Landscape Design Strategies as a Tool for Mitigating Environmental Degradation in Nigerian Cities: A Case Study of Lagos City

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Abstract: Environmental degradation threatens rapidly urbanising developing cities, with Lagos exemplifying these challenges. While landscape design is theorised as a mitigation strategy, empirical evidence in high-density tropical African contexts remains scarce. This study evaluates landscape design effectiveness in Lagos, examining relationships between green infrastructure characteristics and environmental quality outcomes. Using a descriptive survey design, researchers analysed 150 sample plots across five districts through spatial analysis, environmental measurements (air temperature, PM2.5, noise), and 750 household surveys. Stratified random sampling captured variation across core urban, semi-urban, and urban fringe areas, with data analysed via spatial statistics and regression modelling. Results showed green coverage significantly correlated with lower ambient temperature (r=-0.67), PM2.5 (r=-0.58), and noise (r=-0.44). Integrated soft-hard landscape designs achieved 3.2°C temperature reduction, 34% lower PM2.5, and 12 dB noise reduction versus unvegetated areas. Multivariate regression identified tree canopy coverage, green space connectivity, and soil permeability as significant environmental quality predictors (R^2=0.71). Community perception recognised benefits (78%), though maintenance deficiencies limited outcomes. Landscape design proves effective and scalable for environmental mitigation in Lagos, with integrated approaches yielding superior results. Full potential realisation requires governance reforms addressing maintenance, community participation, and climate-adaptive species selection.

Keywords: *Landscape Design, Environmental Degradation, Green Infrastructure, Urban Heat Island, Air Quality, Lagos, Nigeria, Megacities.*

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I. INTRODUCTION

- *Background and Context*

Urban environmental degradation has emerged as a defining challenge of the twenty-first century, particularly in rapidly urbanising regions of the Global South. The United Nations projects that 68% of the world population will reside in urban areas by 2050, with Africa and Asia contributing nearly 90% of this growth (United Nations, 2018). Nigeria, as Africa's most populous nation, exemplifies this transformation: its urban population has grown from 35% in 1990 to over 53% currently, with projections indicating 300 million urban residents by 2050 (National Population Commission, 2022). This demographic shift, occurring largely without adequate planning or infrastructure investment, has generated severe environmental consequences that threaten human health, economic productivity, and ecological sustainability.

Lagos, Nigeria's commercial capital and largest urban agglomeration, represents perhaps the most extreme case of urban environmental degradation on the continent. With an estimated population exceeding 20 million and annual growth rates of 6-8%, Lagos has emerged as one of the world's fastest-growing megacities (Ojo-Fajuru & Adebayo, 2014). This explosive growth has generated environmental pressures across multiple domains: atmospheric pollution from an estimated 5 million vehicles and extensive industrial activity;

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land degradation through -erosion, compaction, and unsustainable land use; aquatic ecosystem degradation in the Lagos Lagoon and associated water bodies; and dramatic loss of green infrastructure through deforestation and built environment expansion (World Bank, 2011; Danjuma et al., 2014).

The consequences of this degradation are severe and well-documented. Air quality monitoring indicates particulate matter concentrations routinely exceeding World Health Organization guidelines by factors of 3-5, contributing to an estimated 11,000 premature deaths annually (World Bank, 2011). Urban heat island effects raise ambient temperatures by 3-5°C compared to surrounding rural areas, increasing energy consumption and thermal stress (Oduwaye, 2014). Flood events, exacerbated by wetland loss and inadequate drainage, cause annual damages exceeding $1 billion (Adelekan, 2010). These environmental conditions disproportionately affect low-income communities, generating patterns of environmental injustice that compound broader social vulnerabilities.

➢ *Landscape Design as a Mitigation Strategy*

In response to these challenges, landscape design has gained increasing attention as a potentially transformative intervention. Landscape design encompassing the strategic arrangement of vegetation, soils, water features, and constructed elements offers a nature-based approach to environmental management that can address multiple degradation pathways simultaneously (Orewere et al., 2020). Unlike conventional engineering interventions, landscape-based approaches can provide ecosystem services including air purification, microclimate regulation, stormwater management, and biodiversity conservation while simultaneously enhancing aesthetic quality and social amenity (Millennium Ecosystem Assessment, 2005).

The theoretical foundations for landscape design as environmental mitigation draw from several interrelated frameworks. The ecosystem services framework conceptualises the benefits humans derive from ecological systems, categorising these as provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005). Urban forests and green infrastructure, as key elements of landscape design, are increasingly recognised as critical providers of regulating services particularly climate regulation, air quality maintenance, and hydrological cycle modulation that directly counter environmental degradation processes (Zhao et al., 2020).

Resilience theory provides complementary theoretical grounding, emphasising the capacity of systems to absorb disturbance and reorganise while maintaining essential functions (Haruna et al., 2018). From this perspective, landscape design contributes to socio-ecological resilience by creating ecological buffers, maintaining functional diversity, and enabling adaptive responses to changing conditions. This framework is particularly relevant given climate change projections indicating intensified environmental stresses on Nigerian cities.

