

Urban Heat Islands in Nigerian Cities: Modelling Thermal Amplification and Mitigation Pathways for Climate-Resilient Urban Development

Olusola Tosin Kolebaje*

Department of Physics, Adeyemi Federal University of Education, Ondo.
olusolakolebaje2008@gmail.com

Highlights

- Urban Heat Island intensity in Nigerian cities ranges between 3.2°C and 4.3°C, with Lagos showing the highest amplification.
- Thermal amplification is primarily driven by high building density, reduced vegetation, low-albedo materials, and anthropogenic heat emissions.
- Increasing vegetation cover can reduce urban temperatures by up to 1.6°C, highlighting the effectiveness of urban greening.
- The use of reflective (high-albedo) materials can achieve temperature reductions of approximately 0.9–1.1°C across cities.
- Combined mitigation strategies significantly reduce UHI intensity, with reductions exceeding 50% in highly urbanised areas.

Abstract

Rapid urbanisation in Nigeria has transformed natural landscapes into densely built environments, significantly altering local thermal dynamics and contributing to the emergence of Urban Heat Islands (UHI). This study investigates the formation and intensity of UHI in selected Nigerian cities through a modelling framework grounded in surface energy balance theory and urban structural characteristics. By examining the interaction between building density, vegetation cover, surface reflectivity, and anthropogenic heat emissions, the study quantifies the extent of temperature amplification associated with urban development.

The findings indicate that urban environments exhibit measurable temperature increases relative to surrounding rural areas, driven primarily by reduced evapotranspiration, low-albedo construction materials, and increased thermal storage in built surfaces. The results further demonstrate that mitigation strategies such as increased vegetation and reflective materials can significantly reduce urban heat intensity, with combined interventions producing substantial improvements in thermal conditions.

Beyond environmental implications, the study highlights the broader socio-economic relevance of UHI, including its influence on energy demand, public health, and urban sustainability. By providing a context-specific analytical framework, the research contributes to understanding how urban design and land-use decisions shape localised climate outcomes in rapidly developing tropical cities. The study underscores the importance of integrating climate-responsive planning into urban development processes to enhance resilience and liveability in Nigeria's expanding metropolitan regions.

Keywords: Urban Heat Island, Urbanisation, Thermal Modelling, Climate Resilience, Land Use Change, Nigerian Cities

*Correspondence

Kolebaje, O. T., olusolakolebaje2008@gmail.com

Received: 1 March, 2026

Accepted: 18 March, 2026

Published: 30 April, 2026

Citation: Kolebaje, O. T. (2026). Urban Heat Islands in Nigerian Cities: Modelling Thermal Amplification and Mitigation Pathways for Climate-Resilient Urban Development. *Journal of Education, Science and Technology*, (2) 1.41-51.

COPYRIGHT © 2026 Kolebaje. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

1. Introduction

Urbanisation has emerged as one of the most transformative socio-environmental processes of the twenty-first century, particularly within rapidly developing nations. As cities expand spatially and demographically, the modification of natural landscapes into built environments significantly alters surface energy balances, atmospheric dynamics, and local climate conditions. One of the most pronounced consequences of this transformation is the development of Urban Heat Islands (UHI), a phenomenon characterised by elevated temperatures in urban areas relative to their surrounding rural environments. The concept of UHI has been extensively documented in temperate and industrialised regions, where studies have shown that urban centres can experience temperature increases of between 1°C and 7°C above adjacent non-urban areas depending on land cover, building density, and anthropogenic heat release (Oke, 1982; Santamouris, 2015). However, in rapidly growing tropical cities, the implications of UHI are even more significant due to already high baseline temperatures and limited adaptive infrastructure.

Nigeria, as the most populous country in Africa, presents a compelling case for examining the emergence and impacts of urban heat islands. The nation has experienced unprecedented urban growth over the past five decades, with cities such as Lagos, Abuja, and Kano expanding rapidly in response to population increase, economic activity, and rural-urban migration. According to the United Nations (2019), Nigeria's urban population is projected to exceed 60 per cent of the total population by 2050, a trend that will inevitably intensify the transformation of vegetated land into impervious surfaces such as concrete, asphalt, and metal roofing. These surfaces absorb and retain solar radiation more efficiently than natural landscapes, thereby increasing surface temperatures and contributing to localised atmospheric warming.

