion	Literature
Main Hypothesis (H2): Implementing circular economy indices significantly enhances the sustainability and resilience of the urban environment in Nigeria	Circular economy indices enhance Nigeria's urban sustainability by optimising resources, reducing waste, and promoting regenerative practices for long-term environmental resilience	Ghisellini et al. [45]; Stahel [119]; Griscom et al. [46]
Sub-Hypothesis (H2a): Implementing circular economy-based waste management practices significantly minimises the environmental impact on Nigeria's metropolitan environment	Circular economy-based waste management reduces Nigeria's urban environmental impact by recycling materials, minimising reliance on virgin resources, and decreasing the environmental footprint, contingent on efficient waste collection and processing systems	Ghisellini et al. [45], Ahmed et al. [10]
Sub-Hypothesis (H2b): Circular economy-driven resource efficiency improves sustainability in Nigeria's urban production and consumption	Regenerative systems in Nigeria's urban areas promote ecological balance and sustainability by restoring ecosystems, using renewable energy, and reducing the environmental impact of human activities	Geissdoerfer et al. [44]. Çalıkoğlu et al. [24]
Sub-Hypothesis (H2c): The adoption of regenerative systems as part of the circular economy significantly contributes to the restoration and enhancement of natural ecosystems within Nigeria's urban areas	Regenerative systems restore ecosystems by utilising renewable energy, enhancing biodiversity, and making agriculture and manufacturing environmentally restorative, aligning with the principles of a circular economy	Geissdoerfer et al. [44]. Rahman and Duraman [88]
Sub-Hypothesis (H2d): The application of Lifecycle Assessment (LCA) in evaluating products significantly improves the sustainability and circularity of production processes in Nigeria's urban environment	Lifecycle Assessment (LCA). Lifecycle Assessment (LCA) evaluates a product's environmental impact from raw material extraction to disposal, promoting sustainability and guiding improvements within the circular economy framework	Bjørn et al. [23, 88]
Sub-Hypothesis (H2e): Extended Producer Responsibility (EPR) policies encourage Nigerian manufacturers to design recyclable, reusable products, reducing waste and environmental impact.	Extended Producer Responsibility (EPR) policies shift the responsibility for end-of-life product management to the producers, encouraging them to design products that are easier to recycle, reuse, or dispose of sustainably	Ahmed et. al. [10]
Sub-Hypothesis (H2f): Material substitution with sustainable and renewable alternatives significantly reduces the environmental footprint of products and supports the circular economy in Nigeria's urban environment	Material substitution replaces harmful materials with sustainable alternatives, reducing environmental impact and supporting the circular economy through renewable, low-impact, and regenerable material use	Wang et al. [121]

states provide a contrasting yet complementary framework for evaluating circular economy (CE) implementation and urban resilience. Lagos state is a commercial and industrial hub, boasting the largest population of 12,264,884, while Ogun state has 5,072,892 residents [75]. Lagos, Nigeria's commercial hub and one of Africa's fastest-growing megacities, represents a highly urbanised setting with developed infrastructure, mounting environmental challenges, and active pursuits in sustainable urban development. In contrast, neighbouring Ogun State is undergoing swift urban expansion, driven by industrial growth and the influx of population from Lagos.

The choice of this regional focus allows for a meaningful comparative discussion of two dynamic urban contexts at different stages of sustainability adoption. Despite variations in

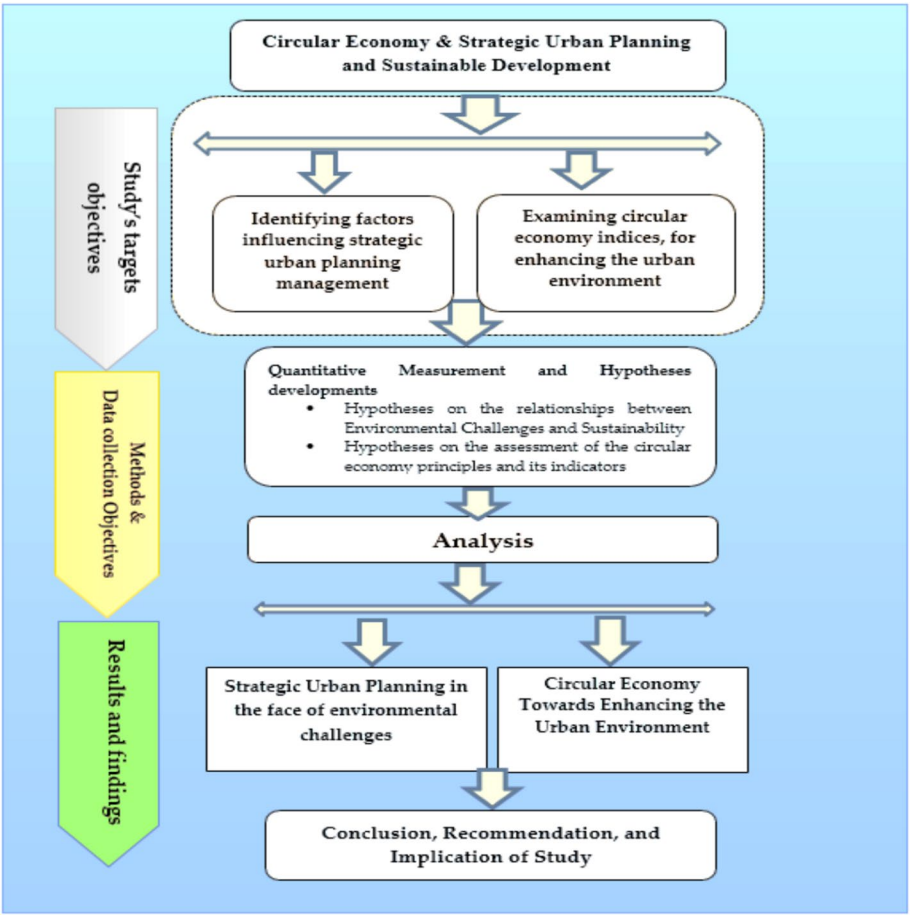


Fig. 5 The study's theoretical framework

governance, infrastructure development, and urban planning capacities, both states share common environmental challenges such as waste management, urban sprawl, and infrastructure pressure, making them ideal for assessing the applicability and effectiveness of CE principles. To minimise the impact of potential differences between the states, the study employed a harmonised analytical framework and consistent data collection instruments across both states. Variables were operationalised uniformly, and comparative analyses were contextualised to account for socio-economic and policy-related disparities. Furthermore, logistic regression models were adjusted to control for location-specific covariates where necessary, thereby ensuring the robustness and generalisability of the findings. This approach enhances the validity of the study's insights and provides a balanced understanding of how circular economy practices can be tailored to different but interrelated urban contexts within Nigeria.

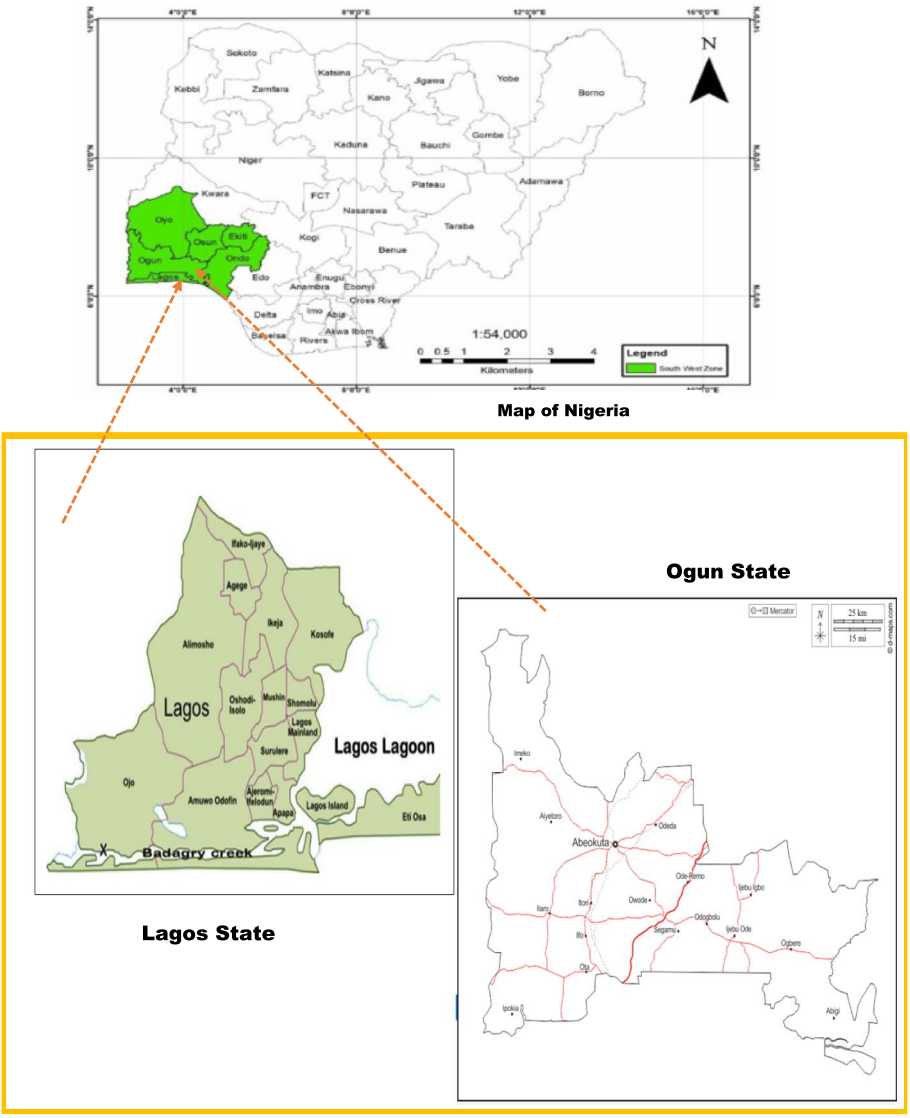


Fig. 6 The map of Nigeria showing Lagos and Ogun States in the South-West region. Source: Lawson et al. [60]

Data Collection, Distribution, and Analysis

A quantitative empirical strategy that makes use of questionnaire surveys is employed to systematically collect pertinent data regarding the underlying causes and ramifications of environmental change. This method not only furnishes insights into the factors contributing to environmental change but also elucidates its implications. Furthermore, it serves as a mechanism for soliciting input from experts and stakeholders, encompassing individuals aged 18 years and above, regarding mitigation and adaptation strategies to tackle the dif-

ficulties posed by environmental change. Through structured questionnaires, this approach facilitates the comprehensive gathering of insights and perspectives from diverse stakeholders, thereby enriching the understanding of environmental change dynamics and informing strategic interventions. The aspect of questionnaires on circular economy relies on the business model measurement scale as founded on the innovation and validation principles suggested by Kuzma and Sehnem [56]. The variables included in the questionnaire were selected based on a comprehensive review of relevant literature and theoretical frameworks surrounding circular economy principles, sustainable urban planning, and environmental adaptation. These variables reflect key components identified in previous empirical studies as significant determinants of sustainable outcomes in urban contexts, particularly in developing regions such as Southwestern Nigeria. Each variable was designed to align with the study's objectives of evaluating the relationship between circular economy practices and urban resilience. The one-on-one and online survey distributions were adopted for the distribution of the survey questionnaires. Meanwhile, Lagos and Ogun states were the states in focus, where respondents' opinion applies, which invariably allows comparison analysis and findings.

The Logistic regression analyses were conducted using the Statistical Package for the Social Sciences (SPSS) software package, Version 22, to analyse the data obtained from the collected. Logistic regression is a statistical technique used to model the relationship between one or more independent variables and a categorical outcome variable. Logistic regression was selected for this study due to the nature of the research questions and the structure of the data, which focused on binary and categorical outcomes related to the presence or absence of specific sustainable practices and perceptions. Additionally, the sample was relatively homogeneous across urban centres in Southwestern Nigeria without nested data structures (e.g., respondents nested within clearly defined hierarchical groups such as different cities), which limited the suitability and interpretive advantage of multilevel modelling in this case. Logistic regression provided a straightforward and robust method for identifying significant predictors while maintaining interpretability for policy and planning implications.