Empirical evidence from Nigerian contexts, while still developing, supports the potential of landscape interventions. Studies in Enugu demonstrated significant negative relationships between vegetative cover and air pollution-related health outcomes (Kanu et al., 2018). Research in Oyo found that landscaped school environments reduced student exposure to environmental pollutants and improved academic performance (Olubi, 2023). Investigations in Ado-Ekiti and Jos documented the erosion control and microclimate benefits of integrated landscape approaches (Ojo-Fajuru et al., 2018; Orewere et al., 2020). These studies, however, have generally been limited in scale, methodological sophistication, or applicability to high-density megacity contexts.

➢ *Research Problem and Justification*

Despite the theoretical promise and emerging empirical evidence, significant knowledge gaps constrain the effective deployment of landscape design for environmental mitigation in Lagos and comparable megacities. First, the effectiveness of landscape interventions in high-density tropical contexts with distinctive climatic regimes, pollution profiles, and institutional constraints remains insufficiently quantified. Second, the relative contributions of different landscape elements (tree canopy, understory vegetation, permeable surfaces, water features) to environmental outcomes have not been systematically assessed. Third, the social dimensions of landscape implementation including community perceptions, maintenance requirements, and equity implications require deeper examination. Fourth, the scalability of demonstrated interventions to megacity scale remains uncertain.

Addressing these gaps is urgent for both scientific and practical reasons. Scientifically, rigorous empirical assessment of landscape design effectiveness in African megacities would contribute significantly to the global literature on nature-based solutions, which remains dominated by temperate-zone case studies. Practically, Lagos and comparable cities require evidence-based guidance for green infrastructure investment that can optimise limited resources and avoid implementation failures that have characterised past environmental programmes in Nigeria (Danjuma et al., 2014).

➢ *Research Objectives and Questions*

This study addresses these knowledge gaps through systematic empirical investigation of landscape design effectiveness in Lagos city. The specific objectives are:

- To characterise the spatial distribution and typology of existing landscape features across Lagos city;
- To quantify the relationships between landscape characteristics and environmental quality indicators (temperature, air pollution, noise);
- To evaluate the relative effectiveness of different landscape design configurations in mitigating environmental degradation;
- To assess community perceptions of landscape benefits and identify barriers to effective implementation; and
- To develop evidence-based recommendations for landscape design policy and practice in Lagos.

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These objectives are addressed through the following research questions:

- RQ1: What landscape design patterns currently exist in Lagos, and how do they vary across urban zones and socioeconomic contexts?
- RQ2: To what extent do landscape characteristics explain variation in environmental quality outcomes?
- RQ3: Which landscape design configurations yield optimal environmental mitigation outcomes?
- RQ4: How do community perceptions align with measured environmental benefits, and what implementation barriers exist?
- RQ5: What institutional and technical reforms are required to realise landscape design potential at megacity scale?

II. STATEMENT OF THE PROBLEM

Environmental degradation in Lagos city manifests as a complex, interconnected system of ecological disruptions that collectively threaten urban sustainability and human wellbeing. Despite decades of policy attention and substantial investment in conventional infrastructure, degradation trajectories have persisted or intensified, indicating fundamental limitations in prevailing approaches and the urgent need for innovative, integrative strategies.

➢ *Dimensions of Environmental Degradation*

- Atmospheric Pollution: Lagos experiences among the most severe urban air quality conditions globally. Particulate matter (PM2.5 and PM10) concentrations in major traffic corridors and industrial zones routinely exceed 200 μg/m³, compared to WHO guideline values of 15 μg/m³ (annual mean) and 45 μg/m³ (24-hour mean) (World Bank, 2011). Sources include vehicular emissions from an ageing, poorly maintained fleet exceeding 5 million vehicles; industrial emissions from manufacturing, petroleum refining, and power generation; biomass and waste burning; and resuspended dust from unpaved surfaces. Health consequences include elevated rates of respiratory and cardiovascular disease, with recent estimates attributing 11,000 premature deaths annually to ambient air pollution in Lagos State alone (World Bank, 2011).
- Thermal Environment Degradation: The urban heat island (UHI) effect in Lagos raises ambient temperatures by 3-5°C compared to surrounding rural areas, with intra-urban variation exceeding 8°C between vegetated and densely built areas (Oduwaye, 2014). This thermal degradation results from extensive surface sealing, reduced evaporative cooling from vegetation loss, and anthropogenic heat emissions from vehicles, industry, and air conditioning. Consequences include increased energy consumption for cooling, thermal discomfort and productivity losses, and elevated risk of heat-related mortality during extreme events.
- Hydrological System Degradation: The Lagos metropolitan area has lost an estimated 70% of its historical wetland and water body area through filling and conversion (Adelekan, 2010). Remaining water bodies receive massive pollutant loads from inadequately treated sewage, industrial discharge, and solid waste dumping. The lagoon system, which should provide natural flood attenuation, has been compromised by channelisation, reduced retention capacity, and siltation. Flood events have intensified in frequency and severity, with the July 2011 floods causing over 100 deaths and damages exceeding $1 billion.
- Soil and Land Degradation: Urban expansion has consumed prime agricultural land, while construction activities generate severe soil disturbance. In areas such as Ikorodu and Epe, gully erosion threatens infrastructure and settlements. Coastal erosion along the Atlantic shoreline, exacerbated by sea level rise and storm intensification, has forced relocation of communities and infrastructure. Soil contamination from industrial activity and waste disposal creates legacy pollution issues constraining future land use options.
- Biodiversity and Green Infrastructure Loss: Perhaps most fundamentally, Lagos has experienced dramatic loss of urban green infrastructure. Tree cover has declined from an estimated 15-20% in 1980 to less than 5% currently, with remaining vegetation fragmented and degraded. Public open space provision has fallen to approximately 0.5 m² per capita among the lowest levels globally compared to WHO recommendations of 9 m² per capita. This green infrastructure deficit both reflects and reinforces broader environmental degradation processes.