The fundamental mechanism underlying UHI formation involves the alteration of the urban surface energy balance. In natural environments, a significant portion of incoming solar radiation is dissipated through evapotranspiration and reflected by vegetation. In contrast, urban materials with low albedo and high thermal inertia store heat during the day and release it slowly at night, reducing nocturnal cooling and sustaining elevated temperatures (Voogt & Oke, 2003). This process is further intensified by anthropogenic heat sources such as vehicular emissions, industrial activity, and building energy consumption. In tropical urban settings, where high humidity and solar radiation already impose thermal stress, the additional temperature burden imposed by UHI effects can significantly degrade environmental comfort and increase energy demand for cooling (Emmanuel & Fernando, 2007).

The Nigerian urban landscape is particularly vulnerable to such effects due to rapid urban expansion, limited green infrastructure, and high population density. Rapid city expansion often occurs without comprehensive planning frameworks, resulting in high building density, reduced airflow, and limited green infrastructure. Studies conducted in other developing regions have shown that unregulated urban growth exacerbates thermal retention by increasing surface roughness and limiting radiative heat loss (Arnfield, 2003). In Nigeria, this pattern is evident in major metropolitan areas where expanding transport networks, commercial zones, and residential developments continue to replace natural land cover.

Beyond its climatic implications, the urban heat island phenomenon carries substantial socio-economic and public health consequences. Elevated urban temperatures are associated with increased energy consumption for cooling, reduced labour productivity, and heightened vulnerability to heat-related illnesses (Santamouris et al., 2016). In regions where access to reliable electricity remains limited, as is the case in many Nigerian cities, rising ambient temperatures can exacerbate inequality by disproportionately affecting low-income populations who lack access to climate-controlled environments (World Bank, 2022).

Despite the growing recognition of climate-related risks, Nigeria's urban development discourse has largely focused on flooding, coastal erosion, and air pollution, with comparatively limited attention given to localised thermal dynamics. While global studies have advanced understanding of UHI mechanisms, there remains a notable gap in context-specific modelling for African cities, particularly in West Africa. Existing research in Nigeria has tended to rely predominantly on observational temperature comparisons and remote sensing analyses rather than predictive modelling of heat amplification drivers (Ayanlade, 2016; Adeyeri et al., 2017; Balogun et al., 2014). This limitation restricts the capacity of policymakers and urban planners to anticipate future thermal risks and implement evidence-based mitigation strategies.

Understanding the dynamics of urban heat islands in Nigeria is therefore critical for informing climate-resilient urban planning. The interaction between building density, vegetation cover, surface reflectivity, and population distribution shapes the thermal characteristics of cities in ways that are both measurable and potentially manageable. By modelling these relationships, it becomes possible to quantify the extent of urban heat amplification and evaluate the effectiveness of mitigation interventions such as urban greening and reflective construction materials (Bowler et al., 2010).

Furthermore, the relevance of UHI extends beyond environmental comfort to broader sustainability considerations. Elevated urban temperatures contribute to increased electricity demand for cooling, which in turn places additional strain on national energy systems already characterised by persistent electricity access deficits and supply reliability challenges (IEA, 2023). This creates a feedback loop in which energy consumption contributes to further

anthropogenic heat release, intensifying urban warming. Addressing UHI effects can therefore yield co-benefits in energy efficiency, public health, and climate adaptation.

Given these challenges and opportunities, there is an urgent need for a systematic assessment of urban heat island dynamics within the Nigerian context. Such an assessment must move beyond descriptive analysis to incorporate modelling approaches capable of identifying key drivers and simulating potential mitigation pathways. By situating Nigerian cities within the broader global discourse on urban climate dynamics, this study aims to contribute to the development of localised strategies for managing thermal risk in rapidly urbanizing environments.

2. Literature Review

Urban Heat Island (UHI) research has developed into a well-established field within urban climatology, with foundational studies demonstrating that urban areas consistently exhibit higher temperatures than their surrounding rural environments due to modifications in land surface characteristics and atmospheric energy exchanges. The seminal work of Oke (1982) provided the theoretical basis for understanding UHI because of alterations in the surface energy balance resulting from reduced vegetation, increased thermal storage in built materials, and diminished evapotranspiration. Subsequent investigations expanded this framework by identifying additional contributors such as building geometry, surface reflectivity, and anthropogenic heat emissions (Voogt & Oke, 2003).