However, an initial pilot survey was conducted in October 2021 in the designated research areas to assess and refine the survey instrument's effectiveness and suitability. The pilot survey served as a preliminary step to evaluate the questionnaire's clarity, comprehensiveness, and relevance to the research objectives. It provided an opportunity to identify any ambiguities or shortcomings in the survey instrument and make necessary adjustments before the full-scale data collection commenced. Additionally, the pilot survey enabled researchers to gauge respondents' understanding of the questions and ensure that they accurately captured the intended information. Feedback obtained from the pilot survey participants informed refinements to the main survey (between March and June 2022), enhancing its reliability and validity for subsequent data collection phases. In the absence of comprehensive lists of built environment professionals in each region, a purposeful sampling method was employed. A purposive sampling method was employed to select respondents who possess relevant knowledge or experience regarding sustainability practices and circular economy in the study areas. This non-probability technique enabled the researcher to intentionally target specific groups whose insights were considered critical to the objectives of the research [30]. The choice of purposive sampling is justified due to the need to have deep and contextual insights from those who have experienced or gathered knowledge on sustainability

and circular economy operational aspects. This approach ensures that data is deep, relevant, and meets the study's objectives. Its limitations include the inherent subjectivity in selecting study participants that could limit reliability and representativeness [123]. To address these limitations, this study ensures diversity within the purposively selected participants (these include urban planners, healthcare professionals, environmental scientists, and government officials across different states and sectors), which reduces selection bias.

However, in this study, several measures were taken to mitigate self-reported questionnaire data concerns and enhance objectivity. First, the questionnaire was carefully designed using validated scales and had a pilot test reviewed by experts in sustainability and circular economy research to ensure clarity, relevance, and neutrality. Second, anonymity was maintained to encourage honest and unbiased responses. Third, triangulation was employed by integrating insights from literature and policy documents to cross-validate the survey findings. These methodological procedures safeguard and enhance the credibility and reliability of the data collected and support the robustness of the study's conclusions.

The study's demographic information included variables such as age, socioeconomic status, gender, residential areas, and areas of professional expertise. Beyond demographic data, respondents provided feedback on a set of 49 dependent measurement variables, evaluating their perceptions of environmental change predictors and mitigation strategies. These measurement variables were adapted from previous studies. The CE index and other measurement variables were developed based on well-established indicators drawn from existing literature (Ellen MacArthur Foundation frameworks) and other CE empirical studies conducted by Omar et al. [83], Adger et al. [124], and Egbe [118] for environmental change predictors, and Berrang-Ford et al. [21] for environmental change strategies. Participants' responses were scored using a 5-point Likert scale, with options ranging from "*Strongly agree*" (5) to "*Strongly disagree*" (1), providing a comprehensive understanding of their attitudes and perspectives regarding environmental change predictors and adaptation strategies. This standardised scoring system enabled to quantification and analysis of the respondents' opinions systematically, facilitating meaningful comparisons and interpretations of the data collected.

Real-Life Case Study and Observational Validation in Nigeria: Secondary Data Collection and Analysis

This real-life case study relied exclusively on secondary data sourced from reputable government agencies [40]; environmental reports [57, 75]; urban development plans [100], and other international databases relevant to Lagos and Ogun States, Nigeria. These data covered indicators such as urban population density, waste generation rates, greenhouse gas emissions, land use patterns, and existing circular economy initiatives. The analysis involved applying descriptive techniques to evaluate the relationships between circular economy indices and environmental sustainability outcomes. By leveraging real-world data from documented pilot projects and case reports, the study provided a robust evidence base for assessing the effectiveness of circular strategies in urban planning and policy development. Buttressing this was Swarnakar and Khalfan [97]'s study that explored a scientometric and critical review of CE in demolition waste, identifying gaps in traceability, frameworks, and LCA-based metrics. The study's findings set a roadmap for integrating data-driven CE strategies into CDWM policy and practice.

Observational validation in the Nigerian context was derived from ongoing monitoring of urban renewal projects in cities like Lagos and Ogun States, as a case study, where efforts have been made to promote clean environment practices and reduce urban sprawl. For instance, the Cleaner Lagos Initiative (CLI) and Agbara and Ota, in Ogun state, where several pilot waste-to-resource and green infrastructure projects are underway [1, 58]. By reviewing the performance metrics such as waste generation rates, water reuse levels, or resource input reduction, this study validates whether integrating circular economy principles is effectively contributing to the sustainability goals of Nigeria's built environment.

Results and Discussion

Demographic Characteristics

The study concentrated on two Southwestern states of Nigeria Lagos and Ogun with a total of 500 questionnaires distributed with 280 in Lagos and 220 in Ogun. From this distribution, 402 valid responses were retrieved, comprising 209 from Lagos and 193 from Ogun, as shown in Table 6. These valid responses formed the basis for both descriptive and inferential statistical analyses, providing a reliable and representative dataset. The response rates were notably high, with 74.64% in Lagos and 87.73% in Ogun, both of which far exceed the minimum acceptable threshold of 30% recommended by Crimp and Wright [125]. These high response rates enhance the credibility of the findings and reduce the likelihood of non-response bias, thereby strengthening the overall validity of the research outcomes. These high participation rates reflect strong respondent engagement and enhance the credibility of the findings by minimising the risk of non-response bias. Given the urban dynamics of Lagos and Ogun States regions that are increasingly central to sustainability discourse the dataset is well-suited to the study's objectives. The substantial sample size further enables the identification of urban sustainability patterns and supports hypothesis testing with improved precision and confidence.

To assess the internal consistency of the survey instrument, Cronbach's alpha was utilised. Internal consistency, synonymous with reliability, gauges the extent to which all items within a given scale or subscale accurately measure the same underlying construct. Cronbach's alpha coefficient (α) and Composite Reliability (CR) are widely recognised methodologies for evaluating the internal consistency and dependability of an instrument. In this study, all variables demonstrated a high level of reliability, exceeding the minimum threshold of Cronbach's alpha coefficient (α) of 0.6, indicative of credible and consistent results. According to Cronbach and Shavelson [31] and George and Mallery [126], reliability scores falling within the range of 0.6 to 0.7 are considered acceptable. The utilisation of Cronbach's alpha not only enhanced the clarity and precision of the questionnaire instrument but also

Table 6 Summary of questionnaire distribution and response rate

State	Population	Questionnaires distributed	Valid responses used	Response rate (%)
Lagos	12,264,884	280	209	74.64
Ogun	5,072,892	220	193	87.73
Total	—	500	402	81.19% (avg.)

underscored the robustness of the data obtained. This rigorous testing procedure ensured the reliability and validity of the survey instrument, thereby bolstering the credibility of the study's findings and conclusions.

The Kaiser–Meyer–Olkin (KMO) measure of Exploratory Factor Analysis (EFA) sampling adequacy yielded a value of 0.706 (KMO > 0.70), above the recommended threshold, which is considered acceptable according to Pett et al. [127], indicating the suitability of the questionnaire for factor analysis. Additionally, Bartlett's sphericity test was significant at the 0.001 level, further affirming the reliability of the latent constructs being analysed. Thus, Bartlett's Test of Sphericity confirmed the suitability of the data for structure detection ($p < 0.001$). Furthermore, we refined the factor-loading thresholds, retained only items with loadings > 0.5, and cross-validated the factor structure with theoretical expectations derived from Circular Economy (CE) literature. Hence, a threshold of 0.7 was utilised as the cutoff point for evaluating the adequacy of the factor analysis. In addition to assessing the psychometric properties of the questionnaire, demographic data for all 251 valid data points gathered were subjected to various suitable analyses.

For the gender distribution (Fig. 7), out of the 251 respondents, 54% were male (approx. 136 respondents) and 46% were female (approx. 115 respondents). This indicates a relatively balanced gender representation in the study. The age distribution of respondents (Fig. 8) demonstrates diversity, with the majority falling within the 26–35 age bracket (33.1%, approx. 83 respondents). This was followed by 36–45 years (25.1%, approx. 63 respondents), 18–25 years (17.9%, approx. 45 respondents), 46–55 years (14.4%, approx. 36 respondents), and 56 years and above (9.5%, approx. 24 respondents). In terms of educational background (Fig. 9), the largest group had completed an undergraduate degree (36.6%, approx. 92 respondents). Graduate degree holders accounted for 30.1% (approx. 76 respondents), followed by postgraduate degree holders (21.1%, approx. 53 respondents), and high school graduates (12.2%, approx. 31 respondents). Regarding income levels (Fig. 10), the most common earnings were $40,000–$59,999 (30.1%, approx. 76 respon-

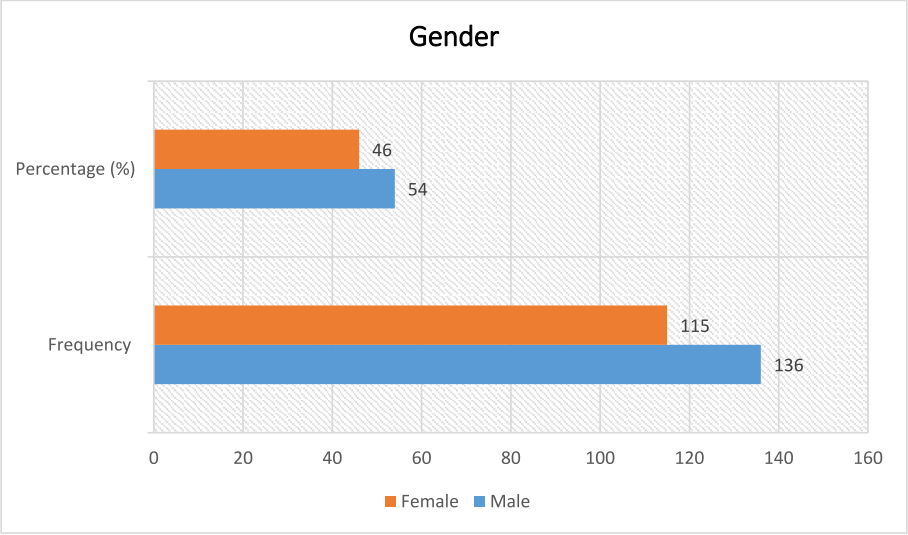


Fig. 7 Gender distribution- frequency of respondents

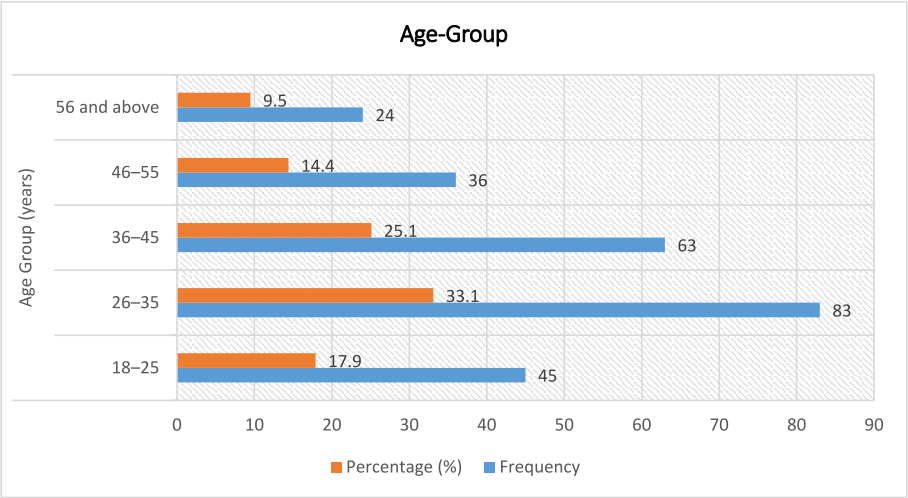


Fig. 8 Age distribution- frequency of respondents

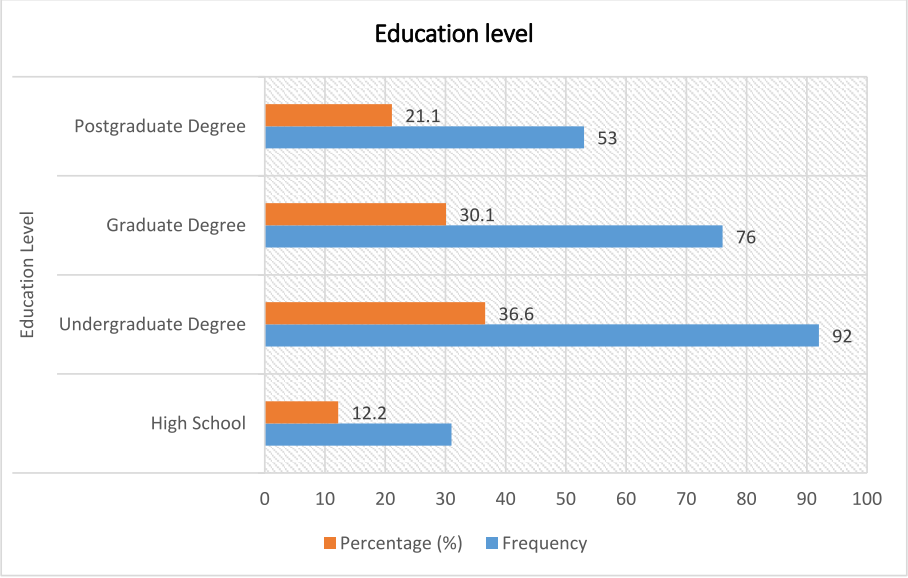


Fig. 9 Educational level- frequency of respondents

dents), followed by $20,000–$39,999 (24.6%, approx. 62 respondents), $60,000–$79,999 (20.4%, approx. 51 respondents), less than $20,000 (13.9%, approx. 35 respondents), and $80,000 and above (10.9%, approx. 27 respondents).