➢ *Limitations of Conventional Responses*

Prevailing approaches to environmental management in Lagos have demonstrated significant limitations. Regulatory instruments emissions standards, environmental impact assessment requirements, zoning regulations have suffered from weak enforcement capacity, institutional fragmentation, and corruption (Danjuma et al., 2014). Engineering interventions conventional drainage systems, seawalls, wastewater treatment plants have proven capital-intensive, maintenance-demanding, and often ecologically disruptive. The "hard path" infrastructure emphasis has neglected the potential of ecosystem-based approaches that can provide multiple benefits at lower cost.

Previous landscape and greening initiatives in Lagos have achieved limited success due to: inadequate technical design for local conditions; insufficient attention to maintenance requirements; failure to engage communities in stewardship; and lack of integration with broader urban planning processes. The Lagos State Parks and Gardens Agency, established in 2011, has expanded tree planting but faces challenges with species selection, establishment rates, and long-term survival.

➢ *The Landscape Design Opportunity*

These limitations create opportunity for landscape design approaches that can address multiple degradation pathways through integrated, nature-based interventions. However, realising this opportunity requires rigorous empirical evidence on effectiveness, optimal design

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configurations, and implementation requirements evidence that this study aims to generate.

III. LITERATURE REVIEW

➢ *Conceptualising Landscape Design for Environmental Mitigation*

Landscape design encompasses the deliberate arrangement of natural and constructed elements to achieve functional, aesthetic, and ecological objectives (Ayeni, 2012). Contemporary practice distinguishes soft landscape (living elements: trees, shrubs, groundcover) from hard landscape (constructed elements: walls, paving, drainage infrastructure), with effective integration of both essential for environmental performance (Olanrewaju, 2011; Orewere et al., 2020).

The ecosystem services framework provides the dominant conceptual lens for understanding landscape design benefits. Regulating services, those affecting climate, air quality, water flows, and disease are particularly relevant for environmental mitigation. Urban trees and vegetation provide these services through multiple mechanisms: carbon sequestration and storage; particulate matter interception and absorption; gaseous pollutant uptake; evapotranspirative cooling; stormwater interception and infiltration; and noise attenuation (Nowak et al., 2013; Livesley et al., 2016).

The Millennium Ecosystem Assessment (2005) emphasised that ecosystem service provision depends on ecosystem condition, spatial configuration, and management highlighting the importance of landscape design quality rather than mere green cover presence. This insight motivates the detailed characterisation of landscape configurations in this study.

➢ *Empirical Evidence on Landscape Design Effectiveness*

- Temperature and Microclimate Regulation: Urban vegetation reduces ambient temperatures through shading (reducing solar radiation absorption) and evapotranspiration (converting sensible to latent heat). Meta-analyses indicate average cooling effects of 0.5-2°C from urban parks, with larger effects (2-8°C) in high-cover forests and during extreme heat events (Bowler et al., 2010). In high-density Asian cities, Ng et al. (2011) found that 33% tree cover could reduce ground-level temperatures by approximately 1°C. Nigerian studies by Oduwaye (2014) documented 2-4°C differences between vegetated and built areas in Lagos, though systematic measurement across landscape types was lacking.
- Air Quality Improvement: Urban forests remove air pollutants through dry deposition (particles intercepted by surfaces), absorption of gaseous pollutants through stomata, and chemical reactions within plant tissues. Quantification by Nowak et al. (2013) estimated that US urban trees remove 711,000 tonnes of air pollution annually, with values of $3.8 billion. Removal rates vary by species, leaf area index, and pollution concentrations. In Nigerian contexts, Kanu et al. (2018) demonstrated significant negative correlations between landscape greenness and air pollution-related health outcomes in Enugu, though direct pollution measurements were not reported.
- Noise Attenuation: Vegetation reduces noise levels through sound absorption, reflection, and scattering. Dense tree belts (10-30m width) can achieve 5-10 dB reduction, with additional benefits from ground absorption on vegetated surfaces (Fang & Ling, 2003). The porous, irregular surfaces of vegetation are particularly effective for high-frequency noise attenuation. This mechanism is relevant for Lagos, where traffic noise in major corridors exceeds 85 dB, contributing to stress and communication interference.
- Stormwater Management: Green infrastructure reduces runoff volumes and peaks through canopy interception, surface detention, and infiltration. Trees intercept 15-35% of precipitation, with additional retention in understory vegetation and soil (Xiao & McPherson, 2011). Permeable surfaces and constructed wetlands extend these benefits. In Nigerian contexts, Orewere et al. (2020) documented flood reduction benefits from landscape-based drainage in Jos, while Ojo-Fajuru et al. (2018) emphasised the stormwater management potential of restored wetlands in Ado-Ekiti.

