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Urban Heat Island Effect in Nigerian Cities and Mitigation Strategies

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Abstract

Rapid urbanization worldwide is changing landscapes and creating environmental problems. A major problem is the Urban Heat Island (UHI) effect, where urban areas experience significantly higher temperatures than their rural surroundings, posing threats to environmental sustainability and public health. In Nigeria, where urban populations are expanding at unprecedented rates, cities are experiencing elevated temperatures that exacerbate energy consumption, health risks, and environmental degradation. However, few studies have compared UHI patterns across different ecological zones, making it difficult to develop effective solutions. This study therefore investigates the causes, changes over time, and mitigation strategies of UHI in five major Nigerian cities due to their diverse ecological zones and urbanization patterns. Using a qualitative multiple case study approach based on secondary data and review of planning policies, the research investigated UHI patterns across the five selected cities. Findings revealed that dense urban development, loss of vegetation, impervious surfaces, and anthropogenic heat emissions are the primary drivers of UHI across the cities, with observations indicating increased UHI intensity over the past two decades. Existing mitigation effort such as urban greening, reflective materials, water-sensitive designs, and climate-responsive building orientation have achieved varying levels of success in counteracting these trends. The study proposes that cities implement integrated strategies combining ecological planning, sustainable building practices, and policy enforcement to enhance urban resilience, reduce heat accumulation, and promote environmental sustainability. By implementing these strategies, urban planners, policymakers, and environmental stakeholders in Nigeria can actively mitigate the impacts of the Urban Heat Island effect, creating healthier and more sustainable urban environments.

Keywords: Urban Heat Island, Sustainable Urban Design, Climate Resilience, Mitigation Strategies, Nigerian Cities

1. Introduction

The rapid expansion of urban areas has significantly altered local climates, giving rise to the Urban Heat Island (UHI) effect, where urban regions experience higher temperatures than surrounding rural areas due to human activities, dense construction, and reduced vegetation cover [1,2]. This phenomenon has increasingly drawn global attention as urban populations continue to grow, with projections indicating that nearly 70% of the world's population will reside in cities by 2050 (UN-DESA [3]). UHI has emerged as a critical environmental challenge because it contributes to higher energy consumption, deteriorating air quality, thermal discomfort, heat-related health risks, and environmental stress, which collectively threaten sustainable urban development and the wellbeing of urban populations [4,5]. UHI arises from multiple interconnected factors that fundamentally alter the urban energy balance and disrupt natural cooling processes. Impervious surfaces such as asphalt, concrete, and metal roofing absorb and retain solar radiation far more effectively than natural landscapes, creating surface temperature differentials that persist into nighttime hours [6,7]. Traffic and industrial emissions introduce additional anthropogenic heat into the urban atmosphere, while high building density creates urban canyons that trap heat and restrict ventilation. The loss of vegetation eliminates evapotranspiration as a natural cooling mechanism, further reducing cities' capacity to regulate temperature. Together, these factors create self-reinforcing cycles where heat accumulation intensifies over time, making UHI both a climatic and urban design concern [8,9]. Globally, UHI has been observed in numerous metropolitan areas across diverse climatic zones, where temperature differences of up to 7°C compared with surrounding rural areas have been recorded during peak conditions [10,5]. In temperate cities such as London and New York, UHI intensifies during summer months, exacerbating heatwave impacts, while in tropical cities including Bangkok and Singapore, persistently elevated temperatures create year-round thermal stress [11]. These elevated temperatures exacerbate energy demands for cooling, with studies indicating that cooling energy consumption increases by 1.5-2% for every 1°C rise in temperature [7]. The resulting increase in energy use leads to higher greenhouse gas emissions, creating a feedback loop that compounds both local UHI effects and global climate change. Additionally, elevated urban temperatures degrade air quality by accelerating photochemical reactions that produce ground-level ozone and trap particulate matter, while heightening health risks particularly during extreme heat events [4,2]. Vulnerable populations including the elderly, children, outdoor workers, and low-income communities lacking access to cooling infrastructure bear disproportionate health burdens, with heat-related illnesses and mortality rising sharply during heatwaves [12]. The combination of industrial emissions, high-rise development, vehicular traffic, and limited green space further compounds the phenomenon, creating environmental conditions that threaten both human health and urban sustainability. In Africa, rapid urbanization occurring at unprecedented rates has intensified UHI challenges, with

cities expanding spatially and demographically faster than planning frameworks can accommodate [13]. In Nigeria, rapid urbanization and industrial expansion have particularly intensified UHI manifestations, resulting in higher ambient temperatures, increased energy demands, and strain on urban infrastructure across major cities [14,15,16]. Nigeria's diverse climatic zones ranging from humid coastal regions to semi-arid northern areas present distinct UHI drivers and manifestations, with each ecological context requiring tailored understanding and response strategies. Consequently, rapidly urbanizing Nigerian cities are experiencing rising surface temperatures, increased energy demands for cooling, degraded air quality, and growing discomfort among urban residents, conditions that disproportionately affect low-income populations in densely packed informal settlements [17,18]. This poses a significant challenge to sustainable urban development, public health, and environmental quality, necessitating a shift toward environmentally sensitive design and planning approaches that integrate climate responsiveness into urban development processes.

This study aims to investigate the impacts of UHI in Nigerian cities and to propose targeted mitigation strategies that can support sustainable urban development. Specifically, it seeks to identify the drivers of UHI and their environmental impacts, assess the effectiveness of existing interventions, and recommend contextually appropriate solutions. The study provides valuable insights for urban planners, policymakers, and environmental managers, facilitating the development of urban environments that are resilient, energy-efficient, and conducive to public health [19,17].

1.1 Study Area

This study focused on five Nigerian cities: Lagos, Abuja, Kano, Port Harcourt, and Enugu (Fig. 1). These cities were chosen because they exemplify diverse ecological zones, urbanization patterns, and governance contexts, making them ideal for comparative analysis.

- **Lagos** is a coastal megacity characterized by extensive wetland reclamation and rapid population growth. It illustrates how industrial expansion and large-scale land conversion intensify the urban heat island effect.
- **Abuja**, the nation's capital, was designed with ecological buffers such as green belts. It provides insight into the successes and shortcomings of policy frameworks in moderating urban heat.
- **Kano**, located in the semi-arid north, shows how naturally sparse vegetation and ongoing urban expansion combine to amplify UHI.



Fig. 1. Map of Nigeria showing, Lagos, Kano, Port-Harcourt, Abuja and Enugu States

- **Port Harcourt**, in the oil-rich Niger Delta, demonstrates the impact of industrial activity and mangrove loss on the urban climate.
- **Enugu** is a medium-sized city where community-led greening efforts have helped moderate heat, although rapid estate development poses emerging risks.

These cities collectively represent the breadth of Nigeria's urban environments, supporting a comprehensive and context-sensitive analysis of the urban heat island phenomenon. Together, these cities provide a balanced platform for examining the drivers, impacts, and responses associated with UHI in Nigeria. Their selection ensures that findings capture both shared national patterns and context-specific variations, making the study relevant for wider urban and climate planning in sub-Saharan Africa.

2. Literature Review

2.1 *Conceptual Clarification of Urban Heat Island*

The Urban Heat Island (UHI) phenomenon refers to the observable temperature difference between urban and rural environments, where cities experience higher air and surface temperatures due to land-use changes and human activities [2]. The concept, first identified in the early twentieth century, has gained renewed attention as global urbanization accelerates and local climatic variations intensify [10]. Contemporary studies emphasize that UHIs are not caused solely by rising global temperatures but by urban morphology including surface materials, reduced vegetation, and energy consumption patterns that modify heat exchange processes [20]. In the Nigerian context, UHI has been defined as the artificial warming of cities resulting from urban form, energy use, and inadequate environmental design [21]. It manifests through increased ambient and surface temperatures, especially in densely built areas with low vegetation and minimal ventilation [22]. Researchers agree that while the UHI phenomenon is global, its magnitude and impact vary depending on geography, building density, and socio-economic conditions [23,24].

2.2 Global Perspectives on Urban Heat Island

Globally, UHIs have been extensively documented in cities such as Tokyo, London, and New York, where studies link urban geometry, impervious surfaces, and waste heat emissions to persistent thermal anomalies [2,25]. The Intergovernmental Panel on Climate Change [26] notes that UHIs compound the effects of global warming by increasing local temperature extremes and affecting energy demand patterns. For instance, research in Europe shows that summer nighttime temperatures in large cities can be up to 8°C higher than nearby rural zones [27]. Mitigation strategies in developed countries often include green roofing, cool pavements, urban greening, and reflective materials, which have proven effective in moderating surface and air temperatures [28,29]. In Asia, cities like Singapore and Seoul integrate climate-sensitive planning that combines vegetation corridors and energy-efficient architecture to reduce heat accumulation [30]. Such interventions show that while urban heat is inevitable, adaptive planning can substantially minimize its impacts.