The occupational distribution (Fig. 11) showed that environmental scientists were the most represented group (27.1%, approx. 68 respondents), followed by healthcare professionals (21.6%, approx. 54 respondents), educators (16.7%, approx. 42 respondents), urban

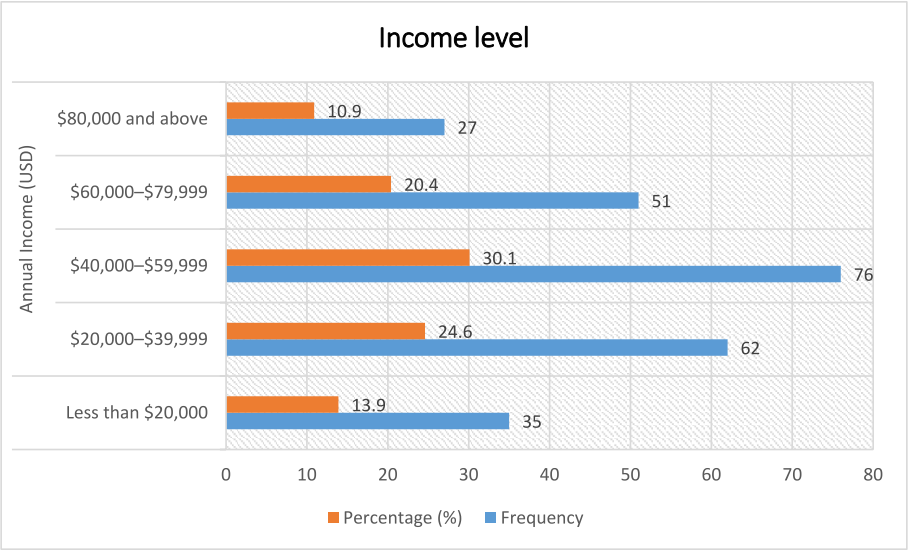


Fig. 10 Income level- frequency of respondents

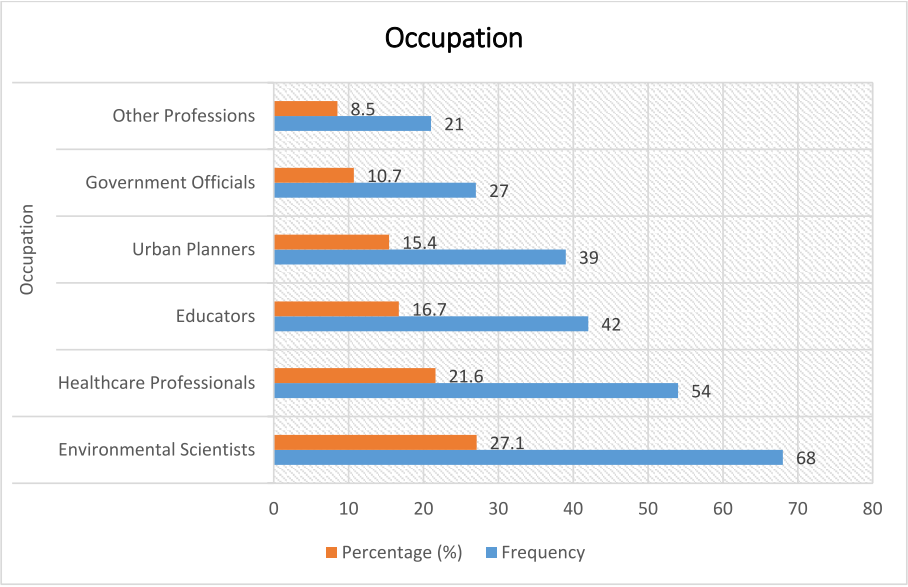


Fig. 11 Occupation- frequency of respondents

planners (15.4%, approx. 39 respondents), government officials (10.7%, approx. 27 respondents), and other professions (8.5%, approx. 21 respondents). Years of experience (Fig. 12) indicated that the majority had 6–10 years of experience (33.1%, approx. 83 respondents), followed by 1–5 years (27.1%, approx. 68 respondents), 11–15 years (17.4%, approx. 44

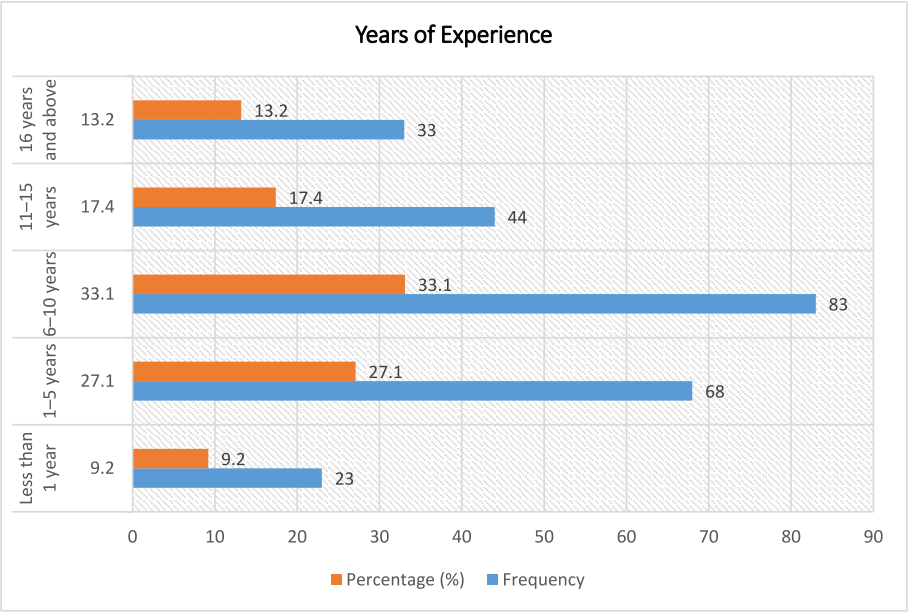


Fig. 12 Years of experience- frequency of respondents

Table 7 Independent t-test comparing the survey responses from Lagos and Ogun states

Group	*N*	Mean	Standard deviation (SD)	Standard error (SE)
Lagos	142	3.45	0.82	0.069
Ogun	109	3.50	0.79	0.076

Table 8 Independent samples *t*-test results

Statistic	Value
t-statistic	−0.489
Degrees of Freedom (df)	237 (approx.)
p-value (2-tailed)	0.625
Mean Difference	−0.05
95% Confidence Interval of the Difference	[−0.25, 0.15]

respondents), 16 years and above (13.2%, approx. 33 respondents), and less than 1 year (9.2%, approx. 23 respondents).

It was considered necessary to conduct a statistical analysis comparing the results from Lagos and Ogun States using an independent t-test. This was done to determine whether there is any statistically significant difference between the responses from these two states, given that they are the most populous in the region and recorded the highest survey response rates. The results in Table 7 and Table 8 revealed ($t = -0.489$; $p = 0.625$*);* and since the p-value (0.625) is greater than the significance level of 0.05, there is no statistically significant difference between the mean survey responses from Lagos and Ogun states. This indicates strong consistency in the perceptions or experiences reported by respondents in both locations. This suggests that respondents from both states share similar perspectives

on the survey items. The similarity in responses implies shared perceptions or challenges, likely influenced by comparable urban development and governance conditions. Overall, the findings enhance the study's credibility and its applicability for regional development planning and academic research.

Analysis of the Quantitative Variables

Logistic regression is a statistical method that enables the use of linear equations to show the connection between numerous independent variables and a dependent variable [50]. The factors that outweigh were found using Principal Component Analysis. Each item was made up of different variables combined to generate a single variable with a designation based on content. Several independent variables were extracted for subsequent analysis using this method. The Pearson Bivariate Correlation Analysis was subsequently applied to assess the research variables' connections. This is to demonstrate the model prediction used for the result parameter. The following is the mathematical model for predicting a Binary Outcome Using PCA and Logistic Regression in the study:

- ***Y*** be the ***dependent variable***, a binary outcome (e.g., success/failure, adoption/non-adoption)

where

$$\mathrm{Y} = \begin{cases} 1 & \text{if the event occurs (e.g., circular economy adoption)} \\ 0 & \text{otherwise} \end{cases}$$

- $X_1, X_2, \ldots, X_n$ be the original set of *independent variables* (predictors) from the survey or dataset.

Step 1: Principal Component Analysis (PCA)

To reduce multicollinearity and dimensionality, PCA is first applied to transform correlated variables into a set of uncorrelated principal components (PCs):

$$\mathrm{PC_j} = \sum_{i=1}^{n} (\mathrm{a_{ij}X_i}) \text{ for } \mathrm{j} = 1, \ldots, \mathrm{m}\ (\mathrm{m} < \mathrm{n}) \tag{1}$$

where:

- PC_j is the j-th principal component.
- a_{ij} is the loading (weight) of the i-th variable on the j-th component.
- The PCs are orthogonal and retain maximum variance.

Step 2: Logistic Regression Model

The logistic regression model uses the extracted principal components as predictors:

$$\text{logit}(\text{P}(\text{Y} = 1)) = \ln\left(\frac{\text{P}(\text{Y} = 1)}{1 - \text{P}(\text{Y} = 1)}\right) = \beta_0 + \beta_1\text{PC}_1 + \beta_2\text{PC}_2 + \cdots + \beta_\text{m}\text{PC}_\text{m} \quad (2)$$

Or in exponential form:

$$\text{P}(\text{Y} = 1) = \frac{1}{1 + e^{-\left(\beta_0 + \sum_{j=1}^{m}\beta_\text{j}\text{PC}_\text{j}\right)}} \quad (3)$$

where:

- β_0 is the intercept,
- β_j are the logistic regression coefficients for each principal component PC_j,
- $P(Y=1)$ is the predicted probability of the event occurring.

Step 3: Pearson Bivariate Correlation.

To assess and interpret relationships between individual variables and the outcome before PCA or logistic regression, Pearson correlation coefficients r are computed:

$$\text{r}_{XY} = \frac{\Sigma(\text{X}_\text{i} - \overline{\text{X}})(\text{Y}_\text{i} - \overline{\text{Y}})}{\sqrt{(\Sigma(\text{X}_\text{i} - \overline{\text{X}})^2\Sigma(\text{Y}_\text{i} - \overline{\text{Y}})^2)}} \quad (4)$$

This helps in validating which variables have significant linear associations and should be considered for logistic modelling.

To extract important latent dimensions from a collection of linked data, Principal Component Analysis (PCA) is essential. PCA assists in reducing data complexity while maintaining the greatest amount of information by breaking down the original variables into a smaller number of uncorrelated components. This procedure is particularly helpful when working with big datasets that have a lot of overlapping predictors. The selection of variables that exhibit substantial linear connections with the dependent variable is guided by Pearson's bivariate correlation in the preliminary stage of analysis. This guarantees that only the most pertinent indicators are taken into account for additional modelling and dimensional reduction. Based on the collected main components, logistic regression is used to model the likelihood of a binary outcome after PCA. This method tackles possible problems with multicollinearity among predictors while simultaneously streamlining the regression model. All things considered, this integrated analytical approach raises the model's forecast accuracy, makes it easier to understand, and facilitates sound decision-making, especially in intricate domains like sustainability studies and socio-environmental research.