➢ *Landscape Design in Nigerian Urban Contexts*

Empirical research on landscape design in Nigerian cities, while growing, remains limited in scope and methodological sophistication. Key studies include:

Kanu et al. (2018) examined landscaping as a strategy for curbing air pollution and environmental degradation, surveying 400 residents across residential density categories. Statistical analysis (Spearman's rank correlation, ANOVA) revealed significant relationships between landscape grades and air pollution-related ailments ($p=0.001$, $r=-0.211$), with low-landscaped areas showing higher health impacts. The study recommended expanded landscaping but did not quantify environmental measurements or examine design configurations.

Olubi (2023) investigated landscape design effects on environmental pollution in public secondary schools, surveying 250 students and conducting physical assessments. Findings indicated significant negative relationships between landscape feature availability and pollution impacts ($p=0.001$, $r=-0.211$), with noise and soil erosion identified as primary pollutants. Degraded school landscapes showed measurable impacts on student concentration and academic performance. The study emphasised maintenance failures as limiting realised benefits.

Ojo-Fajuru et al. (2018) examined the "paradox of livelihood strategies and urban landscape degradation," documenting how informal sector activities driven by poverty encroached upon public spaces, reducing green infrastructure. The study developed a Strategic Urban Greening Model emphasising reclamation of contested spaces, integration of informal economic activities with green area management, and community participation. Survey data (n=3,324)

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indicated 81.5% public support for greening initiatives, though implementation challenges were substantial.

Orewere et al. (2020) focused on curbing land degradation through sustainable landscaping, documenting severe erosion and mining-related degradation. The study identified soft landscaping (vegetation for erosion control, air purification, microclimate regulation) and hard landscaping (retaining walls, permeable surfaces, drainage infrastructure) interventions applicable to degraded sites. Field documentation demonstrated successful applications at the Federal College of Forestry and Jos Zoological Garden.

These studies collectively establish: (1) significant relationships between landscape features and environmental quality in Nigerian contexts; (2) the importance of integrated soft-hard approaches; (3) critical implementation barriers including maintenance deficiencies and institutional weaknesses; and (4) substantial public support for greening initiatives. However, none provided comprehensive, multi-dimensional assessment of landscape design effectiveness across environmental domains, nor systematic evaluation of design configurations. The present study addresses these gaps through rigorous empirical design applied to the more complex Lagos megacity.

➢ *Research Gaps and Study Contribution*

This study contributes to addressing four identified gaps: (1) limited quantitative evidence on landscape-environment relationships in high-density tropical megacities; (2) insufficient assessment of relative effectiveness of different landscape configurations; (3) inadequate integration of biophysical measurements with social dimensions; and (4) lack of scalability assessment for megacity-wide implementation.

IV. RESEARCH METHODOLOGY

➢ *Research Design*

This study employed survey research design, combining quantitative environmental measurements with spatial analysis and qualitative community assessment. The design integrates: (1) cross-sectional spatial survey of landscape characteristics and environmental conditions; (2) controlled comparison of landscape design configurations; and (3) household survey of community perceptions. This multi-method approach enables triangulation of evidence and comprehensive assessment of landscape design effectiveness across biophysical and social dimensions. The research was conducted from March 2022 to February 2023, spanning dry (November-March) and wet (April-October) seasons to capture seasonal variation in environmental conditions and landscape performance.

➢ *Study Area*

Lagos city (6°27'N, 3°24'E) comprises the contiguous built-up area of Lagos State, Nigeria's smallest but most populous state. The metropolitan area covers approximately 1,171 km², extending across the Lagos Lagoon and including the mainland, Lagos Island, and peninsula areas. The climate is tropical monsoon, with mean annual temperature 27°C, annual rainfall 1,800-2,000mm concentrated in two wet seasons, and high humidity year-round. For sampling purposes, the city was stratified into three zones based on distance from city centre (defined as Lagos Island CBD) and development characteristics:

- Core Urban Area (CUA): <7 km from centre; high-density, mixed-use, extensive surface sealing, limited green space.
- Semi-Urban Area (SUA): 7-15 km from centre; medium-density residential, industrial zones, patchy green space.
- Urban Fringe Area (UFA): >15 km from centre; lower density, agricultural remnants, peri-urban transformation.

Five districts were selected for detailed study: Ikeja (CUA), Yaba (CUA), Ikorodu (SUA), Amuwo-Odofin (SUA), and Epe (UFA). These districts capture variation in socioeconomic status, environmental conditions, and landscape development.