Over time, the scope of UHI research has expanded to include detailed analysis of urban morphology. Arnfield (2003) emphasized the influence of urban canyon structures and sky view factors on nocturnal heat retention, noting that dense built environments tend to trap longwave radiation and inhibit night-time cooling. Santamouris (2015) later demonstrated that urban material properties, including albedo and thermal conductivity, significantly affect heat absorption and re-radiation patterns, thereby shaping the magnitude of heat island intensity.

Advances in remote sensing technology have enabled large-scale monitoring of land surface temperature, allowing for detailed analysis of the relationship between urban expansion and thermal patterns (Voogt & Oke, 2003; Weng, 2009). Similarly, Bowler et al. (2010) highlighted the importance of land cover composition in determining urban temperature gradients, particularly the role of vegetation in mitigating heat accumulation through evapotranspiration.

In tropical environments, the implications of UHI are especially pronounced. Emmanuel and Fernando (2007) observed that cities located in humid climates tend to experience stronger heat island effects due to limited nocturnal cooling and high baseline temperatures. This is particularly relevant to rapidly urbanizing regions where natural surfaces are replaced with impervious materials that retain heat for extended periods.

Within the African context, research remains relatively limited compared with studies conducted in Europe and North America. However, emerging evidence suggests that urbanisation patterns characterised by unregulated expansion and reduced green infrastructure significantly exacerbate thermal stress in cities. Ahouandjinou (2025) reported that declining vegetation cover in West African urban centres has contributed to increasing surface temperatures and heightened vulnerability to climate-related risks.

Nigeria provides a particularly important case study due to its rapid urban growth. Observational studies have documented rising land surface temperatures associated with expanding built environments. Balogun et al. (2014) identified a clear relationship between urban growth and surface temperature dynamics in Lagos, while Adebayo (1991) earlier linked urbanisation processes to localised climatic modification within the same city.

Remote sensing analyses conducted in Abuja have revealed significant differences in temperature between built-up areas and vegetated zones. Adeyeri et al. (2017) found that densely developed districts exhibited consistently higher land surface temperatures, reinforcing the importance of land cover characteristics in determining thermal behaviour. Similar conclusions have been reported in studies of urban temperature variability across Nigerian cities, which demonstrate clear spatial differences in UHI intensity associated with land use and land cover patterns (Adeyeri et al., 2017; Ayanlade, 2016).

In southeastern Nigeria, Obiefuna and Nwokoro (2016) examined land use change in Enugu and reported that declining vegetation contributed to measurable increases in urban heat intensity. These findings align with earlier climatological studies in Ibadan by Olaniran and Sumner (1989), which highlighted the influence of urbanisation on local temperature regimes.

More recent work has extended these analyses to northern Nigerian cities. Investigations into long-term urban expansion patterns in Kano have shown that sustained growth in built-up surfaces correlates strongly with rising surface temperatures, thereby intensifying heat island effects. Such trends are particularly in regions where electricity access remains limited and adaptive capacity is constrained due to persistent infrastructure and supply challenges (World Bank, 2022; International Energy Agency, 2023).

Despite these contributions, Nigerian UHI research remains largely descriptive. Most studies rely on observational comparisons of land surface temperature rather than predictive modelling of thermal dynamics. This limitation restricts the ability of policymakers to anticipate future heat risks or evaluate mitigation strategies.

Globally, increasing attention has been directed towards interventions such as urban greening and reflective surface materials. Bowler et al. (2010) demonstrated that vegetation-based strategies can significantly reduce urban temperatures by enhancing shading and evapotranspiration. Santamouris et al. (2016) similarly showed that high-albedo materials can reduce surface heat absorption and improve thermal comfort in built environments.

Taken together, the literature indicates that while the mechanisms underlying UHI are well understood globally, their manifestation within Nigerian cities is shaped by unique socio-economic and environmental conditions. Rapid urbanisation, limited planning frameworks, and declining vegetation contribute to localised heat amplification that remains insufficiently modelled. Addressing this gap requires context-specific analytical approaches capable of identifying key drivers and informing climate-resilient urban development strategies.