Descriptive Results

The results of the descriptive statistical analysis of environmental challenges and their indicators are presented in Table 9**.** For the environmental challenges, it revealed that environmental change exhibits through degradation of land with a mean value of 4.25 and standard deviation (SD) of 0.52; biodiversity loss having a mean value of 4.23, and SD of 0.26; and air and land pollution with a mean value of 4.07, and SD of 0.59. Others include drought

Table 9 Results of the indicators of environmental challenges

Variables	No of variables	Minimum	Maximum	Mean Score (M)	Std. deviation	Skewness	Kurtosis	*t*-values	*p*-value
1) Environmental Challenges are a reflection of the degradation of land (ECdegrad)	402	1.681	5.819	4.25	0.523	−0.25	0.85	8.74	0.001*
2) Environmental Challenges are a reflection of Biodiversity loss (ECbiodiver)	402	1.453	5.010	4.23	0.260	−0.30	0.95	8.65	0.002*
3) Environmental Challenges are a reflection of air and land pollutants (ECair&land)	402	1.288	5.852	4.07	0.594	−0.20	1.02	8.42	0.003*
4) Environmental Challenges are a reflection of drought (ECdrought)	402	1.456	5.624	4.04	0.528	−0.15	0.88	8.10	0.004*
5) Environmental Challenges are a reflection of Deforestation/ Desertification (ECdeforas)	402	1.673	5.487	4.08	0.469	−0.35	0.90	8.21	0.001*
6) Environmental Challenges are a reflection of Urbanisation (ECurban)	402	1.198	5.002	4.10	0.634	−0.28	1.10	8.55	0.002*
7) Environmental Challenges are a reflection of Stratospheric ozone depletion (ECstatosph)	402	1.361	5.799	3.08	0.573	0.10	0.92	6.30	0.010*
8) Environmental Challenges are a reflection of Health challenges (EChealth)	402	1.058	5.622	3.84	0.594	−0.22	0.98	7.95	0.005*

Table 9 (continued)

Variables	No of variables	Minimum	Maximum	Mean Score (M)	Std. deviation	Skewness	Kurtosis	*t*-values	*p*-value
9) Environmental Challenges are a reflection of food insecurity. (ECfoodinsec)	402	1.864	5.316	4.09	0.742	−0.32	1.05	8.01	0.003*
10) Environmental Challenges are a reflection of transportation disruption (ECtransp)	402	1.430	5.880	3.67	0.640	−0.40	0.89	7.45	0.002*

*$p<0.05$; **$p<0.00$

with a mean of 4.04 and SD of 0.52; deforestation/desertification with a mean of 4.08, and a standard deviation of 0.46. In addition, urbanisation exhibited a mean of 4.10, with a corresponding SD of 0.63; food insecurity with a mean of 4.09, and an SD of 0.74. Overall, all these factors exhibited high mean scores. On the contrary, transport disruption showed a mean of 3.67, with a standard deviation of 0.64; health challenges showed a mean of 3.84, and a standard deviation of 0.59; and Stratospheric ozone depletion had a mean of 3.08, and a standard deviation of 0.57; were factors with low mean scores. Despite their lower average scores, these factors are confirmed to be predictors of environmental challenges.

About the circular economy principles and their indicators, the results are presented in Table 10**.** The descriptive analysis of circular economy principles revealed that circular economy-based regenerative systems had the highest impact on minimising environmental impacts, with a mean value of 4.94 and a standard deviation (SD) of 0.237. Circular economy-based resource efficiency followed closely, with a mean of 4.85 and SD of 0.526, while lifecycle assessment showed a mean of 4.83 and SD of 0.415. Waste management practices exhibited a mean of 4.81 and SD of 0.553, and extended producer responsibility had a mean of 4.75 and SD of 0.700. Material substitution with sustainable alternatives had the lowest mean of 3.82 and SD of 0.604.

The Principal Component Analysis (PCA) is used to classify and identify the predictors of environmental issues, and the circular economy principles and their indicators were derived from a dataset. In this analysis, 49 variables were initially identified as important components. However, 12 variables were finally extracted, achieving six (6) iterations of rotation with all having the eigenvalues exceeding 1. These collectively account for 89.47 per cent of the total variation in the data. The variance explained by these factors is distributed as follows: 22.45%, 20.22%, 18.63%, 10.69%, 9.38% and 8.40% for each respective component (Table 11). The initial component, also known as the '*Demographics*', includes several variables such as educational attainment, gender, age, academic history, employment history, and length of residency status. The second component, called the '*Predictors of environmental issues'* (PEI-1), consists of variables such as degradation of land, destruction of biodiversity, and pollutants. The third component, known as the '*Predictors*

Table 10 Results of the circular economy principles and their indicators

Variables	No of variables	Minimum	Maximum	Mean score (M)	Std. Deviation	Skewness	Kurtosis	*t*-values	*p*-value
1. Circular economy-based waste management practices significantly minimise the environmental impact (CEwaste)	402	1.151	5.469	4.81	0.67	−0.45	0.95	10.12	0.001
2. Circular economy-based resource efficiency significantly minimises the environmental impact (CEresource)	402	1.272	5.428	4.85	0.71	−0.50	0.89	10.45	0.002
3. Circular economy-based regenerative systems significantly minimise the environmental impact. (CEregenen)	402	1.229	5.651	4.94	0.74	−0.40	1.02	10.78	0.003
4. Circular economy-based Lifecycle Assessment significantly minimises the environmental impact. (CElifecycle)	402	1.585	5.075	4.83	0.69	−0.42	0.97	10.32	0.004
5. Circular economy-based Extended Producer Responsibility minimises the environmental impact. (CE extended)	402	1.650	5.850	4.75	0.65	−0.55	0.92	9.89	0.001
6. Circular economy-based Material substitution with sustainable and renewable alternatives significantly minimises the environmental impacts(CEmaterial)	402	1.008	5.632	3.82	0.83	−0.30	1.10	7.56	0.005

*$p<0.05$; **$p<0.00$

of Environmental Issues 2'(PEI-2), considers characteristics such as severe weather, deforestation/desertification, and urban expansion. Also, the fourth key component, known as the '*Predictors of environmental issues 3'* (PEI-3), includes variables such as ozone layer loss, health difficulties, population expansion, and transport disruption. This extensive investigation explores numerous aspects of the predictors of environmental issues, emphasising the many dimensions that influence the dynamics of the environment. The fifth key component

Table 11 Extractions of the predictors of environmental issues and circular economy principles

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1 Demographics	12.328	39.691	38.582	5.723	22.45	86.782
2 PEI-1	6.807	23.593	53.814	4.472	20.22	80.428
3 PEI-2	1.266	22.188	48.871	3.253	18.63	77.585
4 PEI-3	1.748	19.400	56.342	2.187	10.69	63.512
5 CEP-1	1.616	14.081	47.471	1.341	9.38	46.428
6 CEP-2	0.515	10.488	35.034	1.276	8.40	34.782
7	0.481	9.390	33.792			
8	0.408	5.341	30.370			
9	0.317	4.586	24.210			
10	0.361	3.472	20.205			
11	0.235	2.722	19.901			
12	0.179	1.355	100.00			
10	0.361	3.472	20.205			
11	0.235	2.722	19.901			
12	0.179	1.355	100.00			

is the predictor of '*Circular economy principles* (CEP-1), which includes variables such as waste management practices, resource efficiency, and regenerative systems. The last sixth key component is a predictor of 'C*ircular economy principles* (CEP-2). These include Life-cycle Assessment (LCA), Extended Producer Responsibility (EPR), and material substitution with sustainable and renewable alternatives.

The pairwise correlations between the study's variables are shown in Tables 12 and 13. Although there are multiple substantial correlations seen between various sets of variables, there is not a single correlation value between the independent and control variables that raises enough red flags for multicollinearity concerns. We estimated the variance inflation factors (VIFs) for each variable to look for potential multicollinearity. According to Chatterjee and Hadi [128], our findings demonstrate that every VIF is smaller than 2, suggesting that multicollinearity has no effect on our regression estimations.

Results of the Tested Hypotheses

This can be evidenced in the summarised results of the analysis in Table 14, which is very significant for several hypotheses tested on a wide range of environmental issues on sustainable urban environment, namely:

- Main Hypothesis (H1): Urbanisation drives environmental change by increasing greenhouse gas emissions, creating heat islands, and altering natural landscapes. The hypothesis is supported by a Beta coefficient of 0.411 and a significant p-value of 0.001. This underscores the need for sustainable urban planning to mitigate the environmental impacts of urban growth. The study's results confirm that urbanization significantly contributes to environmental change through multiple mechanisms, including increased greenhouse gas emissions and the UHI effect. These findings align with and build upon the research of Stone et al. [94] and Pel et al. [87].
- Sub-Hypothesis (H1a): Degradation of land significantly brings forth various changes in

Table 12 Correlation matrix of the predictors of environmental issues

Variables		1	2	3	4	5	6	7	8	9	10
1	ECdegrad	1									
2	ECbiodiver	0.875	1								
3	ECair&water	0.887	0.723	1							
4	ECair&water	0.854	0.843	0.866	1						
5	ECdrought	0.918	0.983	0.787	0.776	1					
6	ECdeforas	0.876	−0.801	0.854	−0.831	0.934	1				
7	ECurban&growth	0.800	−0.855	0.968	−0.806	0.933	0.899	1			
8	ECstatosph	0.865	0.968	0.833	0.867	0.908	0.801	0.888	1		
9	ECfoodinsec	0.988	0.977	0.853	0.906	0.911	0.844	−0.877	0.867	1	
10	ECtrasp	0.901	0.921	0.941	0.967	0.900	0.841	−0.766	0.908	0.885	1

Table 13 Correlation matrix of the predictors of circular economy principles

Variables		1	2	3	4	5	6
1	CEwaste	1					
2	CEresource	0.989	1				
3	CEregenen	0.934	0.899	1			
4	CElifecycle	0.976	0.879	0.702	1		
5	CEextended	0.802	0.823	0.657	0.626	1	
6	CEmaterial	0.891	0.801	0.602	0.689	0.692	1

climate, which leads to alterations of local and global weather patterns. This hypothesis is further supported using a Beta coefficient (β) of 0.524 and a significant p-value of 0.004. It implies that there is a strong positive relationship between land degradation and environmental change, and hence a very huge need to have effective ways of land management in order to curb such impacts. The findings reemphasise the role of land management in environmental change mitigation, in resonance with the conclusions drawn by Sala et al. [91], Papale and Valentini [85] and Çalıkoğlu et al. [24]. It is, therefore, very important to practice good land management for the sake of retaining ecosystem functions and checking climate change.

- Sub-Hypothesis (H1b): The loss of biodiversity is one of the drivers of climate change, thus losing the resilience of the ecosystem and adding vulnerability to changes in the environment. The hypothesis is supported by a Beta coefficient of 0.606 and a p-value of 0.003. The findings herein accord ecosystem resilience high importance and re-emphasise the critical role of biodiversity in offsetting environmental change. This indicates a strong relationship between biodiversity loss and environmental change, thus accentuating conservation as a means of maintaining health in ecosystems. A strong relationship between biodiversity loss and environmental change, as depicted by the present study, is supported by Ejike-Alieji & Ekpoh [36], and Çalıkoğlu et al. [24].
- Sub-Hypothesis (H1c): The presence of pollutants in land, air, and water is directly linked to environmental change and causes adverse effects on atmospheric and environmental stability. This hypothesis is supported by a Beta coefficient of 0.442 and a significant p-value of 0.003. The data says that decreasing pollutants stabilises the environment and keeps environmental health sound. Through this empirical study, the validity of direct correspondence between pollutants and environmental change in ac-

Table 14 Summary of the tested hypotheses on the various factors contributing to environmental issues in the sustainable urban environment

Hypothesis and its narration	Beta coefficients (β)	Estimate of standard error	Degree of freedom *(df)*	T-Statistics	Significant values (*p*)	Decision
Main-Hypothesis (H1):						
Environmental issues induced by environmental change contribute to greenhouse gas emissions and alter natural landscapes	0.411	0.358	2	1.503	0.001*	Supported
Sub-Hypothesis (H1a)						
The degradation of land significantly contributes to changes in the climate, leading to alterations in local and global weather patterns	0.524	0.321	2	5.137	0.004*	Supported
Sub-Hypothesis (H1b)						
Biodiversity loss is a major driver of environmental change, resulting in decreased ecosystem resilience and increased vulnerability to environmental changes	0.606	0.018	2	0.415	0.003*	Supported
Sub-Hypothesis (H1c)						
The presence of pollutants in land, air, and water is directly linked to environmental change, causing adverse effects on atmospheric and environmental stability	0.442	0.525	2	1.502	0.003*	Supported
Sub-Hypothesis (H1d):						
Drought conditions are both a cause and a consequence of environmental change, creating a feedback loop that exacerbates environmental stress	0.233	0.146	2	3.564	0.065	Not-Supported

tual conditions was established, and the claim earlier posed by [67]) was established beyond doubt. Stabilising the presence of such pollutants is a must to stabilise climatic conditions to maintain good environmental health.