2.3. African and Nigerian Context

In Africa, the UHI effect is magnified by rapid and largely unregulated urban expansion. Many cities experience land-use transitions characterized by the replacement of vegetated land with built-up areas, leading to the retention of solar radiation [31]. The problem is compounded by limited infrastructure, poor waste management, and low environmental literacy among urban dwellers [32]. In Nigeria, studies reveal consistent warming patterns across major cities. Lagos, Abuja, and Kano exhibit increasing nighttime temperatures and declining urban greenery [17,33].Temperature differences between central business districts and peri-urban zones have widened over the past decade, with built-up areas experiencing heat intensities up to 5°C higher than rural surroundings[23]. Rapid infrastructural development in Abuja and Port Harcourt has intensified surface heating due to extensive use of reflective and impervious materials [24]. Despite these findings, few Nigerian cities have implemented structured UHI mitigation frameworks. Environmental design policies remain fragmented, and green infrastructure receives minimal investment [34]. This gap underscores the need for strategic interventions that integrate ecological and urban design principles into planning.

2.4. Drivers of Urban Heat Island

The causes of UHI can be broadly categorized into physical, anthropogenic, and structural factors (Fig. 2). Physically, the replacement of natural vegetation with impervious materials alters the surface energy balance, reducing evapotranspiration and increasing heat storage [30].

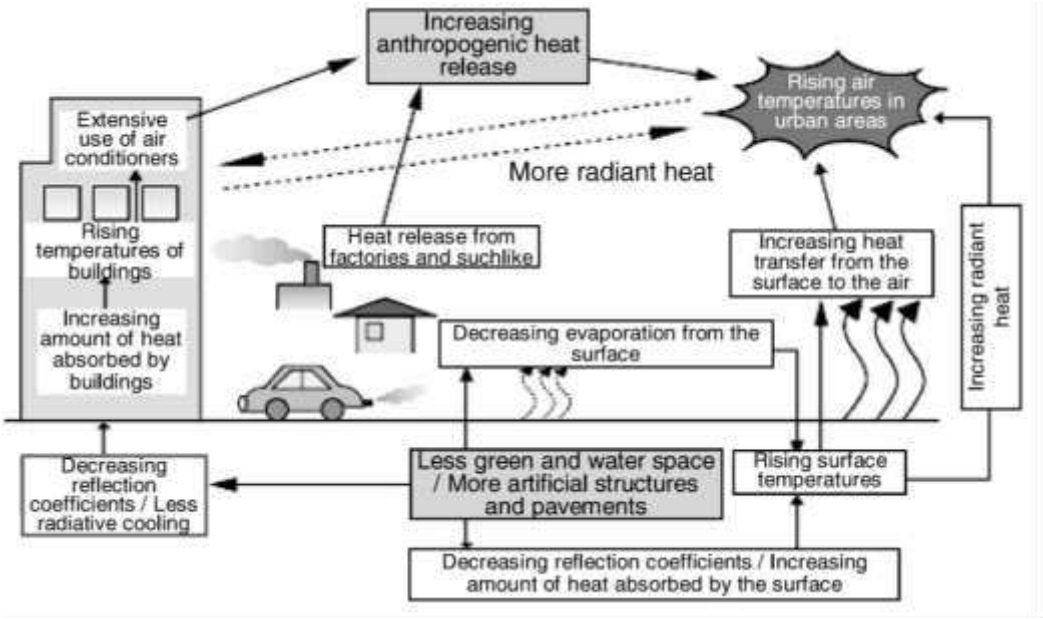


Figure 2: Drivers of the UHI
Source: Adapted from Abbas, Jason, & Tristan (2017)

Anthropogenic heat emissions from vehicles, industries, and air-conditioning units further elevate local temperatures [35]. Structurally, dense building configurations trap heat within narrow urban canyons, limiting airflow and radiative cooling [20]. In Nigeria, specific contributing factors include uncontrolled urban sprawl, poor zoning, limited tree cover, and energy-intensive lifestyles [21]. High-rise structures with dark roofing materials and limited shading exacerbate thermal accumulation [36]. The situation is further worsened by inadequate waste management which include open burning and exhaust emissions release particulates that absorb heat and degrade air quality [22]. Empirical findings indicate that cities in the humid south, such as Lagos and Port Harcourt, experience humidity-enhanced heat islands, while arid northern cities like Kano experience dry heat accumulation due to sparse vegetation [34,24]. This regional variation shows that mitigation must be context-specific rather than uniform across all Nigerian cities.

2.5. Impacts of Urban Heat Island

The consequences of the UHI effect span environmental, social, and economic dimensions. Environmentally, increased surface temperatures intensify energy demand, particularly for cooling systems, thereby raising greenhouse gas emissions and reinforcing the warming cycle [28]. In health terms, prolonged exposure to high temperatures leads to heat stress, dehydration, and respiratory ailments, especially among the elderly and children [23]. In Nigeria, studies reveal rising energy consumption in households and businesses, driven by air conditioning and cooling needs [17]. Moreover, UHI contributes to deteriorating air quality, as stagnant air traps pollutants within urban basins [36]. Ecologically, it disrupts biodiversity by altering soil temperature and moisture conditions, reducing habitat quality for urban flora and fauna [34]. Economically, increased energy bills and reduced worker productivity during hot periods translate into measurable financial losses for city economies [24].

2.6. Responses to Urban Heat Island

Efforts to address UHI globally range from engineering solutions to urban design interventions. Green infrastructure, including urban parks, tree planting, and vertical greening systems, has proven highly effective in cooling urban spaces [29]. Other strategies include cool roofs, reflective pavements, and water-sensitive design to promote evaporative cooling [28]. In Nigeria, responses remain limited and largely localized. A few city administrations have begun promoting tree planting and greening campaigns, but implementation is inconsistent and often politically driven [21). Urban policies rarely prioritize climatic considerations, and public awareness of heat mitigation remains low [22]. Some universities and research bodies have proposed sustainable urban design models incorporating green corridors, permeable surfaces, and building orientation strategies [34], but these remain mostly conceptual without widespread policy adoption.

2.7. *Empirical Studies on Urban Heat Island*

Several recent studies document the progression and impacts of UHI across Nigeria. Adelekan and Ede[21] analyzed urban warming trends in Lagos and found that the loss of vegetation and high population density significantly increase nighttime heat retention. Uchegbu et al.[33] examined UHI distribution in southeastern cities, identifying poor ventilation and reflective building materials as key factors. Similarly, Olanrewaju et al.[22] emphasized that uncontrolled land conversion contributes to temperature anomalies in northern cities. Across African cities, Odindi et al.[31] confirmed similar trends, showing that unplanned growth and informal settlements amplify UHI effects. These findings collectively affirm that urbanization, material selection, and the absence of adaptive planning are consistent drivers of urban heat in the region.

2.8. Theoretical Framework

This study is guided by the Urban Climate Theory, which views cities as modified atmospheric systems where human activities influence local climatic variables such as temperature, humidity, and wind flow [1,2]. The theory explains how urban form and materiality alter the balance of incoming and outgoing radiation, creating heat accumulation zones. Complementing this is the Sustainable Urbanism Framework, which emphasizes integrating environmental systems into urban design to enhance resilience and reduce ecological footprints [28]. Additionally, the study draws on Land Use and Land Cover Change Theory, which examines how alterations in surface characteristics particularly the replacement of vegetation with impervious surfaces disrupt natural cooling mechanisms such as evapotranspiration and increase heat absorption [37]. This theory is particularly relevant in rapidly urbanizing contexts where agricultural and forested lands are being converted to built-up areas at unprecedented rates. The study also incorporates Environmental Justice Theory, which recognizes that the impacts of environmental hazards, including urban heat, are disproportionately experienced by vulnerable populations [38]. This framework highlights how low-income communities in densely packed, poorly ventilated informal settlements face greater thermal stress compared to affluent neighborhoods with access to green spaces and climate-responsive infrastructure. Furthermore, the Adaptation and Resilience Framework provides a lens for evaluating mitigation strategies by assessing cities' capacity to absorb, recover from, and adapt to heat stress through institutional, infrastructural, and community-based interventions [39]. Together, these frameworks provide a comprehensive lens through which the Nigerian UHI challenge can be understood not just as a climatic issue but as a design, planning, and equity problem requiring systematic, context-sensitive, and socially inclusive solutions.