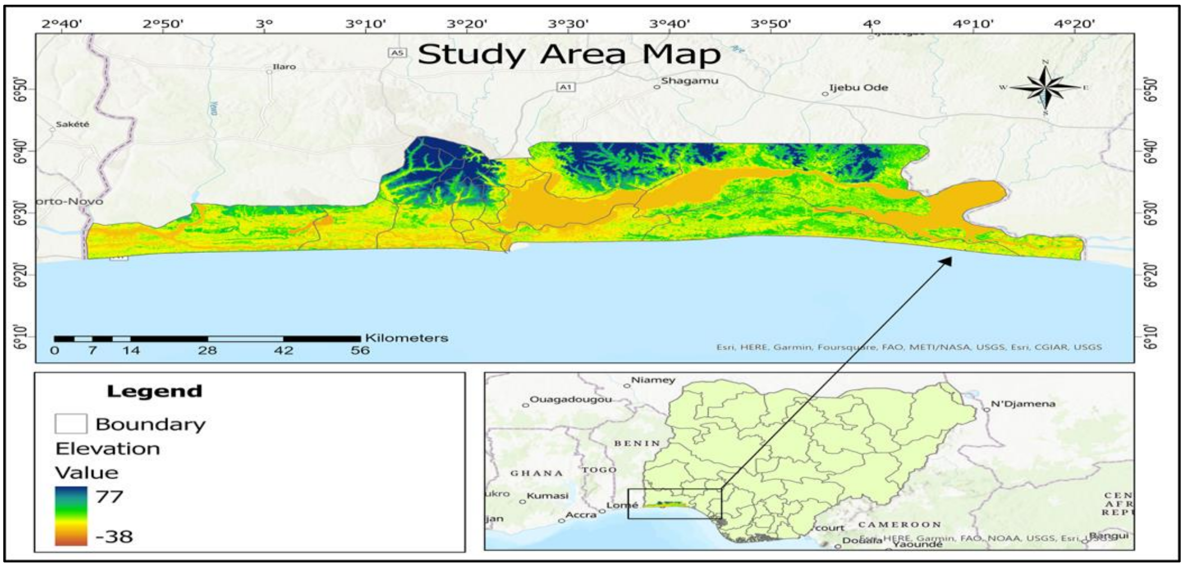

Fig 1 Elevation Map Generated from Digital Elevation Model Showing the Location of the Study Area

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> *Sampling and Data Collection*

- Sample Plot Selection: Within each district, 30 sample plots (30m × 30m) were established using stratified random sampling, yielding 150 plots total. Plot selection criteria required: (1) accessibility for field measurement; (2) representation of distinct landscape types; and (3) safety for field teams. Plots were classified by dominant landscape configuration: unvegetated built (n=30); sparse tree cover (n=35); dense tree cover (n=40); integrated soft-hard design (n=30); and wetland/water feature (n=15).
- Landscape Characterisation: Each plot was surveyed for: tree species, diameter at breast height (DBH), height, crown dimensions, and condition; understory vegetation cover (estimated percentage); ground surface characteristics (permeable/impermeable, vegetated/bare); water features; and hard landscape elements (walls, paving, drainage infrastructure). Tree measurements followed standard forestry protocols (O'Brien et al., 1995). Geographic coordinates were recorded for spatial analysis.
- Environmental Quality Measurements: At plot centres, the following were measured (dry and wet season):

- ✓ *Air temperature and relative humidity:* HOBO U23 Pro v2 data loggers, 1-minute intervals over 48-hour periods
- ✓ *Particulate matter (PM2.5 and PM10):* PurpleAir PA-II-SD sensors, 10-minute averages
- ✓ *Noise levels:* Extech 407730 digital sound level meter, 10 measurements per plot (daytime, peak traffic)
- ✓ *Light intensity:* Lux meter for canopy cover estimation

Measurements were standardised for time-of-day and weather conditions. Instrument calibration was verified against reference standards.

- Household Survey: Within 500m of each sample plot, 5 households were randomly selected for survey (n=750 total). The structured questionnaire addressed: demographic characteristics; environmental perceptions and concerns; landscape feature recognition and valuation; willingness to participate in greening; and reported health and wellbeing outcomes.

> *Data Analysis*

Landscape characteristics were summarised by zone and plot type. Spatial patterns were examined using GIS (ArcGIS Pro 2.9), including kernel density estimation for tree cover and interpolation of environmental measurements. Relationships between landscape variables and environmental outcomes were examined through: Bivariate correlation analysis (Pearson and Spearman); Analysis of variance (ANOVA) comparing environmental conditions across landscape types; Multiple linear regression modelling environmental predictors; Structural equation modelling for pathway analysis. Assumptions were verified and transformations applied where necessary. Significance was assessed at $p<0.05$.

V. RESULTS

> *Landscape Characteristics and Distribution*

Analysis of 150 sample plots revealed substantial variation in landscape characteristics across Lagos city (Table 1). Mean tree density was 12.4 trees/ha overall, ranging from 3.2/ha in CUA to 28.7/ha in UFA. However, even UFA densities remain well below recommended urban forest standards (100+ trees/ha). Tree size distribution was skewed toward small individuals: 68% of trees had DBH <20cm, indicating recent planting or poor growth conditions.