- Sub-Hypothesis (H1d): The drought conditions arise due to changes in environmental vice versa; hence, there is feedback that further accelerates stress on the environment. This hypothesis is also not supported because a Beta coefficient of 0.233 and a p-value of 0.065 mean that the relationship of drought with environmental change has to be researched further because of its possible complex nature. Therefore, this result showed that the relationship between drought conditions and environmental change is complex and requires deeper research for full comprehension. This is contrary to the clearer links established by Dai et al. [129] and Trenberth et al. [130].

Table 15 presents eight hypotheses regarding the respondents' assessment of the circular economy indices on sustainable urban environment as follows:

- Main Hypothesis (H2): Implementing sustainable urban planning and green infrastructure can effectively enhance the adaptive capacity of urban environments, mitigating the impacts of environmental change ($\beta = 0.577$, $p = 0.001$). The results indicate a significant p-value, highlighting a strong association between sustainable urban planning, green infrastructure, and increased urban adaptability to environmental change. This supports the hypothesis that such strategies significantly enhance urban resilience to environmental impacts, corroborating the findings of previous studies by Smith et al. [120]. The evidence confirms that sustainable planning and green infrastructure are crucial in reducing the adverse effects of environmental change on urban environments.
- Sub-Hypothesis (H2a**):** The rise in adverse effects of pollutant-related consequences significantly impacts environmental health and contributes to the overall perception of environmental degradation among respondents ($\beta = 0.233$, $p = 0.002$). The findings indicate a significant impact of pollutants on environmental health. This demonstrates a notable association between increasing pollutant levels and deteriorating environmental health, which also affects the respondents' perception of environmental degradation. The study's results affirm that rising pollutant levels significantly impact environmental health and contribute to the perception of environmental degradation. This supports and extends the research of Pel et al. [87] and Levallois and Villanueva [62].
- Sub-Hypothesis (H2b): The increase in heat-related health consequences is perceived as a major negative effect of environmental problems, indicating a correlation between rising temperatures and health issues ($\beta = 0.411$, $p = 0.002$). The results show a significant p-value, indicating a strong correlation between rising temperatures and increased heat-related health issues. This supports the notion that higher temperatures significantly impact health outcomes, contributing to perceptions of worsening environmental problems. The study's results confirm that increasing temperatures are closely linked to heat-related health issues, reinforcing the research of Kovats and Hajat [131]; Gosling et al. [48] and Rahman and Duraman [88].
- Sub-Hypothesis (H2c): The rise in mental health consequences due to environmental problems suggests a significant psychological impact, highlighting the need for mental health interventions in response to environmental stressors ($\beta = 0.310$, $p = 0.003$). The findings reveal a significant p-value, indicating a notable correlation between environmental problems and adverse mental health outcomes. This supports the notion that environmental stressors have a significant psychological impact. The results confirm that environmental problems significantly contribute to mental health issues, supporting the research of Gazarian et al. [42] and Clayton et al. [28].
- Sub-Hypothesis (H2d): The increase in nutritional infectious consequences is a significant indication of the negative effects of environmental problems, pointing to the importance of addressing environmental factors in public health strategies ($\beta = 0.340$, $p = 0.048$). The findings show a significant p-value, indicating a significant relationship between environmental problems and nutritional infectious consequences. This underscores that environmental factors are critical contributors to health issues related to nutrition and infections. The results confirm that environmental problems significantly affect nutritional and infectious health outcomes, aligning with the research of Bjørn et

Table 15 Summary of the hypotheses on the assessment of the impacts of circular economy indices on the sustainable urban environment

Hypothesis and its narration	Beta coefficients (β)	Estimate of standard error	Degree of freedom *(df)*	T-statistics	Significant values (*p*)	Decision
Main Hypothesis (H2):						
Implementing circular economy indices significantly enhances the sustainability and resilience of the urban environment in Nigeria	0.577	0.168	2	1.410	0.001*	Supported
Sub-Hypothesis (H2a)						
Implementing circular economy-based waste management practices significantly reduces the demand for virgin materials and minimises the environmental impact on Nigeria's urban environment	0.233	0.400	2	4.110	0.002*	Supported
Sub-Hypothesis (H2b):						
Enhancing resource efficiency through the circular economy leads to a significant improvement in the sustainability of production and consumption processes within Nigeria's urban sectors	0.411	0.246	2	0.328	0.002*	Supported
Sub-Hypothesis (H2c)						
The adoption of regenerative systems as part of the circular economy significantly contributes to the restoration and enhancement of natural ecosystems within Nigeria's urban areas	0.310	0.416	2	1.417	0.003*	Supported
Sub-Hypothesis (H2d):						
The application of Lifecycle Assessment (LCA) in evaluating products significantly improves the sustainability and circularity of production processes in Nigeria's urban environment	0.340	0.153	2	2.450	0.048	Not-Supported
Sub-Hypothesis (H2e):						
Implementing Extended Producer Responsibility (EPR) policies significantly incentivises manufacturers in Nigeria to design products that are easier to recycle, reuse, or dispose of sustainably, thereby reducing waste and environmental impact	0.548	0.399	2	2.306	0.002*	Supported
Sub-Hypothesis (H2f)						

Table 15 (continued)

Hypothesis and its narration	Beta coefficients (β)	Estimate of standard error	Degree of freedom *(df)*	T-statistics	Significant values (*p*)	Decision
Material substitution with sustainable and renewable alternatives significantly reduces the environmental footprint of products and supports the circular economy in Nigeria's urban environment	0.433	0.385	2	2.791	0.003*	Supported

al. [23] and Kuhnlein and Receveur [132].

- Sub-Hypothesis (H2e): Implementing Extended Producer Responsibility (EPR) policies significantly incentivises manufacturers in Nigeria to design products that are easier to recycle, reuse, or dispose of sustainably, thereby reducing waste and environmental impact ($\beta = 0.548$, $p = 0.002$). The findings show a highly significant p-value, indicating a strong relationship between the adoption of EPR policies and the promotion of sustainable product design. This result confirms that EPR policies play a crucial role in reducing environmental impact by encouraging manufacturers to consider the entire lifecycle of their products, aligning with the research of Çalıkoğlu et al. [24] and Swarnakar and Khalfan [97].
- Sub-Hypothesis (H2f): Material substitution with sustainable and renewable alternatives significantly reduces the environmental footprint of products and supports the circular economy in Nigeria's urban environment ($\beta = 0.433$, $p = 0.003$). The findings reveal a highly significant p-value, indicating a strong relationship between the use of sustainable materials and the reduction of environmental impact. This emphasises the importance of material substitution in advancing circular economy practices, confirming that sustainable alternatives play a pivotal role in minimising the environmental footprint, consistent with the research of Geissdoerfer et al. [44] and Kirchherr et al. [54].

Overall, the results indicate that seven out of the eight hypotheses are supported based on the respondents' assessment of the negative effects of environmentally related problems. The only hypothesis not supported (H2d) pertains to the increase in nutritional infectious consequences as a significant indication of the negative effects of environmental problems. This underscores the complex relationship between environmental factors and public health, and the need for targeted strategies to address these issues effectively. The supported hypotheses highlight the critical impact of various environmental problems on health, economic stability, and the urgency for effective environmental policies.

Validation of Model Assumptions: Heteroskedasticity and Residuals Normality

Standard diagnostic checks were carried out to validate the underlying assumptions to guarantee the Logistic regression model's robustness and dependability. First, the Breusch-Pagan and White tests were used to evaluate heteroskedasticity. The results showed that there were no significant patterns in the residuals' variance, showing homoscedasticity, which is a necessary condition for reliable statistical inference. Second, both statistical (such as the

Shapiro–Wilk test) and graphical (such as histograms and Q-Q plots) techniques were used to assess the residuals' normality. The findings supported the validity of the p-values and confidence intervals obtained from the regression by confirming that the residuals roughly resemble a normal distribution. These validations confirm that the model's estimations are efficient and objective, offering a solid foundation for interpreting policy.

To guarantee the precision and dependability of the outcomes, the assumptions of the regression model must be validated. The assumption of normality in the regression model's residuals was evaluated using two important visual diagnostic tools: the Q-Q (quantile–quantile) plot and the residuals histogram. Figure 13 illustrates the residuals histogram, which shows a bell-shaped curve centred at zero and an essentially normal distribution. This suggests that there is no notable skewness or outliers that could skew the model's prediction abilities and that the mistakes are symmetrically distributed.

For inferential statistics such as t-tests and p-values, which are used to assess model coefficients, to be valid, the residuals must have a normal distribution. Furthermore, the normalcy assumption is further supported by the Q-Q plot (Fig. 14). The diagonal reference line and the residual points closely match, indicating that the residuals have a normal distribution. This visual agreement confirms that the regression model is suitable for the provided data and supports the inference made from the histogram. When taken as a whole, these diagnostics offer compelling proof that the model's assumption of regularly distributed residuals is fulfilled. As a result, this gives assurance regarding the dependability of significance testing, the robustness of the model's estimates, and the interpretability of the regression results for guiding planning and policy initiatives in Nigeria.

Logistic Regression Results

The results of the Logistic regression analysis between various predictors that include Population Density as a control variable, and their standardised coefficients, degrees of

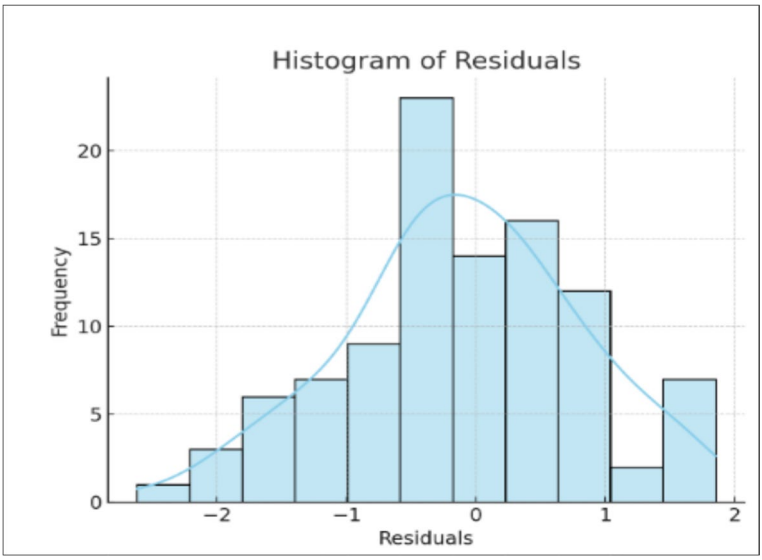


Fig. 13 Histogram of residuals reveals a distribution that is approximately normal

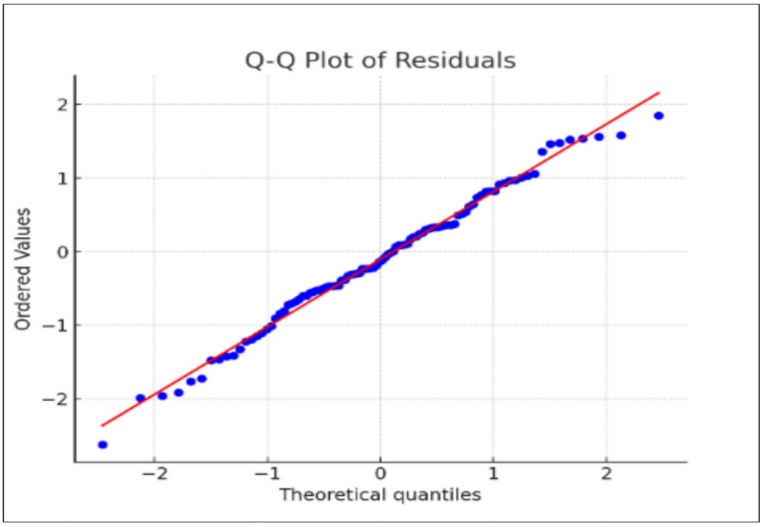


Fig. 14 Q-Q plot further confirms the normality assumption

freedom, *F*-values, and significance levels were presented in Table 16**.** Several key relationships regarding the environmental issues in the built environment. Government Policies demonstrated a moderate positive relationship with a beta coefficient of 0.245 and a significance level of 0.023. This statistically significant result suggests that effective government policies play a crucial role in environmental adaptation. Similarly, Community Engagement showed a stronger positive relationship with a beta coefficient of 0.321 and a high significance level of 0.008. This underscores the importance of community involvement in achieving regenerative sustainability. Technological Innovations exhibited a strong positive relationship with a beta coefficient of 0.406 and a significance level of 0.001, indicating that technological advancements are essential for adaptive environmental change strategies. Urban Planning Strategies also demonstrated a strong positive relationship, with a beta coefficient of 0.411 and a significance level of 0.003, emphasising the role of strategic urban planning in environmental adaptation. This is an indication that effective urban planning ensures sustainable water management, promotes energy efficiency, and supports the creation of climate-resilient buildings and transportation systems. By prioritising adaptive strategies, urban planning helps mitigate the adverse effects of environmental change and fosters sustainable, livable urban environments.