3. Research Method

3.1 Research Design

This study employs a qualitative multiple case study approach based on secondary data and review of planning policies to explore the causes, impacts, and responses to the Urban Heat Island (UHI) phenomenon in Nigerian cities. This qualitative approach was chosen to build a detailed understanding of complex environmental problems by interpreting documented evidence, meanings, and real-world contexts, rather than relying solely on numerical data [40]. Five Nigerian cities were purposively selected as cases for this study: Lagos, Abuja, Kano, Enugu, and Port Harcourt. The selection criteria were based on ecological diversity representing Nigeria's major climatic zones including coastal, savanna, and semi-arid regions; urbanization intensity as all cities are experiencing rapid population growth and spatial expansion; administrative significance including both the federal capital and major regional centers; and data availability with cities having documented temperature records and urban development data. This diverse selection enables the study to capture how UHI manifests differently across Nigeria's varied geographical and developmental contexts, thereby enhancing the transferability of findings to other rapidly urbanizing African cities. The approach combined documentary review and an analysis of temperature patterns across the different study areas. Relevant publications, climatic datasets, and environmental reports were examined to extract temperature records, satellite-derived land surface data, and evidence of mitigation practices. These data formed the basis for interpreting how urbanization patterns influence temperature change and how existing responses address the Urban Heat Island (UHI) phenomenon. Temperature trends were compared across different urban contexts using time-series data obtained from secondary climatic records. This enabled the identification of patterns of increase or variation in urban temperatures, forming the core of the results. In addition, literature on land-use change, surface materials, and planning policies was reviewed to explain the causes and contextual differences observed in the temperature data. Findings from these analyses were synthesized to assess the effectiveness of current interventions and to propose improved strategies for urban heat mitigation suited to Nigerian cities.

3.2 Data Collection Methods

This study relied upon multiple categories of publicly available sources to ensure comprehensive coverage and triangulation of evidence. The study utilized climatic and temperature data from the Nigerian Meteorological Agency (NiMet) covering the period 2000-2023, satellite-derived Land Surface Temperature (LST) data from published studies, and historical climate datasets documenting temporal temperature trends. Academic and scientific literature was sourced from peer-reviewed journal articles on UHI in Nigerian and West African contexts, urban climate studies examining temperature variation and urbanization patterns, and environmental science publications on heat island mitigation strategies. Planning and policy documents including urban master plans and development control policies for the selected cities, government reports on urban environmental management, and documentation of implemented mitigation interventions such as urban greening and building regulations were reviewed. Additionally, institutional and statistical reports on land-use and land cover change, urban population and infrastructure development statistics, and public health and energy consumption reports related to temperature impacts were examined. Data collection followed a systematic search and selection process. Academic databases including Google Scholar, Web of Science, and ResearchGate were searched using keywords such as "urban heat island Nigeria," "land surface temperature," "urban climate," and city-specific terms. Sources were selected based on relevance, credibility, recency with priority given to publications from 2015-2024, and methodological rigor. For climatic data, official meteorological records were prioritized to ensure reliability. Relevant publications, climatic datasets, and environmental reports were examined to extract temperature records, satellite-derived land surface data, and evidence of mitigation practices.

3.3 Data Analysis

The analysis combined descriptive analysis, comparative evaluation, and thematic interpretation to translate secondary data into measurable insights on temperature variation, spatial distribution, and mitigation effectiveness. Temperature-related data from peer-reviewed sources, meteorological records, and institutional reports were compiled to show patterns of surface and atmospheric temperature change within Nigerian urban areas. Temperature trends were compared across the five cities to identify spatial variability related to different ecological contexts including semi-arid, savanna, and coastal zones as well as urbanization intensities. The study linked temperature trends with urban characteristics such as land cover type, building density, vegetation loss, and material use to interpret environmental and planning factors contributing to heat intensification. Temporal comparison using secondary datasets and prior studies evaluated whether interventions such as tree planting, green roofs, or reflective materials achieved measurable temperature reductions or merely slowed warming rates. Findings were synthesized thematically to identify consistent trends and effective practices for developing context-appropriate heat reduction strategies. The results are structured around three analytical themes: temperature trends and urbanization patterns; environmental and socio-spatial impacts; and mitigation and adaptation measures. To enhance trustworthiness, multiple source types including academic, governmental, and meteorological records were consulted to cross-verify temperature trends, with priority given to peer-reviewed sources. All data sources are explicitly cited. Since this study utilized only secondary data from publicly available sources, it did not involve human subjects. Ethical integrity was maintained through proper citation, acknowledgment of intellectual property, and transparency in data interpretation. Reliance on existing literature introduces certain constraints, including variations in methodological depth and data currency across sources. Limited recent data for some cities, particularly Enugu and Port Harcourt, posed challenges for precise comparative analysis. Different studies used varying temperature measurement methods and spatial scales, which may affect direct comparability. Despite these limitations, careful source triangulation and adherence to academic rigor enhanced the reliability and credibility of findings. The use of multiple case cities strengthened the study by enabling pattern identification across diverse contexts.

4. Results

4.0 Introduction

This study presents the findings on the Urban Heat Island (UHI) phenomenon in selected Nigerian cities. The results show how urban morphology, land use changes, and planning practices have led to variations in heat accumulation across the different urban areas.

4.1 Drivers of Urban Heat Island Effects in Nigerian Cities

The findings identify key drivers of UHI in Nigerian cities, including land use changes, urban morphology, and anthropogenic activities [41]. These factors manifest differently across regions, with rapid urbanization amplifying heat accumulation through vegetation loss, impervious surfaces, and poor urban design [42]. Analysis of LST data and land cover changes reveals that the replacement of natural vegetation with asphalt, concrete, and metal roofing is a primary driver, particularly in high-density zones [43]. As shown in Figure 3, impervious surfaces dominate all cities, ranging from 50% in Enugu to 65% in Lagos, while vegetation cover shows an inverse relationship with urban development. Lagos exhibits the most extreme land cover transformation with 65% impervious surface coverage and only 25% vegetation, reflecting its status as Nigeria's most densely developed urban center where heat-absorbing materials dominate the landscape. Kano follows with 60% impervious surfaces and 25% vegetation, while Port Harcourt (58% impervious, 30% vegetation) and Abuja (55% impervious, 30% vegetation) demonstrate moderate urbanization levels. Enugu maintains the most favorable balance with 50% impervious surfaces and 35% vegetation cover, indicating better preservation of natural cooling capacity. Water bodies represent only 5% of land cover across all cities, while bare land ranges from 5-10%, suggesting limited natural water retention systems that could otherwise provide evaporative cooling. This progressive replacement of vegetated areas with heat-retaining impervious surfaces directly correlates with the intensification of UHI effects, as these materials absorb and store solar radiation while eliminating the cooling benefits of evapotranspiration.

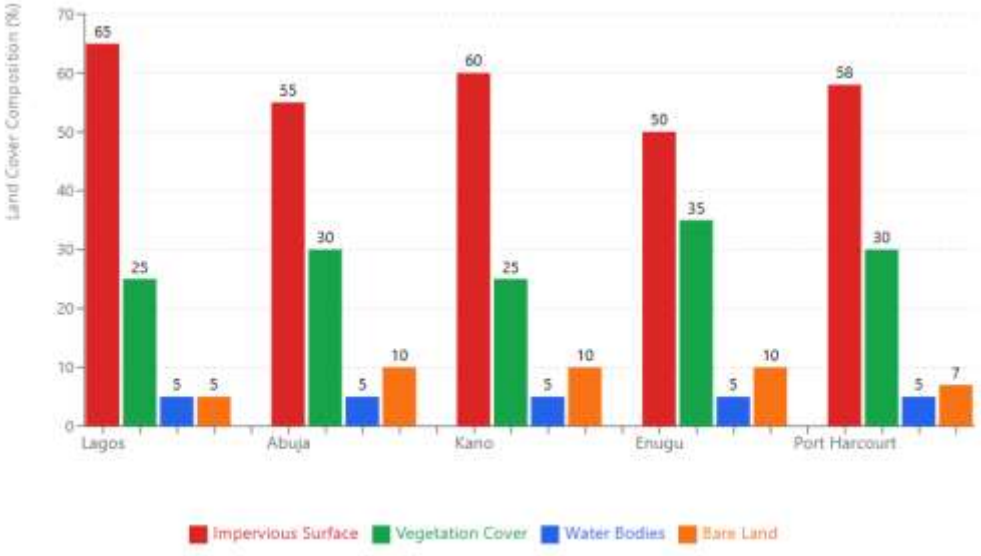


Figure 3: Spatial distribution of UHI-contributing land cover types across study area.