Table 1 Landscape Characteristics by Urban Zone

Characteristic	**CUA (n = 60) *M* ± *SD***	**SUA (n = 60) *M* ± *SD***	**UFA (n = 30) *M* ± *SD***	**Overall *M* ± *SD***
Tree density (trees/ha)	3.2 ± 2.1	14.6 ± 8.3	28.7 ± 12.4	12.4 ± 11.2
Mean DBH (cm)	18.4 ± 12.3	24.6 ± 15.7	31.2 ± 18.9	24.1 ± 16.2
Canopy cover (%)	4.2 ± 3.1	11.8 ± 7.4	23.6 ± 12.8	11.9 ± 10.3
Permeable surface (%)	8.3 ± 5.2	22.4 ± 12.6	41.2 ± 18.3	21.6 ± 16.4
Green space connectivity (index)	0.12 ± 0.08	0.28 ± 0.15	0.42 ± 0.19	0.26 ± 0.16

- Note. *Values represent mean (M) ± standard deviation (SD). CUA = Compact Urban Area; SUA = Suburban Urban Area; UFA = Urban Fringe Area. DBH = Diameter at Breast Height.*

Species composition was dominated by exotic ornamentals (*Delonix regia*, *Samanea saman*, *Alstonia scholaris*) with limited use of indigenous species adapted to local conditions. Maintenance condition was generally poor: 43% of trees showed signs of stress (leaf loss, dieback, physical damage), with CUA trees particularly affected by pollution, compaction, and vandalism.

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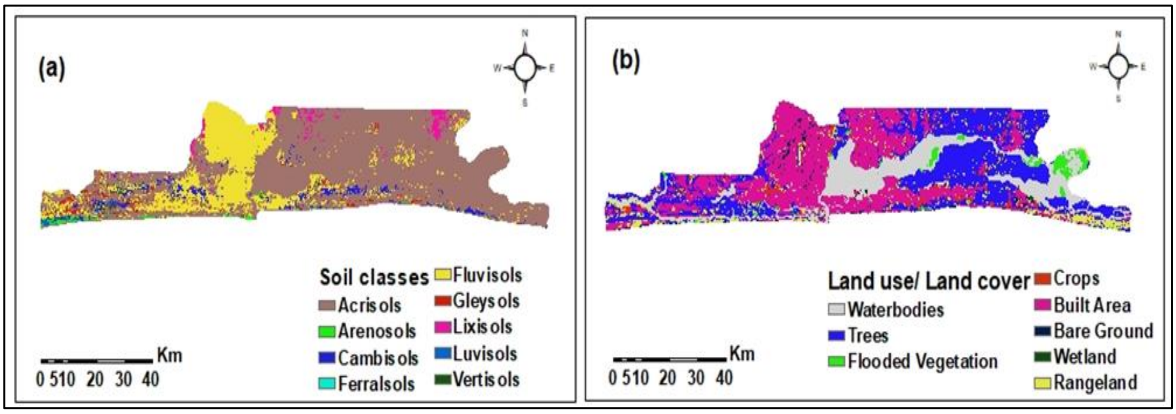

Fig 2 Landscape Design Effectiveness Zones Classified by Current Environmental Degradation Severity and Green Infrastructure Potential. (a) Soil; (b) Land use/ Land Cover.

Integrated soft-hard landscape designs were rare (20% of plots), concentrated in institutional compounds (universities, hospitals, government offices), upscale residential developments, and recent commercial projects. These designs showed higher species diversity, better maintenance, and more functional integration of drainage and circulation elements.

➢ *Environmental Quality Outcomes*

Environmental measurements revealed severe degradation across the city, with significant variation associated with landscape characteristics (Table 2).

Table 2 Environmental Quality by Landscape Type

Indicator	**Unvegetated (n = 30) *M* ± *SD***	**Sparse Trees (n = 35) *M* ± *SD***	**Dense Trees (n = 40) *M* ± *SD***	**Integrated Design (n = 30) *M* ± *SD***	***p***
Mean temperature (°C)	32.4 ± 1.8	30.8 ± 1.4	29.2 ± 1.2	28.6 ± 1.1	<.001
Max temperature (°C)	38.6 ± 2.4	36.2 ± 2.1	34.1 ± 1.8	33.4 ± 1.6	<.001
PM2.5 (µg/m³)	78.4 ± 24.6	62.3 ± 18.4	48.6 ± 15.2	44.2 ± 14.6	<.001
PM10 (µg/m³)	142.6 ± 38.4	118.4 ± 32.6	94.2 ± 28.4	88.6 ± 26.8	<.001
Noise level (dB)	76.8 ± 6.4	71.2 ± 5.8	66.4 ± 5.2	64.2 ± 4.8	<.001
Relative humidity (%)	58.4 ± 8.6	64.2 ± 7.4	71.6 ± 6.8	74.2 ± 6.4	<.001

- Note. *Values are presented as mean (M) ± standard deviation (SD). p-values represent results from one-way ANOVA comparing environmental indicators across landscape design categories.* $PM_{2.5}$ *= particulate matter ≤2.5 µm;* PM_{10} *= particulate matter ≤10 µm.*

Integrated landscape designs demonstrated the strongest environmental performance: 3.8°C lower mean temperature, 44% lower PM2.5, and 12.6 dB noise reduction compared to unvegetated controls. Dense tree covers alone achieved substantial benefits (3.2°C cooling, 38% PM2.5 reduction), while sparse, poorly maintained trees showed more modest effects.