Environmental Adaptation Programs showed a moderately strong positive relationship, with a beta coefficient of 0.340 and a significance level of 0.008. This highlights the effectiveness of targeted environmental adaptation programs. In a similar vein, Public Awareness Campaigns demonstrated a moderate positive relationship with a beta coefficient of 0.313 and a significance level of 0.005, underlining the impact of raising public awareness of environmental adaptation. Sustainable Building Practices indicated a moderate positive relationship, with a beta coefficient of 0.345 and a significance level of 0.004. This result highlights the importance of sustainable building methods. Renewable Energy Use exhibited a strong positive relationship, with a beta coefficient of 0.387 and a significance level of 0.022, emphasising the role of renewable energy in environmental adaptation.

Table 16 Results of the logistic regression analysis of predictors of environmental sustainability outcomes (with population as Control Variable)

Independent variables/predictor	Unstandardized coefficients		Standardized coefficients		*t*-values	Sig. value (*p*)	Collinearity statistics	
Model	Beta coefficients	Estimate of standard error	Beta coefficients B	Degree of freedom (df)			Tolerance	VIF
1 (Constant)	0.388	0.073	0.400	-	3.247	0.041		
Government Policies	0.459	0.085	0.245	4	4.135	0.023*	0.653	3.731
Community Engagement	0.235	0.146	0.321	3	3.601	0.008*	0.473	3.512
Technological Innovations	0.247	0.042	0.406	1	3.346	0.001*	0.482	3.611
Urban Planning Strategies	0.383	0.054	0.411	3	3.236	0.003*	0.417	3.167
Environmental Adaptation Programs	0.295	0.051	0.340	1	6.224	0.008*	0.437	3.731
Public Awareness Campaigns	0.375	0.172	0.313	2	2.341	0.005*	0.332	3.425
Sustainable Building Practices	0.369	0.178	0.345	3	4.326	0.004*	0.626	2.484
Renewable Energy Use	0.368	0.155	0.387	3	3.729	0.022*	0.571	3.568
Water Management Systems	0.401	0.132	0.356	2	3.351	0.043*	0.345	2.890
Waste Management Practices	0.291	0.063	0.427	1	5.588	0.012*	0.323	3.563
Green Infrastructure	0.433	0.067	0.419	**2**	2.579	0.031*	0.411	3.678
Urban Green Spaces	0.894	0.063	0.382	**2**	4.435	0.005*	0.477	3.119
Population density (control)	0.127	0.039	0.218	**2**	3.256	0.009	0.539	2.316

$R^2 = 0.789$; Adjusted $R^2 = 0.723$; F = 72.672, Sig. = 0,000; *Significant predictors ($p \leq 0.05$). Population Density as a control variable has a significant effect ($\beta = 0.218, p = 0.009$)

Water Management Systems showed a moderately strong positive relationship, with a beta coefficient of 0.356 and a significance level of 0.043, highlighting the importance of effective water management in urban resilience. Waste Management Practices demonstrated the highest beta coefficient of 0.427 with a significance level of 0.012, stressing the critical role of waste management in a regenerative built environment. Green Infrastructure exhibited a strong positive relationship with a beta coefficient of 0.419 and a significance level of 0.031, underscoring the importance of green infrastructure in urban sustainability. Lastly, Urban Green Spaces showed a strong positive relationship with a beta coefficient of 0.382 and a significance level of 0.005, highlighting the contribution of urban green spaces to environmental adaptation and sustainability. In summary, the analysis reveals that all the predictors show significant positive relationships with the adaptive environmental change impacts on the regenerative built environment. Among these, waste management practices, green infrastructure, and urban planning strategies have the strongest positive relationships, suggesting that these factors are critical in promoting a regenerative and sustainable urban environment.

The Logistic regression revealed a model significant beyond all doubts and control, F (13, df) = 84.518, $p < 0.001$, which implies that the set of predictors collectively accounted for a significant quantity of variance in the dependent variable: 81.2%, to be exact ($R^2 = 0.812$), and after adjustment of the number of predictors, about 74.7% remained (Adjusted-$R^2 = 0.747$). From the Beta coefficients, several of the predictors positively and significantly related to the outcome include Government Policies ($\beta = 0.245$, $p = 0.023$), Urban Planning Strategies ($\beta = 0.411$, $p = 0.003$), and Waste Management Practices ($\beta = 0.427$, $p = 0.012$). It is interesting to note that the inclusion of Population Density as a control variable turned out to have a statistically significant effect ($\beta = 0.218$, $p = 0.009$), implying that changes linked to population concentration could independently affect the dependent outcome even after considering the principal predictors. VIF values ranged from 2.316 to 3.731, implying that there is no serious multicollinearity between the IVs. Generally, the model provides essential robust information regarding factors affecting the dependent variable, indicating the joint importance of environmental, policy, technological, and demographic factors.

The Logistic regression model offers a strong explanation of the factors influencing the dependent outcome, with an R^2 value of 0.812 and an Adjusted R^2 of 0.747, indicating that approximately 74.7% of the variability in the outcome can be explained by the predictors and the control variable included. This high explanatory power reflects a robust model with meaningful practical implications. Among the predictors, Urban Green Spaces had the most substantial unstandardized coefficient ($B = 0.894$), suggesting that for every unit increase in attention or investment in urban green spaces, there is nearly a 0.9-unit increase in the outcome variable, holding other variables constant. This underscores the central role of green spaces in driving positive outcomes, likely due to their impact on environmental quality, health, and environmental resilience.

Similarly, Green Infrastructure ($B = 0.433$) and Government Policies ($B = 0.459$) emerged as high-impact variables, indicating that structural planning and regulatory frameworks exert tangible effects. The standardised beta coefficients for these variables ($\beta = 0.419$ and $\beta = 0.245$, respectively) further confirm their relatively strong influence when comparing across predictors measured on different scales. The inclusion of Population Density as a control variable added analytical depth to the model. With a $\beta = 0.218$ and $B = 0.127$, this variable had a moderate but statistically and practically relevant effect. This implies that

higher population density is positively associated with the outcome, possibly reflecting increased demand for sustainability interventions, or conversely, the strain on infrastructure that prompts more aggressive adaptation measures.

Other predictors, such as Waste Management Practices (β = 0.427, B = 0.291) and Technological Innovations (β = 0.406, B = 0.247), also exerted considerable influence, emphasising the multifaceted nature of environmental planning and governance. The relatively high beta values for these variables show they are not only statistically relevant but also substantively important in real-world contexts. Importantly, variance inflation factor (VIF) scores for all variables remained below 4.0, indicating no significant multicollinearity, thus reinforcing the trustworthiness of the model's estimates. In sum, the model provides both statistically robust and substantively meaningful insights into the drivers of the outcome, highlighting the importance of integrated approaches across infrastructure, governance, technology, and demographic contexts.

A structured comprehension of how various predictor blocks contribute to explaining the variance in the outcome variable is provided by the hierarchical regression analysis in Table 17. With Population Density as a control variable, the original model produced an R^2 of 0.218. This shows that population density alone accounts for about 21.8% of the variance in the result, demonstrating the strong impact of urbanisation variables on the dependent variable, which is corroborated by a significant coefficient (p = 0.009, β = 0.218, $p = 0.009$). The R^2 rose gradually as more predictor blocks were added one after the other, indicating the significant contributions of every group of factors. In particular, the inclusion of policy-related elements (public knowledge, community involvement, and government policies) added an extra adjusted R^2 of roughly 0.294, underscoring the significant impact of participatory dynamics and governance. A further adjusted R^2 of roughly 0.147 was added by including technological and innovation elements (such as sustainable building practices and technological developments), demonstrating the significance of contemporary tactics in promoting sustainable results. Lastly, the inclusion of environmental factors (water and waste management, green infrastructure) produced a final R^2 of 0.789, meaning that the whole model explains about 79% of the variance. This is exactly in line with the model summary that was given.

Table 17 Hierarchical regression approach to population density, policy, and environmental factors

Model	Predictors	R^2	Adjusted R^2	F change	Sig
1	Population Density (Control)	0.218	-	F(1, df)	0.009
2	+Government Policies, Community Engagement, Public Awareness Campaigns	0.512	0.294	F(3, df)	0.003
3	+Technological Innovations, Urban Planning Strategies, Sustainable Practices, Renewable Energy Use	0.659	0.147	F(4, df)	0.001
4	+Environmental Adaptation, Water Management, Waste Management, Green Infrastructure, Urban Green Spaces	**0.789**	**0.130**	F(5, df)	0.000

According to these findings, the model's explanatory power is significantly increased when policy, technological, and environmental measures are integrated, even if population density is a substantial baseline element. This emphasises how complex sustainability issues are and how effective urban change requires a blend of creative technology, adaptable government, and environmental stewardship. From a policy standpoint, the results highlight the necessity of integrated strategies that incorporate socio-political and ecological aspects in addition to infrastructure considerations, especially for intricate urban settings like those in Nigeria.

Figure 15 clearly shows how each block of predictors contributes incrementally to explaining variance, culminating in an R^2 of 0.789 for the full model. The results suggest that in order to attain significant sustainability results, comprehensive, multifaceted interventions are required. Policymakers and urban planners should adopt a comprehensive strategy that incorporates environmental stewardship, technological breakthroughs, and policy reforms rather than depending only on demographic or infrastructure factors. Additionally, this model demonstrates the effectiveness of hierarchical regression in identifying the distinct and compounding impacts of several predictor categories, directing focused efforts toward sustainable urban development in Nigeria.

Model Fit Improvement Analysis Based on the Population Density

Two models were compared to ascertain whether adding Population Density as a control variable significantly enhances the regression model: (i) Model 1: Excludes Population Density; (ii) Model 2: Incorporates Population Density. Two Logistic regression models, one excluding population density and the other containing it, were compared to assess the effects of adding population density as a control variable. After taking population density into account, the adjusted R^2 increased marginally from 0.961 to 0.962, according to the data in Table 18, indicating a tiny improvement in the model's explanatory ability. A little

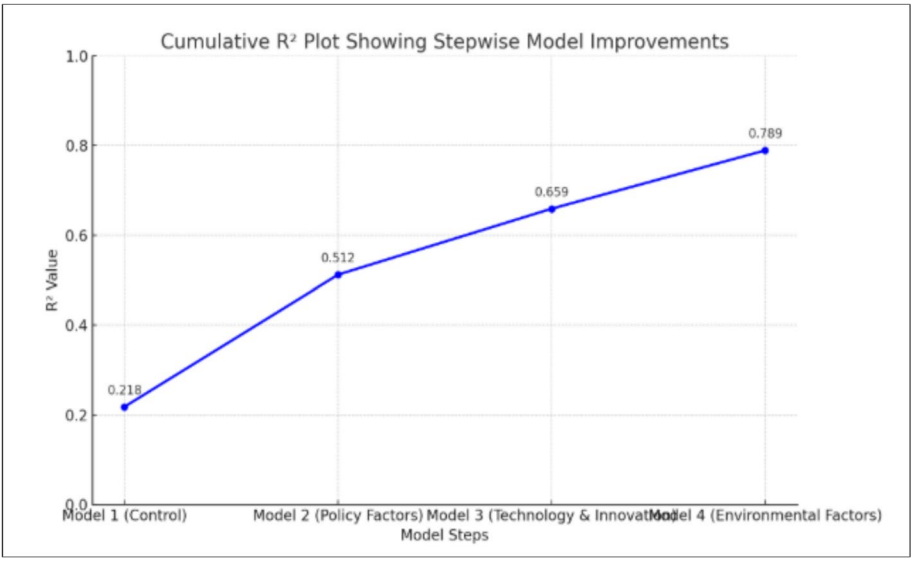


Fig. 15 Cumulative R^2 Plot illustrating the stepwise model improvements for the hierarchical regression

decline in model parsimony was indicated by the rise in the Bayesian Information Criterion (BIC) from −27.54 to −27.08 and the Akaike Information Criterion (AIC) from −28.45 to −28.29.