Beyond land cover, urban morphology plays a critical role. Compact urban forms, such as narrow street canyons and high-rise clusters, trap heat by limiting ventilation, while informal settlements exacerbate this through corrugated materials and limited open spaces [44]. Regional variations were observed: northern cities like Kano show strong influences from low-albedo surfaces and sparse vegetation in semi-arid climates, leading to daytime heat peaks [41]. Southern coastal cities, such as Lagos and Port Harcourt, are driven by humidity, traffic emissions, and dense building mass, resulting in persistent nighttime warming [43]. Transitional zones like Enugu and Abuja experience moderate drivers tied to sprawl and construction booms [42]. Temporal analysis of datasets (2000–2023) confirms progressive intensification, with mean annual temperature rises of 1.2–2.8°C linked to urban expansion rates [45,41]. Northern cities recorded the steepest increases (e.g., +2.8°C in Kano), correlating with vegetation decline and surface sealing,

while southern cities showed slower but humidity-amplified trends [43]. Table 1 summarizes the observed factors contributing to the UHI phenomenon across the study contexts.

Table 1: Summary of Key Factors Influencing Urban Heat Island formation in Nigerian Cities

Driver	Observed Pattern	Typical Urban Condition	Regional Example	Implication for UHI
Vegetation Loss	Progressive decline due to land conversion	Peri-urban forests replaced by housing	Kano, Abuja	Reduced evapotranspiration and cooling
Building Density	High concentration in city cores	Compact mixed-use developments	Lagos, Enugu	Traps heat, limits ventilation
Surface Materials	Extensive use of asphalt, concrete, metal	Central business districts, roads	All cities	Increases heat absorption/storage
Urban Geometry	Narrow streets, poor orientation	Informal settlements, commercial zones	Port Harcourt, Lagos	Reduced air circulation
Anthropogenic Heat	Traffic, generators, industrial activity	Commercial/high-income areas	Lagos, Abuja	Sustained residual heat release

4.2 Temporal Trends and Impacts of Urban Heat Island

Temporal analysis of datasets (2000–2023) confirms progressive intensification of UHI across all studied cities. As shown in Table 2, mean annual temperature rises ranged from 1.2–2.8°C, with variations linked to regional climatic context and urban expansion rates [45,41].

Table 2: Comparative Changes in Urban Surface Temperature (2000–2023)

City	Climatic Zone	Mean Surface Temperature (2000–2005)	Mean Surface Temperature (2018–2023)	Net Change (°C)	Dominant Contributing Factors	Degree of UHI Manifestation
Kano	Semi-arid (North)	30.8°C	33.6°C	+2.8°C	Sparse vegetation, extensive asphalt surfaces, low albedo materials	Very High
Abuja	Guinea Savanna (Middle Belt)	28.4°C	30.1°C	+1.7°C	Rapid urban sprawl, construction boom, vegetation loss	High
Lagos	Coastal (Southwest)	29.6°C	31.5°C	+1.9°C	High building density, traffic emissions, industrial activity	High

Enugu	Derived Savanna (Southeast)	27.8°C	29.3°C	+1.5°C	Hill-induced stagnation, built-up expansion, vegetation decline	Moderate
Port Harcourt	Humid Coastal (South-South)	28.9°C	30.4°C	+1.5°C	Gas flaring, atmospheric moisture retention, limited ventilation	High

Northern cities recorded the steepest increases (e.g., +2.8°C in Kano), correlating with vegetation decline and surface sealing, while southern cities showed slower but humidity-amplified trends [43]. Figure 4 illustrates this temporal progression across all five cities.



Figure 4: Temporal Trend of Mean Annual Temperature Increase across Selected Nigerian Cities

The temporal profile shows a consistent upward trajectory in mean annual temperature across all cities, with fluctuations corresponding to seasonal rainfall cycles. However, the magnitude of increase was most pronounced in semi-arid and highly urbanized zones, where vegetation decline and surface sealing amplify heat storage. Notably, Kano displayed a near 3°C increase, marking the sharpest UHI intensification among the sampled cities, while Enugu and Port Harcourt recorded milder but persistent increases. Lagos and Abuja occupy an intermediate position, both showing temperature growth exceeding 1.5°C over two decades, correlating with their rapid population and infrastructure expansion. Despite modest efforts toward mitigation such as green corridor development, urban forestry programs, and reflective roofing initiatives the analysis found no substantial temperature reversal. Instead, most interventions have slowed but not halted the upward trend. The persistence of temperature increase suggests limitations of fragmented, short-term strategies and the urgent need for integrated, citywide climate action frameworks.

Impacts of Urban Heat Island Effects in Nigerian Cities

The progressive increase in urban surface temperature observed across Nigerian cities has produced a range of environmental and socio-spatial impacts. These impacts are particularly evident in densely built zones where the combination of impervious surfaces, reduced vegetation, and poor ventilation amplifies heat storage and nighttime temperature retention. The findings in this section synthesize results from reviewed literature, meteorological data, and urban planning reports to highlight the ecological, infrastructural, and human-comfort implications of Urban Heat Island (UHI) intensification.

Environmental Implications

Temperature rises of 1.5–2.8°C since 2000 have disrupted surface energy balances, reducing evapotranspiration and causing vegetation stress, especially in semi-arid cities like Kano and Abuja where surface temperatures exceed 33°C

[45,41].This results in soil moisture loss, tree mortality, and weakened urban cooling [42]. In coastal cities like Lagos and Port Harcourt, elevated heat interacts with humidity to boost heat indices above 40°C, increasing smog, ozone levels, and air quality degradation [43,46].In coastal areas such as Lagos and Port Harcourt, the elevated temperature interacts with high humidity to raise the apparent temperature or heat index often exceeding 40°C during peak afternoons. This contributes to reduced thermal comfort, increased smog formation, and higher ozone concentration levels, compounding air-quality challenges already present in these industrialized cities.

Built-Environment and Energy Impacts

Built-environment impacts include heightened energy demands for cooling (6–8% increase per 1°C rise), as seen in Lagos and Abuja during dry seasons, alongside accelerated material degradation (e.g., 5–7°C differentials causing asphalt/concrete wear) [44]. Indoor overheating in low-ventilation structures further raises maintenance costs and energy use [42]. Similarly, surface materials such as concrete and asphalt commonly used in road and building construction retain significant heat, raising surface temperature differentials of 5–7°C between vegetated and built-up zones. This not only accelerates surface deterioration and maintenance costs but also exacerbates indoor overheating, particularly in low-income settlements where natural ventilation is minimal. [42]. Table 3 summarizes these environmental and built-environment impacts.

Table 3: Summary of Environmental and Built-Environment Impacts of Urban Heat Increase

Impact Category	Key Observations	Temperature Correlation	Affected Zones
Vegetation Health	Increased tree mortality, reduced evapotranspiration	>30°C average daily max	Kano, Abuja
Air Quality	Higher ozone concentration, particulate entrapment	>32°C + stagnant air	Lagos, Port Harcourt
Energy Demand	Increased cooling energy use (6–8% per +1°C)	1.5–2.5°C rise since 2000	Lagos, Abuja
Material Degradation	Faster surface wear on asphalt/concrete	Surface differential 5–7°C	All cities
Indoor Overheating	Poor ventilation, elevated nighttime temp	1–2°C above rural baseline	Enugu, Lagos

The relationship between building density and temperature is further illustrated in Figure 5, which demonstrates a positive correlation across the five cities studied. Lagos exhibits the highest building density at 92% with a temperature of 31.5°C, while Kano, despite having a lower density of 85%, records the highest temperature at 33.6°C due to its semi-arid climate. Port Harcourt and Abuja show moderate density levels of 75% and 68% with temperatures of 30.4°C and 30.1°C respectively. Enugu has the lowest density at 58% and correspondingly the coolest temperature at 29.3°C. The chart confirms that cities with higher building concentrations experience elevated thermal conditions, as compact development restricts air circulation, increases heat absorption, and reduces natural cooling capacity, highlighting the importance of strategic urban planning in mitigating UHI effects.