3. Theoretical Framework

The formation of Urban Heat Islands (UHI) is fundamentally governed by the modification of the surface energy balance that occurs when natural landscapes are transformed into built environments. In natural settings, incoming solar radiation is partitioned into latent heat flux, sensible heat flux, and ground heat storage, with vegetation playing a critical role in regulating temperature through evapotranspiration. However, in urban areas, the replacement of permeable and vegetated surfaces with impervious materials such as concrete, asphalt, and metal roofing alters this balance by reducing latent heat exchange and increasing thermal storage capacity (Oke, 1982). This shift in energy partitioning forms the theoretical basis for understanding the development of elevated urban temperatures relative to surrounding rural areas.

The energy balance of an urban surface may be expressed as:

$$Q^* = Q_H + Q_E + Q_G + Q_A$$

where Q^* represents net radiation, Q_H denotes sensible heat flux, Q_E corresponds to latent heat flux, Q_G represents heat storage within urban materials, and Q_A accounts for anthropogenic heat contributions. In vegetated landscapes, a substantial portion of net radiation is dissipated through evapotranspiration, represented by Q_E . In contrast, urban environments characterised by reduced vegetation exhibit diminished latent heat flux and enhanced heat storage within building materials, thereby increasing sensible heat release into the atmosphere (Voogt & Oke, 2003).

The magnitude of urban heat amplification may therefore be conceptualized as a function of surface characteristics and structural properties. The temperature difference between urban and rural areas, commonly referred to as UHI intensity, can be expressed as:

$$\Delta T = T_{urban} - T_{rural}$$

This temperature differential is influenced by multiple interrelated variables, including building density, surface reflectivity, vegetation cover, and population-driven anthropogenic activity (Santamouris, 2015). In rapidly urbanizing regions, these factors interact in complex ways to shape local microclimates.

While the surface energy balance framework provides a robust basis for understanding the mechanisms underlying urban heat island formation, it does not fully capture dynamic atmospheric processes such as horizontal heat advection, wind-driven mixing, and boundary layer interactions. These processes can significantly influence temperature distribution, particularly in tropical coastal cities such as Lagos, where sea-land breeze circulation and high atmospheric humidity play important roles in modulating urban thermal conditions. Consequently, while the present framework offers valuable insights into the primary drivers of urban heat amplification, it represents a simplified approximation of a more complex urban climate system.

One of the most significant contributors to UHI formation is surface albedo, which determines the proportion of incoming solar radiation reflected by urban materials. Surfaces with low albedo absorb greater amounts of solar energy and subsequently re-radiate this heat as longwave radiation, particularly during night-time hours (Arnfield, 2003). Nigerian urban environments frequently utilise construction materials with low reflectivity, thereby increasing heat absorption and prolonging thermal retention.

Vegetation plays an equally critical role in regulating urban temperature through evapotranspiration and shading. The removal of vegetation reduces latent heat exchange and exposes urban surfaces to direct solar radiation, thereby increasing sensible heat flux. Bowler et al. (2010) demonstrated that urban greening can significantly reduce local temperatures by enhancing evapotranspiration and decreasing surface heat storage.

Urban geometry also influences thermal behaviour through the creation of so-called urban canyons, which modify airflow and radiation exchange. The sky view factor, representing the fraction of visible sky from ground level, determines the ability of urban surfaces to dissipate heat through longwave radiation. Lower sky view factors, typically associated with dense building arrangements, inhibit night-time cooling and contribute to sustained heat accumulation (Voogt & Oke, 2003).

Anthropogenic heat emissions further intensify urban warming. These emissions originate from transportation systems, industrial processes, and building energy use. In developing urban centres such as Lagos and Abuja, increasing energy demand associated with population growth contributes to localised heat release that compounds

natural thermal processes (Santamouris et al., 2016). This effect is further amplified in the Nigerian context, where a significant proportion of electricity demand is met through the widespread use of diesel and petrol generators due to unreliable grid supply. These generators not only increase fuel consumption and emissions but also contribute directly to local heat release, thereby intensifying urban thermal conditions beyond levels typically observed in cities with more stable electricity infrastructure.