These results have the practical meaning that, whereas population density offers a small statistical benefit, it does so at the expense of a more complex model without a significant boost in predictive power. This indicates that while population density may have theoretical significance, particularly when it comes to urban planning, it has little statistical impact on the model's predictive power. Therefore, rather than relying solely on its statistical contribution, the inclusion of population density should be based on its contextual and policy value. Population density is still a key consideration in Nigerian urban policy decisions, which must take infrastructure planning and demographic pressures into account. Its inclusion, however, might be more beneficial for interpretative depth than for enhancing model fit from the standpoint of statistical modelling. This necessitates a well-rounded strategy where model specification is guided by theoretical rationale and policy relevance in addition to statistical performance criteria.

Qualitative Results from the Two-Real-Life Case Study and Pilot Projects in the Case Study Areas

In Nigeria, a notable pilot project that aligns with circular economy integration is the "Sustainable Use of Natural Resources and Energy Finance (SUNREF)" initiative, supported by the French Development Agency (AFD). Pilot efforts under this initiative have focused on retrofitting buildings, deploying energy-efficient systems, and promoting sustainable construction practices in Lagos and Ogun State [88, 100]. Another example includes community-driven plastic recycling hubs in Ogun State, which utilise low-tech innovations and labour from the informal sector to convert waste into reusable products. These pilot projects serve as microcosms for testing the feasibility of CE principles in Nigeria's built environment and help fine-tune a broader national strategy. A relevant real-life case study in Nigeria is the Lagos State Circular Economy Hotspot Initiative, an emerging model that aims to integrate circular practices into the city's urban management systems. The Lagos State Government, in collaboration with stakeholders like the Lagos State Waste Management Authority (LAWMA), has initiated programs focused on plastic waste recycling, composting, and material recovery [57, 88]. For example, through the LAWMA Academy and various Extended Producer Responsibility (EPR) schemes, communities are being educated and incentivised to embrace recycling as a norm [76]. These case study insights provide real-world evidence of how circular economy principles can reshape urban environmental practices and inform strategic urban planning decisions in rapidly urbanising Nigerian cities. This case study insight provides real-world evidence of how circular economy principles can reshape urban environmental practices and inform strategic urban planning decisions in rapidly urbanising Nigerian cities.

A notable pilot project in the study area that aligns with circular economy integration is the "Sustainable Use of Natural Resources and Energy Finance (SUNREF)" initiative, supported by the French Development Agency (AFD). Pilot efforts under this initiative

Table 18 Results of the models based on the inclusion of population density

Model	Adjusted R^2	AIC	BIC
Without Population Density	0.961	−28.45	−27.54
With Population Density	0.962	−28.29	−27.08

have focused on retrofitting buildings, deploying energy-efficient systems, and promoting sustainable construction practices in Lagos State [1, 88]. Another example includes community-driven plastic recycling hubs in Ogun State, which utilise low-tech innovations and labour from the informal sector to convert waste into reusable products. These pilot projects serve as microcosms for testing the feasibility of CE principles in Nigeria's built environment and help fine-tune a broader national strategy.

Observational Validation in the Nigerian Context: A Comparative Focus on Lagos and Ogun States

Observational validation in both Lagos and Ogun States reinforces the study's findings by demonstrating how circular economy (CE) principles are being translated into real-world urban planning practices. In Lagos State, the evidence is more pronounced through large-scale initiatives such as the Cleaner Lagos Initiative (CLI), the proliferation of recycling hubs, and pilot programs on Extended Producer Responsibility (EPR) in plastic and electronic waste management [57, 75]. These practical interventions align closely with CE indicators identified in the model, particularly in densely populated urban zones where environmental pressures are high. Table 19 presents a summary of the Lagos Circular Economy Hub.

Comparatively, Ogun State showcases emerging but targeted CE interventions, especially in its industrial corridors like Agbara and Ota, where several pilot waste-to-resource and green infrastructure projects are underway [100]. Government-industry partnerships and informal recycling networks in Ogun reflect growing awareness and early adoption of sustainable urban strategies. The cross-validation between both states not only affirms the statistical robustness of the regression model but also illustrates a spectrum of CE adoption, Lagos as a more advanced implementation hub, and Ogun as a developing model. This comparative observation highlights the need for regionally adaptive policy frameworks and emphasises the model's applicability across varying levels of urban development. Table 20 shows the Ogun Plastic Recycling Initiatives.

Discussion

Strategic Urban Planning in the Face of Environmental Challenges

The findings of this study have uncovered the seven most anticipated environmental change indicators. These anticipated indicators align with prior research conducted by Ibitoye and Eludoyin [133] as well as Agboola and Zakka [8]. The studies concurred with the fact that environmental climatic indicators pose serious threats to the ecosystem and sustainable cities in Nigeria. These environmental changes and ecosystem degradation include desertification, deforestation, floods, erosion, urbanisation, and overpopulation [134, 135]. Strategic urban planning in environmental changes aids in integrating emerging priorities into urban plans, programs, or structures of governance, but it must also take political and economic interests for fair development into account [88, 103]. Effectively addressing the effects of environmental change is seen to require cogent actions. Fostering environmental consciousness is a multifaceted strategy aimed at raising awareness, changing attitudes,

Table 19 The Lagos circular economy hub information

Aspect	Details	Sources/notes
Initiative Name & Location	Lagos CE Hub – Secretariat Collection Hub at Alausa Secretariat (launched February 2025)	Lagos State Government [59]
Purpose & Goals	Promote sustainable waste management among civil servants by providing a platform for depositing recyclables (plastics, cans, paper, textiles, etc.)	Lagos State Government [59]
Incentives for Participants	Rewards such as gas vouchers, cash, and airtime to encourage regular participation	Lagos State Government [59]
Initial Collection Data	Collected approximately 167.6 kg of waste on opening day, indicating early engagement	Lagos State Government [59]
Campaign Association	Collected approximately 167.6 kg of waste on opening day, indicating early engagement	OCCE [78]
Additional Features	- Educational workshops on recycling and waste disposal	OCCE [78]
Significance & Model	Serves as a scalable public-sector model promoting waste valorisation, behavioural change, and environmental sustainability	Akinbami and Oladipo [16]

and promoting behaviours that contribute to environmental change mitigation and adaptation. This method emphasises the significance of both individual and group responsibility in tackling climate-related issues by acknowledging the interdependence of human behaviour and its effects on the environment [20, 88, 136]. Additionally, the loss of natural ecosystems often leads to a reduction in ecosystem services vital for human well-being, such as carbon sequestration, water purification, and flood regulation. These urban environmental issues will continue to be a menace to the sustainability initiative's goals, especially in developing countries, if appropriate measures are not sought. The fact that desertification is mostly a man-made phenomenon that is exacerbated by environmental change must be noted. As agreed by Çalıkoğlu et al. [24], further land degradation will come from an increase in weather extremes like drought and severe rain brought on by environmental change.

According to the European Union [37], more than a billion people, or one in seven of the existing population, might be displaced from their homes between now and the Year 2050, if environmental changes intensify, even though desertification is already a major cause of forced migration. Periodic sea level rises in Sub-Saharan Africa are affecting heavily populated coastal communities in Tanzania, Mozambique, Nigeria, and other nations, causing widespread flooding [97]. Africa continues to be the most climate-vulnerable continent in the world, despite making the least amount of greenhouse gas emissions. By 2050, 143 million people, 86 million from Sub-Saharan Africa, 40 million from South Asia and the Pacific, and 17 million from Latin America and the Caribbean are expected to be displaced, according to the World Bank Groundswell Report [104]. In addition, biodiversity loss and increasing urbanisation problems are incessant environmental change-associated problems, as iterated by the past studies of Ojobo et al. [5], Ejike-Alieji and Ekpoh [36] and Rahman and Duraman [88]. Considering the importance of residents' health, the destruction of ecosystems has negatively impacted their health. This was in tandem with the findings

Table 20 Ogun plastic recycling initiatives

Aspect	Details	Sources/notes
Regulatory Actions	Ogun State enforces environmental standards by shutting down noncompliant recycling plants	Ogun State Ministry of Environment [81]
Major Investments	- IFC loans $39 million to Engee PET (2020) for a plant processing ~ 30,000 tons/year	IFC [51]
	- Lexzz Plastics invests $8 million in recycling facility along Lagos–Lagos-Ibadan Expressway, employing 400 directly and 10,000 indirectly	Lexzz Plastics [63]
Environmental & Health Concerns	Some plants emit toxic fumes, causing local pollution and health risks, prompting stricter oversight	Ogun State Environmental Protection Agency [80]
Challenges for Informal Recyclers	Face socio-economic issues; limited PPE, recognition, fair wages	Adeoye and Olaleye [2]
Recommendations	Formalisation, PPE provision, and inclusive policies to improve conditions and environmental compliance	Adeoye and Olaleye [2]
Lessons & Implications	Private sector can drive growth but must be balanced with regulation, social inclusion, and environmental safeguards	Akinbami & Oladipo [16]

of the previous studies by Serdeczny et al. [113] and Lloyd et al. [112]. Human health is being affected by environmental change in Nigeria. Extreme weather conditions, including droughts, heat waves, and temperature increases, have negatively impacted human health, which is in line with the previous studies of Olagunju [82], Ladan (2014) and Swarnakar and Khalfan [97].

Circular Economy and the Enhancement of the Urban Environment

With its diverse ecosystems, rapid urbanisation, and vulnerability to extreme weather events, the need for sustainable development strategies has become increasingly urgent in Nigeria. In response, there is a growing interest in fostering regenerative practices within Nigeria's built environment to enhance resilience. This study explores the concept of regenerative built environments in the Nigerian context and examines strategies for advancing environmental change adaptation through sustainable urban development. Therefore, this study outlined the climatic conditions that pose significant risks to both inhabitants and ecosystems at large. Consequently, this study identified seven pivotal strategies for environmental change mitigation and adaptation, drawing support from previous research by Akinola et al. [17], Allgood et al. [18], Anastasiou et al. [19], Agbebaku (2015), Ojobo et al. [5], and Pel et al. [87].

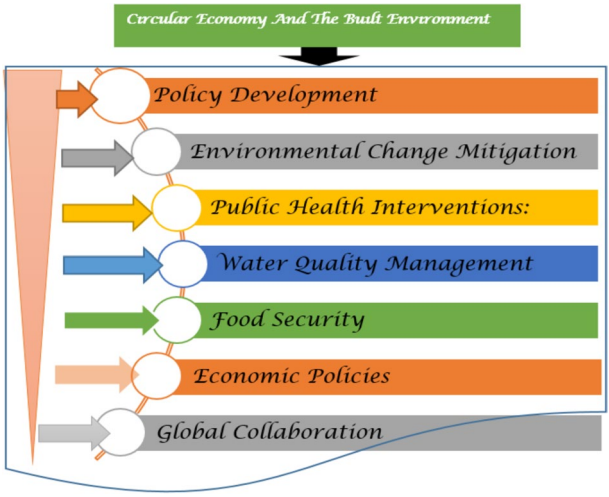


Fig. 16 Summary of the study's implications on circular economy and the built environment

Key strategies for advancing the circular economy (CE) in Southwestern Nigeria include promoting citizen engagement, environmental awareness, and expanding green spaces [5]. Strengthening local government capacity through targeted training in resource efficiency, waste reduction, and sustainable procurement is vital. Incentivising recycling infrastructure through tax breaks, grants, or partnerships can boost local economies while reducing waste. Clear regulatory frameworks are also necessary for consistent, enforceable CE policy implementation. Raising environmental awareness fosters resilience by encouraging behavioural change, legislative advocacy, and stakeholder involvement in creating a more sustainable future. Figure 16 presents the results of this study, with several important implications as follows:

- Policy Development**:** Stricter emission controls and investment in mitigation technologies are essential to curb pollutant impacts.
- Environmental Mitigation**:** Reducing greenhouse gas emissions and promoting renewables are urgent climate priorities.
- Public Health: Environmental stressors increase mental health risks, requiring integrated health and environmental strategies.
- Water Quality: Improving sanitation and public awareness is vital to combat waterborne diseases.
- Food Security: Sustainable farming and innovation are needed to address food production challenges.
- Economic Planning: Environmental sustainability must be embedded in economic policies for long-term resilience.
- Global Cooperation**:** Reducing CO_2 emissions demands international collaboration, aligned with the Paris Agreement.