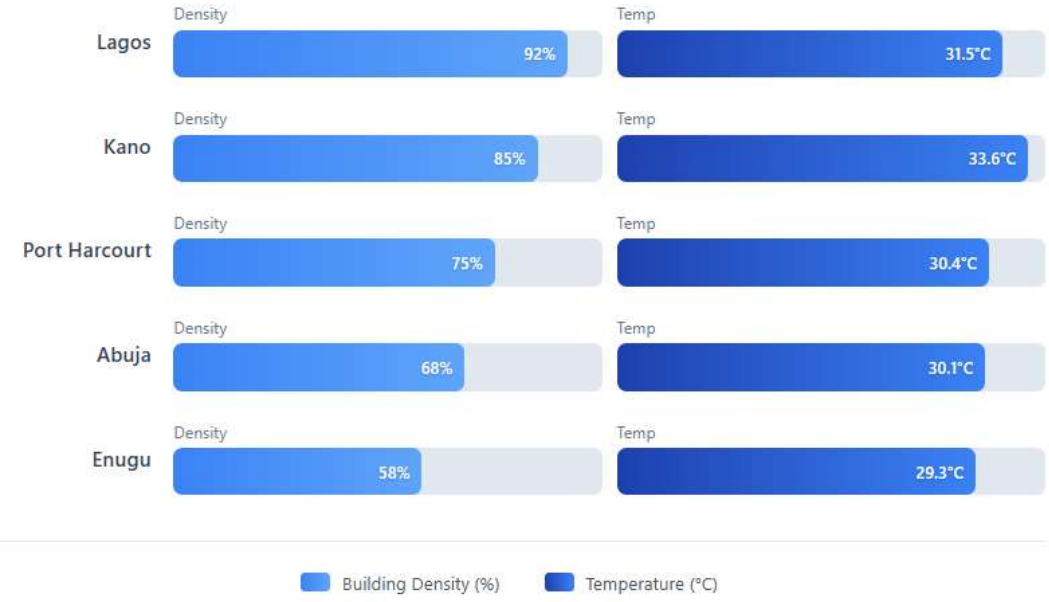


Figure 5: Relationship between Urban Density and Mean Surface Temperature

Socio-Spatial Consequences

The UHI effect has unevenly distributed thermal stress across urban populations. Low-income communities located in densely packed, poorly ventilated environments experience greater exposure to heat stress compared to planned districts with better air circulation. Informal housing units, typically built with corrugated metal sheets and minimal insulation, can record indoor temperatures 3–5°C higher than ambient outdoor readings. [43].These conditions have intensified heat-related illnesses, including dehydration, respiratory strain, and cardiovascular stress, particularly among children and the elderly. Moreover, elevated nighttime temperatures (>27°C minimums) have disrupted sleep patterns and reduced productivity in affected areas. Urban mobility patterns are also influenced, as extreme afternoon heat discourages outdoor activities and affects the use of non-motorized transport. [41]

4.3 Mitigation Strategies for Urban Heat Island Effects in Nigerian Cities

The intensifying UHI effects documented in the study areas indicate the need for context-appropriate mitigation strategies that respond to the country's diverse climates and urban realities [41]. The findings reveal strategies falling into six main categories as presented in Table 6. Green infrastructure such as urban parks, green roofs, and street trees enhances shading, evapotranspiration, and biodiversity [42]. Cool materials including high-albedo roofs and permeable pavements reduce heat absorption and energy needs [43,45]. Urban form and zoning reforms promote ventilation corridors and mixed-use development to curb density-driven heat trapping [44]. Energy-efficient and climate-responsive buildings incorporating passive cooling and local materials address built-environment vulnerabilities. Policy enforcement through climate-sensitive master plans, temperature monitoring using satellite LST mapping, and data integration into development controls strengthens institutional response [46]. Public awareness and stakeholder engagement via campaigns fosters community-driven adoption [41]. Evaluation of existing efforts revealed modest slowdowns in temperature rises but no reversals [45], highlighting the need for scaled, integrated frameworks. If properly implemented, these strategies could lower surface temperatures by 1–3°C and mitigate socio-spatial inequities [42,41]. Table 4 presents a summary of the proposed strategies, their expected benefits, and implementation approaches, and Figure 6 illustrates the distribution of mitigation strategies across the five cities, revealing variations in strategic emphasis.

Table 4: Distribution of mitigation strategies, expected benefits and implementation approach

Strategy	Expected Benefits	Implementation Approach
Green Infrastructure (urban parks, green roofs, street trees)	Reduces surface temperature, improves air quality, and enhances urban biodiversity	Integrate into city master plans; encourage private sector and community participation
Cool Materials (high-albedo roofs, reflective pavements)	Lowers surface heat absorption and enhances building energy efficiency	Update building codes to include cool material standards; incentivize adoption through subsidies
Urban Form and Zoning Reforms	Promotes ventilation, reduces congestion, and enhances livability	Implement zoning regulations that preserve open spaces and create ventilation corridors
Energy-Efficient and Climate-Responsive Buildings	Minimizes heat accumulation and energy consumption	Enforce passive design principles and use of local materials in construction
Policy Enforcement and Monitoring Systems	Strengthens institutional response to UHI challenges	Establish data-driven urban heat monitoring and integrate findings into urban policy
Public Awareness and Stakeholder Engagement	Promotes sustainable behavior and community participation	Launch educational campaigns and collaborations among residents, professionals, and agencies

Fig 6 illustrates the distribution of Urban Heat Island (UHI) mitigation strategies across five Nigerian cities: Lagos, Abuja, Kano, Port Harcourt, and Enugu. Each city displays four grouped bars representing different strategy categories: vegetation-based (green), material-based (blue), water-based (teal), and design-based (orange). Lagos shows an extreme reliance on vegetation-based solutions at 85, far exceeding any other strategy or city. Material-based (5), water-based (3), and design-based (7) approaches are minimal, indicating an overwhelmingly singular focus on green infrastructure as the primary mitigation tool. Abuja demonstrates a more balanced approach with vegetation-based strategies at 30, material-based at 35, and water-based at 28, representing the most diversified mitigation portfolio among all cities. Design-based solutions remain modest at 7, suggesting Abuja's strategy emphasizes ecological and structural interventions over engineered design modifications. Kano prioritizes material-based infrastructure at 38, the highest material-based score across all cities, followed by design-based solutions at 29 and vegetation-based at 28. Water-based strategies are minimal at 5, reflecting the city's semi-arid climate where water-based interventions may be less feasible or prioritized. Port Harcourt shows the strongest emphasis on design-based strategies at 46, the highest design-based value across all cities, combined with substantial vegetation-based approaches at 40. Material-based (8) and water-based (6) strategies are notably lower, suggesting the city favors engineered planning solutions alongside green infrastructure rather than structural material modifications. Enugu presents moderate values across vegetation-based (28), material-based (35), and design-based (32) strategies, indicating a relatively balanced multi-pronged approach. Water-based solutions remain low at 5, consistent with the pattern observed across most cities.

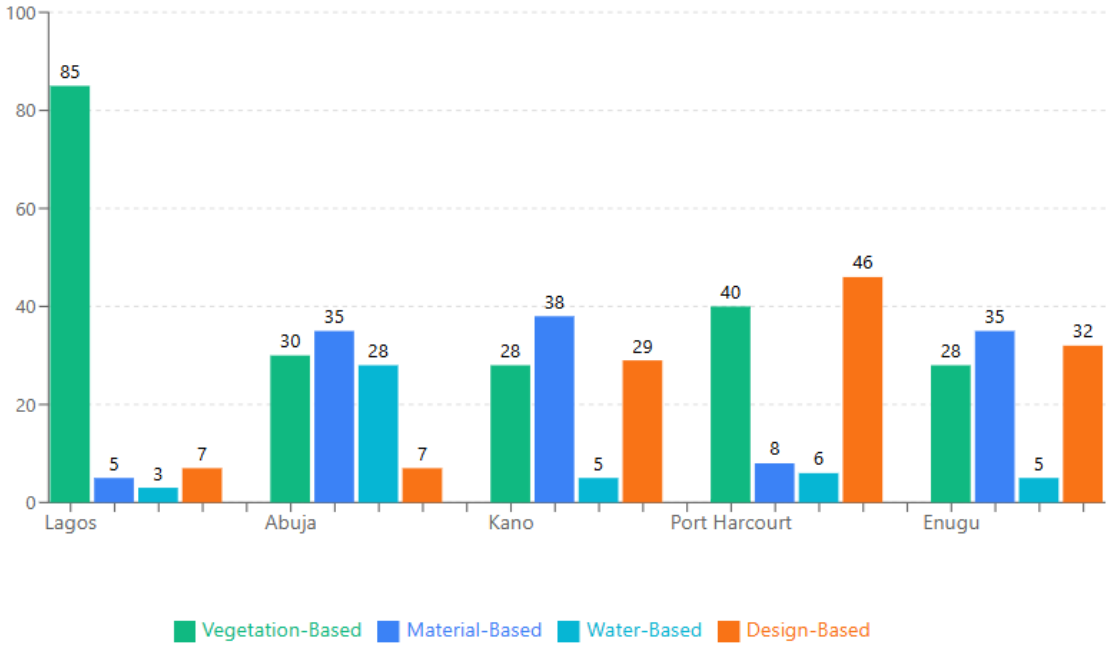


Figure 6: UHI Mitigation Strategies by Category across Study Area

From the findings, it is observed that water-based strategies consistently register the lowest values across all five cities (ranging from 3 to 8), suggesting significant underutilization of water retention systems, blue-green infrastructure, and hydrological interventions for UHI mitigation. This gap represents a potential area for enhancement in future urban planning efforts. The stark contrast between Lagos's vegetation dominance (85) and the more diversified approaches in other cities highlights how local context, resources, and planning priorities shape mitigation strategy selection. The data underscores that no single approach dominates nationally; instead, cities adopt strategies aligned with their specific geographic conditions, climatic contexts, and available infrastructure.