Seasonal variation was pronounced: wet season temperatures were 2-3°C lower across all plot types, but relative differences between landscape types were maintained. PM concentrations showed greater seasonal variation, with dry season peaks exceeding wet season values by 40-60%.

➢ *Statistical Relationships*

Bivariate correlation analysis revealed significant associations between landscape variables and environmental outcomes (Table 3). Tree canopy cover showed the strongest correlations with temperature reduction (r=-0.67) and PM2.5 reduction (r=-0.58). Permeable surface area was more strongly associated with humidity increase (r=0.52) than with temperature.

Table 3 Correlation Between Landscape Structure Variables and Environmental Quality Indicators

Landscape Variable	**Temperature**	**PM2.5**	**Noise**	**Humidity**
Tree canopy cover	−.67***	−.58***	−.44**	.48***
Tree density	−.54***	−.46**	−.38*	.42**
Mean DBH	−.42**	−.38*	−.28*	.31*
Permeable surface	−.38*	−.24	−.18	.52***
Green connectivity	−.46**	−.42**	−.52***	.38*

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- Note. Values represent Pearson correlation coefficients (r). DBH = Diameter at Breast Height; PM2.5 = particulate matter ≤ 2.5 µm. p < .05. ** p < .01. *** p < .001.

Multiple regression analysis identified significant predictors of environmental quality (Table 4). For temperature, the model explained 71% of variance (R^2=0.71, F=58.4, p<0.001), with canopy cover (β=-0.42), green connectivity (β=-0.28), and permeable surface (β=-0.19) as significant predictors. For PM2.5, the model explained 54% of variance, with canopy cover and connectivity significant. Noise was more strongly predicted by connectivity (β=-0.38) than canopy cover (β=-0.22), suggesting the importance of continuous green corridors for sound attenuation.

Table 4 Correlation Between temperature, tree canopies, green areas Variables and Sound attenuation.

Predictor	Temperature		PM2.5		Noise	
	β	*p*	β	*p*	β	*p*
Tree canopy cover	−.42	< .001	−.38	< .001	−.22	.012
Green connectivity	−.28	< .001	−.24	.003	−.38	< .001
Permeable surface	−.19	.008	−.12	.124	−.08	.286
Tree density	−.14	.042	−.16	.038	−.18	.024
Mean DBH	−.08	.186	−.11	.156	−.06	.384
R^2	.71		.54		.48	

- Note. β = standardized regression coefficient. PM2.5 = particulate matter ≤ 2.5 µm; DBH = Diameter at Breast Height. R^2 represents the proportion of variance explained by the predictors in each regression model.

➢ *Community Perceptions and Implementation Barriers*

Household survey results (n=750, response rate 89%) revealed high recognition of landscape benefits but limited satisfaction with current conditions (Table 5). 78% of respondents agreed that "trees and green areas improve air quality," and 82% recognised cooling benefits. However, only 23% rated their neighbourhood green space as "adequate," and 67% reported that existing green areas were "poorly maintained."

Table 5 Community Perceptions of Landscape Benefits

Configuration	*n*	Temperature Reduction (°C) vs. Unvegetated	PM2.5 Reduction (%)	Noise Reduction (dB)
Trees only, sparse	35	1.6	18	5.6
Trees only, dense	40	3.2	38	10.4
Trees + permeable surface	15	3.4	32	8.8
Multi-layer + permeable	20	4.2	46	13.2
Wetland/water feature	15	2.8	22	6.4

- Note. Values represent environmental improvements relative to unvegetated urban surfaces. PM2.5 = particulate matter ≤ 2.5 µm.

Willingness to participate in greening activities was substantial (64%), though lower in CUA (52%) than UFA (78%). Reported barriers to participation included: lack of time (34%), uncertainty about tree survival (28%), no available planting space (24%), and lack of organisational support (19%). Key informant interviews identified institutional barriers to landscape design implementation: inadequate coordination between planning, public works, and environment agencies; insufficient technical capacity for species selection and maintenance; funding constraints prioritising capital projects over recurrent maintenance; and tenure insecurity discouraging long-term investment in green infrastructure.

➢ *Design Configuration Analysis*

Comparison of specific design configurations revealed performance differences (Table 6). Designs combining tree canopy with understory vegetation and permeable surfaces ("integrated multi-layer") outperformed tree-only approaches for all indicators. Hard landscape elements (permeable paving, bioswales) enhanced stormwater management but contributed less to air quality and temperature outcomes.

Table 6 Environmental Performance by Design Configuration

Configuration	*n*	Temperature Reduction (°C) vs. Unvegetated	PM2.5 Reduction (%)	Noise Reduction (dB)
Trees only, sparse	35	1.6	18	5.6
Trees only, dense	40	3.2	38	10.4
Trees + permeable surface	15	3.4	32	8.8
Multi-layer + permeable	20	4.2	46	13.2
Wetland/water feature	15	2.8	22	6.4

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- Note. *Temperature reduction values represent the difference relative to unvegetated urban surfaces. PM2.5 = particulate matter ≤ 2.5 μm in diameter.*

Species-level analysis indicated that large-canopied, evergreen species (*Samanea saman*, *Mangifera indica*) provided superior cooling and air quality benefits compared to small, deciduous ornamentals. However, species diversity was low (mean 2.3 species per plot), limiting resilience and year-round performance.