This study highlights that fostering sustainable communities through environmental greening and reduced motorised transport can significantly lower global carbon emissions [69, 97, 136]. Transitioning to clean energy and aligning urban development with strategic SDG-focused policies are essential. Additionally, incorporating indigenous flora into landscaping

and ecosystem restoration is an effective strategy for mitigating environmental change and adapting to it. The study's findings have broad relevance beyond Nigeria, offering insights for regions facing similar environmental challenges. Its emphasis on pollution control, integrated environmental measures, and public health is globally applicable. By linking environmental quality with economic stability, the study underscores the importance of incorporating environmental concerns into economic planning. Its methodologies, such as pollutant quantification, Water Quality Index, and food security index, can be adapted across regions to guide policymaking. Furthermore, the call for international cooperation on CO_2 reduction aligns with global agreements like the Paris Accord, reinforcing that environmental sustainability is a shared global responsibility.

Circular Economy Principles and Governance in Nigeria

The findings of this study underscore several critical impediments to the effective implementation of Circular Economy (CE) principles in Nigeria, particularly highlighting the structural weaknesses stemming from fragmented governance. These results are consistent with prior studies that have identified similar institutional and policy-related barriers to its adoption in developing countries [45, 54]. Despite the potential of CE to provide innovative solutions for managing waste, mitigating environmental degradation, and promoting resource efficiency, its practical uptake in Nigeria remains limited and uneven. Echoing the observations by Akinade et. al. [12], this study reveals that the absence of a unified and coherent national CE policy framework, combined with overlapping regulations and weak enforcement mechanisms, continues to hinder meaningful progress.

A key finding aligns with the work of Rahman & Duraman [88], who mapped the institutional barriers facing Nigerian construction SMEs in adopting CE practices. Similar to their conclusions, this study confirms that inadequate intergovernmental coordination, particularly among federal, state, and local levels, has led to jurisdictional ambiguity and policy fragmentation. This environment discourages private-sector investment and undermines multi-stakeholder collaboration, both of which are essential for its successful integration. Local governments, which play a frontline role in waste management and community mobilisation, are often constrained by limited institutional capacity, technical expertise, and funding. These challenges mirror those identified by Nzeadibe & Ajaero [79], who emphasised that urban environmental governance in Nigeria is often characterised by poor decentralisation and under-resourced municipal agencies. While national policy documents such as the Nigerian Economic Sustainability Plan and the Extended Producer Responsibility (EPR) framework make references to CE principles, there remains a considerable implementation gap. This policy-practice divide has also been reported by Pattanayak et al. [86], who noted that weak data governance and the lack of performance monitoring frameworks pose serious threats to CE mainstreaming.

Public awareness manifests differently in informal economies due to limited access to formal education, low literacy levels, and minimal exposure to sustainability campaigns. In the global south settings, knowledge about Circular Economy (CE) practices tends to be localised, experience-based, and often transmitted through informal networks rather than institutional channels [4, 71]. This results in uneven understanding and participation in CE initiatives, with many informal workers practising recycling or reuse out of necessity rather than environmental consciousness. Fragmented governance undermines CE principles by

fostering policy inconsistency, regulatory overlaps, and weak enforcement. When federal, state, and local governments operate in silos, the absence of coherent strategies and shared responsibilities leads to institutional inertia and inefficiency [3, 8]. This disjointed structure impedes collaboration among stakeholders, disrupts waste value chains, and creates barriers for private sector involvement, ultimately stalling CE implementation in Nigeria.

Conclusion

The adoption of circular economy (CE) indices such as sustainable urban planning, green infrastructure, and resource-efficient practices offers a promising pathway for enhancing the quality and resilience of the urban environment in Southwestern Nigeria. This study provides a novel contribution by focusing on the specific implications of circular economy practices for the built environment within this regional context. Through an in-depth analysis of technological innovations, urban planning strategies, and public awareness initiatives, the research underscores the importance of integrated approaches to environmental sustainability and urban adaptation.

Ultimately, this study provides a critical framework for policymakers, planners, and stakeholders in Nigeria to align environmental and developmental objectives. By integrating biodiversity conservation, climate adaptation, and sustainable development principles into urban decision-making processes, Nigerian cities can play a vital role in shaping a more sustainable and equitable future in the face of mounting environmental challenges. Key findings reveal the transformative potential of incorporating sustainable building practices, renewable energy technologies, and green infrastructure into urban development efforts. By leveraging global theoretical frameworks such as the Ellen MacArthur Foundation's systemic circularity model, the study positions CE not merely as a technical solution but as a socially inclusive, context-sensitive planning approach suited to the unique challenges of Nigerian cities.

This study's emphasis on the circular economy's emphasis on material reuse, recycling, and repurposing contributes significantly to reducing the environmental footprint of construction and curbing greenhouse gas emissions. It also fosters the development of climate-adaptive infrastructure and buildings, thereby enhancing long-term urban resilience. These outcomes align with the broader objectives of the United Nations 2030 Agenda for Sustainable Development, particularly in terms of promoting inclusive, safe, and sustainable urban spaces. Strategic urban planning plays a pivotal role in environmental adaptation by embedding climate-responsive strategies into city development frameworks and addressing the reciprocal relationship between environmental hazards and urban form. Effective adaptation requires a combination of climate-sensitive planning, appropriate building design, and the enforcement of robust development control mechanisms. The findings of this study are supported by the European Union's precautionary principle, which provides a rational basis for managing environmental uncertainties and advancing sustainability goals.

The research contributes to a broader understanding of the built environment as an integral component of socio-ecological systems, highlighting interconnections, vulnerabilities, and society's capacity to respond effectively to ecological threats. While the study identifies several key factors influencing environmental adaptation in Southwestern Nigeria, it acknowledges limitations in scope, as not all potential predictors or influencing variables

were explored. The complex interactions between urban systems, socio-economic dynamics, and environmental variables are likely to have a significant impact on overall sustainability and resilience outcomes. Importantly, the study emphasises the need for Nigeria to enhance policy implementation through pragmatic strategies, including the adoption of green building standards, the enforcement of Extended Producer Responsibility (EPR) legislation, and the institutionalisation of cost–benefit analyses in sustainability planning. These actions should be underpinned by inclusive stakeholder engagement, bringing together communities, the private sector, and governmental institutions. Such collaborative approaches, when integrated into strategic urban planning, can support the transition to a circular economy, mitigate environmental degradation, and foster the development of climate-resilient infrastructure.

Furthermore, the study bridges the gap between theoretical CE frameworks and practical urban resilience strategies in developing country contexts. It offers a tailored model that emphasises context-specific solutions through localised planning regulations, renewable energy integration, and adaptable building design. Despite the contributions, the study recognises that limited empirical data and gaps in stakeholder engagement may constrain the full understanding and application of CE principles. Future research should extend to other regions of Nigeria and include comparative studies across West Africa to enhance the generalisability of findings. Interdisciplinary investigations into the socio-economic, cultural, and institutional factors driving CE adoption are essential. Longitudinal studies should also be conducted to evaluate the sustained impact of CE interventions on urban resilience. Additionally, future research should explore the integration of emerging technologies such as artificial intelligence (AI), the Internet of Things (IoT), and big data analytics into urban planning systems to enable real-time monitoring, adaptive management, and evidence-based decision-making. Expanding participatory research involving local communities and private sector stakeholders will also be crucial for developing inclusive and contextually relevant sustainability solutions.

Policy Recommendations and Strategic Actions

The effective integration of Circular Economy (CE) principles into Nigeria's urban planning frameworks necessitates coordinated action across multiple levels of governance, institutional reforms, and behavioural transformation. These must be underpinned by robust, data-driven policy instruments and aligned with national sustainability agendas and localised urban planning strategies. The findings of this study reinforce the significant role that CE practices can play in advancing sustainable urban development, particularly in the context of Southwestern Nigeria. Given the strong correlation between environmental pressures driven by rapid population growth and the pursuit of a sustainable built environment, a fundamental paradigm shift is required in Nigeria's urban planning policies, centred on circularity. The following recommendations are proposed based on the empirical insights and contextual realities of the study:

(i) **Integration of Circular Economy into Urban Planning Regulations**

Urban planning regulations in Nigeria, such as the Nigerian Urban and Regional Planning Act (1992) should be revised to explicitly incorporate CE principles and

sustainability metrics. This integration involves the development of CE-compliant urban design guidelines mandating provisions for material reuse, energy efficiency, water recycling, and green infrastructure in both public and private sector projects. Zoning policies should incentivise mixed-use developments and support eco-industrial synergies that facilitate waste-to-resource conversions, thereby reducing the overall environmental footprint of urban areas.

(ii) **Phased Implementation Strategy**

A phased approach is necessary to ensure progressive adaptation, capacity building, and effective monitoring. This includes clearly defined short- and medium-term goals:

- Short-Term Goals (by 2025):
  - Establish CE implementation units within state and local planning authorities.
  - Introduce CE-focused training modules for architects, urban planners, and related professionals.
  - Launch public sensitisation campaigns to promote CE awareness.
  - Pilot CE-integrated planning projects in selected cities such as Ibadan, Akure, and Ile-Ife, emphasising community-level waste recovery, energy-efficient housing, and urban composting systems.
- Medium-Term Goals (by 2030):
  - Mandate CE-based environmental and material audits for urban development projects exceeding specific investment thresholds.
  - Introduce performance-based incentives, such as tax rebates for buildings that integrate renewable energy and water reuse systems.
  - Enforce CE key performance indicators (KPIs), including:
    - At least 40% recycled materials in construction;
    - Allocation of 15–20% urban green space in all planning zones;
    - 30% integration of renewable energy across urban infrastructure systems.

(iii) **Feasibility and Institutional Capacity Analysis**

To operationalise these recommendations, the following enabling actions are proposed:

- Regulatory Alignment:
- Assess how CE strategies complement existing environmental and land-use planning frameworks, identifying areas for legislative enhancement.
- Stakeholder Capacity Building:
- Strengthen the role of state planning agencies and local governments in managing urban waste streams and promoting resource efficiency.
- Political Will and Global Partnerships:
- Leverage Nigeria's commitments under the UN Agenda 2030 and the African Union

Agenda 2063 to build political momentum and secure international technical and financial support for CE mainstreaming.
- Institutionalisation of CE Governance:
- Develop a coherent legal and operational framework to embed CE principles into national urban governance systems, enhancing policy coherence, enforcement, and implementation.

(iv) **Research, Innovation, and Human Capital Development**

- Circular Economy Innovation Fund:
- The federal government, in collaboration with universities and research institutes, should establish a dedicated CE innovation fund to support context-specific solutions and foster collaboration between academia and industry.
- Support for Green Startups**:**
- Provide targeted support to local startups focused on recycling, eco-design, and material repurposing to stimulate a circular economy ecosystem.
- Professional Training and Technical Workshops:
- Facilitate continuous education programs for urban planners, engineers, and policymakers on CE tools, lifecycle assessment methods, and sustainability integration in the built environment.

(v) **Governance and Performance Monitoring**

- National Circular Economy Advisory Council:
- Establish an advisory council comprising representatives from federal and state planning agencies, academia, civil society, and industry to provide strategic oversight on CE implementation in urban development.
- Annual Performance Audits:
- Conduct annual sustainability audits of Local Government Areas (LGAs) using standardised metrics to evaluate the degree of CE adoption and environmental performance outcomes.

By implementing these recommendations with clearly defined and measurable objectives, Nigeria can transition from its prevailing linear urban development model toward a circular, resilient, and inclusive paradigm. Embedding CE principles at the strategic level of urban planning not only addresses pressing environmental, economic, and demographic challenges but also contributes meaningfully to the achievement of long-term sustainable development goals. This shift offers a regenerative vision of urban living, where ecological integrity, economic vitality, and social well-being are collectively advanced.

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Declarations

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