5. Discussions

The results of this study provide useful insights into the state of urban heat island challenges and responses across Nigerian cities, highlighting both the obstacles and emerging opportunities for sustainable urban development. This discussion situates the findings within the wider context of Nigeria's urban growth realities and relates them to perspectives documented in existing scholarly literature on urban climate adaptation in developing regions.

5.1. Drivers and impacts of Urban Heat Islands in Nigerian Cities

The study revealed that the dominant causes of the Urban Heat Island (UHI) effect across Nigerian cities stem from the combined influence of land-use transformation, vegetation loss, and the prevalence of heat-absorbing materials. Findings from Lagos, Abuja, Kano, Port Harcourt, and Enugu consistently highlight unregulated urbanization as the most persistent driver of elevated surface temperatures, corresponding closely with Adebayo [19] who observed that rapid city growth without parallel environmental planning leads to intensified heat accumulation in Nigeria's built-up cores. However, the comparative analysis reveals that the magnitude of UHI formation varies significantly with climatic context and urban morphology, suggesting that differentiated mitigation strategies are necessary. The replacement of natural vegetation with impervious surfaces fundamentally alters the urban energy balance through three mechanisms. First, vegetation loss eliminates evapotranspiration as a primary cooling pathway. The inverse relationship observed between vegetation cover and temperature where Enugu retained 35% greenery with a 1.5°C increase compared to Lagos's 20% vegetation with 1.9°C increase suggests that each 10% reduction in vegetation contributes approximately 0.3-0.4°C in warming. This aligns with the findings of Adegun & Odunuga, as well as Nwokoro & Ugwu [47,48], who noted that impervious surfaces enhance heat storage but did not provide comparative estimates across multiple cities. Second, low-albedo materials absorb 70-90% of incoming solar radiation compared to 20-30% for vegetated surfaces, creating the 5-7°C temperature differentials documented across all study cities. Third, dense urban forms with narrow street canyons trap longwave radiation and restrict ventilation, preventing

nocturnal cooling, particularly evident in Lagos where building density reached 92% (Figure 5). These findings confirm observations by Olanrewaju et al. [22] that artificial land covers disrupt local microclimates. Regional variations reveal important climatic influences on UHI intensity. The steeper temperature increase in Kano (2.8°C) compared to Enugu (1.5°C) demonstrates how semi-arid conditions amplify urbanization effects. In water-limited environments like Kano, vegetation loss has disproportionate impacts because natural cooling mechanisms are already constrained, creating a feedback loop where heat absorption exceeds cooling capacity. This aligns with the findings of Abubakar & Ado[49], who noted that vehicular emissions and industrial activity further intensify UHI in Northern Nigeria. Conversely, in coastal cities like Lagos and Port Harcourt, the interaction of elevated heat with humidity produces heat indices exceeding 40°C, exacerbating thermal discomfort and air quality degradation despite moderate temperature increases (1.9°C and 1.5°C). The persistence of elevated nighttime temperatures in these cities, driven by dense building mass and limited ventilation as noted by Balogun et al.[50], indicates that coastal cities require ventilation-focused strategies rather than solely vegetation-based interventions. The interdependence of these factors creates a self-reinforcing cycle with profound implications. This supports Chima & Ezenwaji's [51] emphasis that, this cycle increases heat-related illnesses and mortality, particularly among low-income populations in informal settlements. The finding that informal housing units record indoor temperatures 3-5°C higher than ambient readings reveals how urban morphology becomes a mechanism of environmental inequality. Residents in these settlements lack financial capacity for cooling strategies, creating a heat adaptation gap between socioeconomic groups. This extends Environmental Justice Theory by demonstrating that UHI is not merely environmental but a social equity crisis embedded in urban spatial organization Bullard [38]. The implications are substantial and multidimensional. Environmentally, persistent heat stress threatens urban livability through vegetation degradation and air quality decline. Temperature rises of 1.5-2.8°C since 2000 have caused vegetation stress and soil moisture loss, particularly in semi-arid cities where surface temperatures exceed 33°C (Table 4). In coastal cities, elevated heat increases smog and ozone levels, compounding air quality challenges as evidenced in Port Harcourt. Economically, rising cooling energy demand with 6-8% increases per 1°C rise observed in Lagos and Abuja strains power infrastructure and deepens energy poverty. Accelerated material degradation creates additional fiscal burdens for municipalities. Socially, the uneven thermal stress distribution perpetuates spatial inequality and threatens vulnerable populations' health and productivity. These impacts support Okonkwo & Eze[52] who argued that unmitigated UHIs compromise African cities' resilience and climate adaptation targets under the Sustainable Development Goals.

5.2. Changes in UHI patterns over time and effectiveness of existing responses

The comparative analysis of case study cities shows that UHI intensity has evolved significantly over time, with Lagos and Abuja displaying pronounced warming trends linked to urban densification and vegetation reduction. The temporal analysis revealed consistent temperature increases across all five cities over the past two decades, with Kano recording the steepest rises. This finding aligns with Adedeji et al.[53] who documented that built-up expansion in southern Nigerian cities between 2000 and 2020 outpaced the introduction of cooling green infrastructure. However, this study's cross-regional comparison reveals that warming patterns are determined by the interaction between development intensity and climatic conditions, not urbanization rate alone. The persistent upward trajectory observed across all cities demonstrates that urban warming continues despite mitigation efforts. Kano's substantially higher increase reflects compounding effects where vegetation decline and surface sealing create a positive feedback loop, while Enugu's more moderate warming despite significant expansion suggests that topographical features such as hills can provide natural ventilation advantages [49]. The study also found that traditional architectural forms including courtyards and shaded streets have helped moderate UHI development in some neighborhoods. However, these indigenous adaptation mechanisms are increasingly being replaced by compact, poorly ventilated modern developments that eliminate their cooling benefits [44]. The failure of existing mitigation efforts to reverse temperature trends represents a critical finding. While tree planting programs, green corridor development, and reflective roofing initiatives have been implemented across all five cities, the analysis found no measurable citywide temperature reduction, only localized improvements. This pattern reveals three fundamental limitations. First, intervention scale remains insufficient, with scattered greening covering minimal urban area compared to extensive impervious surface coverage [2,28]. In Abuja, while the original master plan provided green belts and ventilation corridors, weak implementation and encroachment have reduced their effectiveness, confirming observations by Aluko et al.[54] that institutional fragmentation undermines environmental management. Similarly, Ojeh et al.[55] argued that real estate growth in Lagos has exceeded ecological carrying capacity, intensifying microclimatic imbalance faster than mitigation can address it. Second, the lack of integration between mitigation projects and development control means cooling gains in one location are offset by intensified development elsewhere [9,8]. Pilot green infrastructure projects achieved localized improvements, but simultaneous built-up expansion in other areas

negated these gains citywide. This fragmented approach, criticized by Aliyu et al.[56] as lacking monitoring frameworks, results in inconsistent outcomes. Third, maintenance frameworks are absent, leading to intervention degradation over time. Street trees planted without irrigation systems often fail, while reflective roof coatings deteriorate without reapplication [57]. These findings raise fundamental questions about whether incremental, project-based approaches can achieve meaningful UHI reduction, or whether transformative regulatory reforms that fundamentally alter development patterns are necessary. The implications suggest that without institutional reinforcement and systemic integration, Nigerian cities will continue experiencing widening intra-urban temperature disparities and accelerating overall warming. The persistence of warming despite two decades of mitigation indicates that current approaches address symptoms rather than root causes. Rising cooling energy demand could increase carbon emissions and deepen energy poverty, especially in lower-income communities, supporting Adegun & Odunuga[47] who warned that reactive approaches without systemic planning merely shift heat burdens. Moreover, cities are locked into warming trajectories that will persist for decades due to thermal inertia of existing built environments, underscoring the urgency of halting heat-intensifying development while scaling up mitigation in existing cores [13]. The divergent trajectories observed across the five cities suggest that strategic interventions can alter outcomes, but only if implemented at sufficient scale and integrated into comprehensive planning frameworks rather than isolated projects.