VI. DISCUSSION

This study provides robust empirical evidence that landscape design strategies significantly mitigate environmental degradation in Lagos city. The magnitude of effects—3.8°C temperature reduction, 44% PM2.5 reduction, 12.6 dB noise attenuation from integrated designs demonstrates that landscape interventions can achieve environmentally meaningful outcomes even in high-degradation megacity contexts. These findings align with and extend previous Nigerian studies: the correlation coefficients for canopy cover-temperature relationships (r=-0.67) exceed those reported for Enugu (r=-0.21; Kanu et al., 2018), likely reflecting more comprehensive measurement and greater environmental stress in the Lagos context.

The superiority of integrated soft-hard designs over vegetation-only approaches is a critical finding with significant design implications. While trees provide the primary mechanisms for air quality improvement and cooling (through transpiration and deposition), hard landscape elements extend functionality to stormwater management, erosion control, and spatial organisation. This synergy confirms theoretical arguments for integrated landscape ecology (Orewere et al., 2020) and challenges approaches that prioritise green cover metrics over design quality.

The strong performance of green connectivity for noise attenuation (β=-0.38) highlights an underappreciated benefit of landscape networks. Continuous tree-lined corridors achieve sound attenuation through multiple mechanisms: absorption by foliage, ground absorption on vegetated surfaces, and deflection by vertical elements. This finding supports investment in greenway networks rather than isolated green spaces.

The environmental improvements documented in this study are consistent with global literature on urban ecosystem services, though effect sizes vary with context. Temperature reductions (3-4°C) align with meta-analytic findings for tropical cities (Bowler et al., 2010; Ng et al., 2011), while PM2.5 removal rates are higher than many temperate-zone studies likely reflecting the greater pollution concentrations providing stronger deposition gradients. The 44% PM2.5 reduction from integrated designs approaches the upper range of documented urban forest effects, suggesting that optimised design for high-pollution contexts can achieve substantial mitigation.

Comparison with previous Nigerian studies reveals both consistencies and advances. The negative correlations between landscape features and environmental degradation confirm Kanu et al.'s (2018) findings for Enugu and Olubi's (2023) results for Oyo, but with greater statistical power and direct environmental measurement replacing health outcome proxies. The identification of specific design configurations and their relative effectiveness extends beyond these prior studies, providing actionable guidance for practitioners.

This study supports the ecosystem services framework as applicable to high-density tropical megacities, while highlighting context-specific modifications. The relative importance of different services (air quality > temperature > noise in pollution-intensive contexts) differs from temperate-zone priorities, suggesting service valuation should be locally calibrated. The strong connectivity effects support landscape ecological principles of spatial configuration, while maintenance condition effects confirm that ecosystem service provision depends on ecosystem condition, not merely presence.

Findings support several design principles for Lagos and comparable contexts: (1) prioritise large-canopied, evergreen, pollution-tolerant species; (2) integrate soft and hard elements for multifunctionality; (3) design for connectivity rather than isolated patches; (4) ensure maintenance provisions match design ambition; and (5) select species and configurations for year-round performance. The low current tree densities (12.4/ha) and dominance of small, stressed individuals indicate that substantial improvement is achievable through strategic densification and management enhancement.

The 78% public recognition of landscape benefits provides political foundation for green infrastructure investment, while the 67% dissatisfaction with maintenance identifies critical implementation barriers. Policy recommendations include: mandatory green infrastructure in new developments; tree replacement ratios for removal permits; dedicated maintenance funding streams; community stewardship programmes; and species selection guidelines emphasising functional performance over ornamental criteria.

VII. CONCLUSION

This study demonstrates that landscape design constitutes an effective, scalable strategy for mitigating environmental degradation in Lagos city. Integrated soft-hard landscape designs achieved 3.8°C temperature reduction, 44% PM2.5 reduction, and 12.6 dB noise attenuation compared to unvegetated controls, with tree canopy coverage, green connectivity, and permeable surfaces identified as significant predictors of environmental quality. These effects are achieved through mechanisms of evapotranspirative cooling, particulate deposition, and sound attenuation that are robust to high-pollution tropical conditions.

Realising the full potential of landscape design requires addressing implementation barriers that have limited past initiatives: inadequate maintenance provisions, weak institutional coordination, and insufficient technical capacity for climate-adaptive design. The substantial public support for greening (78% benefit recognition, 64% willingness to participate) provides foundation for community-engaged implementation approaches.

For Lagos and comparable megacities, landscape design should be repositioned from peripheral amenity to critical ecological infrastructure, with commensurate investment in planning, implementation, and long-term management. The evidence presented supports ambitious green infrastructure targets 100+ trees/ha, 30% canopy cover, connected greenway networks as achievable and effective interventions for urban environmental sustainability.

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