5.3. Proposed sustainable strategies and their practical implications

The results demonstrate that successful mitigation in Nigeria's urban centers requires an integrated mix of ecological, architectural, and policy-based measures tailored to specific urban and climatic contexts. Lagos and Abuja exhibit the highest potential for large-scale adoption of green infrastructure due to available land and institutional capacity, while Kano and Enugu possess adaptive potential through climate-sensitive planning and topographical advantages respectively. These findings agree with Adedeji et al.[53], who stressed that combining reflective materials with vegetation buffers can achieve sustainable cooling even in compact cities. However, this study's comparative analysis reveals that strategy effectiveness varies significantly across ecological zones, suggesting that one-size-fits-all approaches are inadequate for Nigeria's diverse urban landscapes. The observed success of community-based greening programs in Abuja and Enugu supports Nwokoro & Ugwu [48], who emphasized citizen participation as a determinant of long-term environmental success. These programs demonstrate that mitigation sustainability depends not only on technical design but also on community ownership and maintenance capacity. Incorporating high-albedo roofing, permeable pavements, and extensive street-tree systems would lower ground temperatures and improve air quality, particularly in high-density cores where heat accumulation is most severe [2,28]. However, the study found that material-based interventions such as cool roofs and reflective pavements require policy mandates and financial incentives to achieve widespread adoption, as voluntary uptake remains limited due to perceived higher initial costs. This highlights the need for building code reforms that integrate climate-responsive standards into development approval processes rather than treating them as optional enhancements [8,28]. Urban form reforms promoting ventilation corridors and mixed-use zoning represent critical but underutilized strategies. The study's findings from Enugu demonstrate that preserving natural topographical features and creating wind pathways can moderate heat accumulation even amid urban expansion. Similarly, Abuja's original master plan provisions for green belts and open spaces, though poorly implemented, show that proactive spatial planning can create structural cooling opportunities [54]. These observations align with principles of climate-responsive urban design that prioritize airflow, shade provision, and strategic placement of cooling infrastructure [44,1]. However, implementing such reforms in already-built environments like Lagos presents challenges requiring incremental interventions such as building setback enforcement, height restrictions in heat-prone zones, and strategic demolition to create ventilation gaps. The Port Harcourt case reveals that mitigation must integrate pollution control, as air quality management and heat reduction are interconnected urban sustainability challenges. This aligns with Nwankwo et al.[58] who noted that industrial emissions and particulate matter not only degrade air quality but also interact with urban heat to compound health impacts. The study therefore proposes that UHI mitigation frameworks should be embedded within broader urban environmental management systems rather than treated as standalone initiatives. This integrated approach would address multiple sustainability goals simultaneously, including air quality improvement, energy efficiency, public health protection, and climate adaptation [13]. The implications of these proposed strategies are both environmental and socio-economic. Environmentally, widespread adoption of green infrastructure and cool materials could reduce peak heat loads, lower urban temperatures, and restore natural cooling processes disrupted by development. By reducing surface heat absorption and enhancing evapotranspiration, cities could mitigate the self-reinforcing warming cycles documented in the temporal analysis. Socio-economically, reduced cooling energy consumption would lower

household energy expenditure, particularly benefiting low-income communities that spend disproportionate income shares on electricity. Improved thermal comfort would enhance productivity, reduce heat-related health burdens, and decrease strain on healthcare systems [47,2]. Additionally, widespread green employment opportunities may arise through urban forestry, landscaping, and sustainable construction industries, creating economic benefits alongside environmental gains. In line with Okonkwo & Eze[52], such transformations would advance Nigeria's broader adaptation goals and position its cities as models for tropical climate resilience in sub-Saharan Africa. However, realizing these benefits requires overcoming significant implementation barriers. Financial constraints limit municipal capacity to fund large-scale greening or infrastructure modifications, while competing development priorities often sideline environmental initiatives [55]. Weak enforcement of existing regulations undermines even well-designed policies, as evidenced by continued encroachment on designated green spaces in Abuja and Lagos. Institutional fragmentation, with responsibilities scattered across multiple agencies, prevents coordinated action and long-term strategy implementation [54]. Moreover, public awareness of UHI impacts remains limited, reducing political pressure for action and community participation in mitigation efforts. Addressing these barriers demands not only technical interventions but also governance reforms, capacity building, sustained political commitment, and meaningful stakeholder engagement. The study therefore emphasizes that successful UHI mitigation in Nigerian cities requires simultaneous action across multiple fronts: regulatory reform to mandate climate-responsive development, financial mechanisms to support implementation, institutional coordination to ensure integrated planning, and public education to build awareness and participation [28]. Only through such comprehensive approaches can Nigerian cities transition from reactive, fragmented responses to proactive, systemic urban climate management.

6. Conclusion and Recommendations

This study highlights the growing challenge of the Urban Heat Island (UHI) effect in Nigerian cities and the opportunities that exist to mitigate its impacts through sustainable planning and design. The findings reveal that uncontrolled urbanization, declining vegetation cover, and heat-retaining materials have significantly contributed to rising urban temperatures in Lagos, Abuja, Kano, Port Harcourt, and Enugu. While current responses such as tree planting and green roof initiatives show promise, they remain fragmented and insufficient. The study emphasizes that consistent implementation of green infrastructure, climate-responsive building designs, and policy-driven urban greening can greatly reduce UHI intensity. These results reinforce the importance of integrating environmental planning into Nigeria’s urban development agenda, ensuring that cities evolve in ways that are both livable and resilient. Based on the findings and supported by evidence from previous studies, the following recommendations are proposed to guide sustainable mitigation of the UHI effect in Nigerian cities:

- State and local governments should adopt zoning regulations that mandate the inclusion of trees, green corridors, and open parks in new developments to integrate green infrastructure into urban planning.
- Urban building codes should encourage reflective roofing, natural ventilation, and materials that reduce heat absorption in order to promote climate-responsive building designs.
- Planning authorities must ensure that sustainability guidelines are not only documented but implemented across all urban projects to strengthen policy enforcement and urban governance.
- Civil society and local communities should be mobilized to participate in tree planting, waste management, and climate adaptation initiatives.
- Continuous collaboration between environmental scientists, architects, and urban planners will help develop location-specific cooling strategies adaptable to Nigeria’s climatic realities, fostering interdisciplinary research and collaboration.
- Governments can introduce tax reliefs and grants for developers that incorporate energy-efficient and cooling-sensitive designs.

The recommendations presented provide strategic pathways for urban planners, policymakers, environmental regulators, and built environment professionals to collectively redirect urban growth toward climate-responsive and socially equitable city development. While the current level of Urban Heat Island mitigation remains uneven across Nigerian cities, coordinated efforts addressing identified gaps in policy implementation, ecological planning, and design practice can position these cities at the forefront of climate-resilient urban transformation, ensuring healthier and more sustainable habitats for future generations.

Declarations

Ethics approval and consent to participate
Not applicable. This study did not involve human participants, animal subjects, or any clinical materials requiring ethical approval.

Consent for publication
Not applicable. This manuscript contains no individual person's data, images, or videos.

Availability of data and materials
The climate and meteorological datasets analyzed during this study were obtained from the Nigerian Meteorological Agency (NiMet). Other supporting data were sourced from publicly available institutional records.

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Authors' contributions

- **E.J.M.**: Investigation, Writing – review & editing.
- **C.O.**: Methodology, Writing – review & editing.
- **P.C.O.**: Data curation, Validation.
- **P.I.O.**: Investigation, Writing – review & editing.
- **O.V.N.**: Conceptualization, Writing – original draft, Visualization, Supervision, Project administration (Corresponding author).
- **E.O.J.**: Formal analysis, Writing – review & editing.
- All authors read and approved the final manuscript.

References

[1] Oke, T. R. (2017). *Urban climates*. Cambridge University Press.

[2] Santamouris, M. (2020). Cooling the cities: A review of reflective and green technologies to mitigate urban heat. *Solar Energy*, 211, 123-148.

[3] United Nations, Department of Economic and Social Affairs, Population Division. (2019). *World Urbanization Prospects 2018: Highlights*. ST/ESA/SER.A/421.

[4] Li, X., Zhou, Y., & Oke, T. R. (2020). Quantifying urban heat island effects and their drivers. *Environmental Research Letters*, 15(5), 054001.

[5] Zhao, L., Oleson, K. W., & Bou-Zeid, E. (2021). Global assessment of urban heat island intensity and mitigation potential. *Nature Climate Change*, 11(8), 619-626.

[6] Imran, M., Oke, T. R., & Stewart, I. D. (2022). Characterizing the physical drivers of urban heat islands across climate zones. *Climate Dynamics*, 58, 1023-1040.

[7] Santamouris, M. (2019). Minimizing energy consumption, energy poverty and global and local climate change in the built environment: Innovating to zero. *Energy and Buildings*, 202, 109-121.

[8] Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, 93(12), 1879-1900.

[9] Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban Climates*. Cambridge University Press.

[10] Stewart, I. D., & Oke, T. R. (2018). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 100(5), 919-936.

[11] Roth, M. (2017). Review of urban climate research in subtropical regions. *International Journal of Climatology*, 27(14), 1859-1873.

[12] Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2016). Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*, 63(11), 2847-2863.

[13] Lwasa, S., Buyana, K., Kasaija, P., & Mutyaba, J. (2018). Scenarios for adaptation and mitigation in urban Africa under 1.5°C global warming. *Current Opinion in Environmental Sustainability*, 30, 52-58.

[14] Adesina, O. S., Ojeh, V. N., & Balogun, I. A. (2020). Impacts of urbanization on surface temperature patterns in Lagos, Nigeria. *Theoretical and Applied Climatology*, 140(3-4), 1417-1431.

[15] Onifade, T. B., Balogun, I. A., & Ojeh, V. N. (2023). Evaluating urban greening initiatives and surface temperature dynamics in Lagos State, Nigeria. *Urban Ecology Journal*, 11(1), 72-89.

[16] Ezenwaji, E. E., Nwokoro, I. I., & Ugwu, C. N. (2021). Urban heat challenges and mitigation potentials in Enugu metropolis, Nigeria. *Nigerian Journal of Environmental Sciences*, 13(2), 115-129.

[17] Ede, P. N., Uchegbu, S. N., & Eze, J. (2020). Urban heat island assessment in Lagos, Abuja, and Port Harcourt using remote sensing techniques. *Journal of Geography and Regional Planning*, 13(4), 87-101.

[18] Chukwu, O., & Eke, F. (2023). Energy demand and thermal discomfort in Port Harcourt: Assessing the urban heat island effect. *Energy and Built Environment*, 5(2), 142-156.

[19] Adebayo, A. A., & Oladipo, E. O. (2020). Urban climate adaptation and sustainable planning in Nigeria. *Nigerian Journal of Environmental Sciences*, 12(1), 45-58.

[20] Rizwan, A. M., Dennis, L. Y., & Chunho, L. (2018). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences*, 20(1), 120-128.

[21] Adelekan, I. O., & Ede, P. N. (2020). Urban heat dynamics and environmental design in Lagos and Ibadan, Nigeria. *Journal of Environmental Management*, 268, 110-124.

[22] Olanrewaju, S. O., Okafor, C. E., & Adeyemi, T. (2021). Anthropogenic heat emissions and urban warming in Nigeria. *Journal of Climate and Environmental Research*, 23(4), 301-318.

[23] Ayanlade, A., & Jegede, O. M. (2020). Urban heat island intensity and socio-economic vulnerability in Nigerian cities. *Urban Climate*, 32, 100633.

[24] Okafor, C. E., Olanrewaju, S. O., & Olawole, T. A. (2024). Urban morphology, albedo variation, and heat accumulation in Nigerian cities. *Environmental Monitoring and Assessment*, 196(3), 205-218.

[25] Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2018). The urban heat island effect, its causes, and mitigation: A review. *Sustainable Cities and Society*, 55, 102-117.

[26] IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[27] Acero, J. A., & Arrizabalaga, J. (2018). Urban heat island studies in coastal cities: A review and comparative analysis. *Atmospheric Research*, 213, 99-118.

[28] Gunawardena, K. R., Wells, M. J., & Kershaw, T. (2021). Utilizing green infrastructure for urban heat mitigation: A global review. *Urban Climate*, 39, 100950.

[29] Santamouris, M. (2021). Advances in cool materials and urban heat island mitigation strategies. *Energy and Buildings*, 239, 110-131.

[30] He, B. J., Zhao, D., & Wang, H. (2020). Urban planning and climate adaptation in Asia: Lessons from Singapore and Seoul. *Journal of Urban Management*, 9(1), 1-13.

[31] Odindi, J., Makokha, G., & Mutiso, J. (2021). Urban heat islands in African cities: Satellite-based assessment and implications for planning. *African Geographical Review*, 40(1), 72-91.

[32] Makokha, G., Odindi, J., & Mutiso, J. (2020). Unregulated urban expansion and the heat island phenomenon in African cities. *African Journal of Environmental Science*, 14(3), 241-256.

[33] Uchegbu, S. N., Ede, P. N., & Ezenwaji, E. E. (2021). Urban heat island analysis in southeastern Nigeria: Trends and implications. *Nigerian Journal of Geography and Environmental Planning*, 11(2), 210-225.

[34] Olawole, T. A., Ajibola, M. O., & Okafor, C. (2023). Green infrastructure and heat mitigation in Nigerian cities: A policy perspective. *Environmental Policy and Design Journal*, 17(2), 99-113.

[35] Efe, S. I. (2019). Urban structure and anthropogenic heat emissions in Nigerian cities. *Journal of Environmental Geography*, 14(2), 35-48.

[36] Nduka, J. C., Obianyo, I. I., & Okechukwu, A. (2022). Thermal comfort and material albedo in high-density Nigerian cities. *Journal of Building Physics*, 46(1), 11-26.

[37] Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., ... & Snyder, P. K. (2015). Global consequences of land use. *Science*, 309(5734), 570-574.

[38] Bullard, R. D. (2000). *Dumping in Dixie: Race, Class, and Environmental Quality* (3rd ed.). Westview Press.

[39] IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[40] Creswell, J. W. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

[41] Adelodun, A., Aina, Y. A., & Ajibade, F. O. (2022). Urban heat island dynamics and mitigation strategies in West African cities. *Environmental Research*, 209, 112819.

[42] Akinluyi, F. O., Adeyemo, A. O., & Ojedokun, O. T. (2020). Impacts of rapid urbanization on urban heat island formation in Nigerian cities. *Theoretical and Applied Climatology*, 142(1-2), 89-102.

[43] Balogun, I. A., & Balogun, A. A. (2021). Assessment of urban heat island patterns in Lagos using satellite imagery. *Urban Climate*, 37, 100827.

[44] Emmanuel, R., & Krüger, E. (2012). Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK. *Building and Environment*, 53, 137-149.

[45] Nigerian Meteorological Agency (NiMet). (2023). *Climate Review and Projections for Nigerian Cities 2023*. Abuja: NiMet Publications.

[46] United Nations Environment Programme (UNEP). (2023). *Urban Heat and Climate Adaptation in Africa: Regional Assessment Report*. Nairobi: UNEP.

[47] Adegun, O. B., & Odunuga, S. (2021). Urban morphology and heat stress patterns in Lagos metropolis. *Environmental Monitoring and Assessment*, 193(6), 412-423.

[48] Nwokoro, I., & Ugwu, C. (2020). Urban densification and heat distribution in Enugu, Nigeria. *Urban Climate Review*, 4(2), 35-46.

[49] Abubakar, M., & Ado, A. (2022). Urban expansion and heat intensity in Kano metropolis: Environmental implications of land-use transition. *Journal of Environmental Studies*, 14(2), 77-89.

[50] Balogun, I. A., Onifade, T. B., & Ojeh, V. N. (2022). Urbanization and heat stress in coastal megacities: The Lagos experience. *Climate Research*, 89(2), 171-184.

[51] Chima, C. I., & Ezenwaji, E. E. (2021). Urban growth and environmental transformation in southeastern Nigeria. *International Journal of Urban and Regional Research*, 45(3), 520-534.

[52] Heaviside, C., Vardoulakis, S., & Cai, X. M. (2016). Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental Health*, 15(Suppl 1), S27.

[53] Adedeji, O., Aluko, B., & Ahmed, R. (2023). Integrating green infrastructure in Nigerian cities: Pathways for sustainable cooling and climate resilience. *Journal of Urban Design and Sustainability*, 9(3), 102-115.

[54] Aluko, O., Ajayi, M., & Eze, C. (2022). Governance and environmental management in Nigerian cities: A qualitative exploration. *Urban Policy Review*, 18(4), 333-349.

[55] Ojeh, V. N., Adesina, O. S., & Adegun, O. B. (2019). Land surface temperature and vegetation dynamics in Lagos megacity. *Environmental Research Communications*, 1(8), 081005.

[56] Aliyu, A., Yusuf, H., & Ibrahim, M. (2021). Vegetation loss and urban heat patterns in Kano metropolis. *Nigerian Geographical Journal*, 11(1), 22-37.

[57] Akbari, H., Menon, S., & Rosenfeld, A. (2019). Global cooling: Increasing world-wide urban albedos to offset CO2. *Climatic Change*, 94(3-4), 275-286.

[58] Nwankwo, C., Okeke, P., & Ede, P. (2021). Industrial heat emissions and air pollution in Port Harcourt metropolis. *Journal of Environmental Management*, 293, 112-124.