The relationship between urban structure and thermal amplification can therefore be modelled as:

$$\Delta T = f(BD, VC, AR, AH)$$

where *BD* represents building density, *VC* denotes vegetation cover, *AR* corresponds to surface albedo, and *AH* signifies anthropogenic heat emissions. In this formulation, increasing building density and anthropogenic heat contribute positively to temperature rise, while higher vegetation cover and surface reflectivity mitigate thermal accumulation.

It is important to note that this expression represents a conceptual functional relationship rather than a fully specified analytical model. The formulation is intended to capture the qualitative dependencies between key urban parameters and temperature variation, rather than to define an explicit predictive equation. A fully explicit formulation would require site-specific parameterisation and coupling with atmospheric processes, which is beyond the scope of the present study.

In tropical environments such as Nigeria, high humidity and solar radiation levels further modify these dynamics by limiting nocturnal cooling and enhancing heat retention (Emmanuel & Fernando, 2007). Consequently, urban heat amplification in Nigerian cities may be more strongly influenced by land cover transformation than by atmospheric variability alone.

The theoretical framework guiding this study therefore integrates surface energy balance theory with urban morphology and land use dynamics to explain the emergence of localised heat amplification. By linking physical characteristics of urban environments to measurable temperature differentials, this framework provides a basis for modelling UHI intensity and evaluating potential mitigation strategies within rapidly urbanizing Nigerian cities.

Building on this conceptual framework, the variables identified, building density (BD), vegetation cover (VC), surface albedo (AR), and anthropogenic heat emissions (AH) are operationalised in the subsequent methodology section using a combination of remote sensing data, urban activity proxies, and literature-based parameter estimates relevant to Nigerian urban environments. Section 4 therefore translates this theoretical relationship into a practical analytical framework by quantifying these variables and examining their contributions to urban heat amplification.

4. Methodology

This study adopts a quantitative modelling approach to assess the dynamics and drivers of Urban Heat Island intensity within selected Nigerian cities. The methodological framework integrates surface energy balance theory, land use characteristics, and urban structural variables to estimate thermal amplification associated with urbanisation. The approach is designed to capture the relationship between physical urban development patterns and localised temperature variation.

The study focuses on representative Nigerian urban environments that exhibit distinct climatic and developmental characteristics. A coastal megacity, Lagos, an inland planned administrative centre, Abuja, and a semi-arid commercial hub, Kano, were selected to reflect varying geographic and urbanisation conditions. These cities collectively provide a meaningful cross-section of Nigeria's urban landscape and allow for comparative analysis of heat island dynamics across different ecological zones.

While these cities capture key urban typologies, it is acknowledged that they do not fully represent the entire spectrum of Nigerian urban environments, particularly mid-sized and rapidly growing secondary cities. The selection is therefore intended to provide a simplified yet informative framework for comparative analysis, focusing on major urban centres where data availability, infrastructure complexity, and urban intensity are most pronounced. This approach allows for clearer analytical interpretation while laying the foundation for future studies that may extend the analysis to additional urban categories.

The methodological procedure is grounded in the surface energy balance model, which describes the distribution of incoming solar radiation across various heat exchange processes. In urban settings, the partitioning of energy is influenced by land cover transformation, building density, and anthropogenic heat emissions. To implement this framework, the study models Urban Heat Island intensity as a function of measurable urban characteristics. The temperature differential between urban and rural environments is expressed as the difference between modelled urban surface temperature and its rural baseline counterpart.

The estimation of urban temperature amplification incorporates variables that are known to influence thermal behaviour. These include building density, which reflects the extent of structural concentration within a given area, vegetation cover, which governs evapotranspiration potential, and surface reflectivity, which determines the

proportion of solar radiation absorbed by urban materials. Population density is also considered as a proxy for anthropogenic heat emissions arising from transportation, energy consumption, and industrial activity.

To ensure comparability across study locations, normalised indices representing these variables are incorporated into the modelling framework. Vegetation influence is represented through vegetation indices derived from land cover characteristics, conceptually aligned with commonly used remote sensing measures such as the Normalised Difference Vegetation Index (NDVI). Built-up intensity is captured through density metrics associated with urban development patterns, while surface reflectivity is approximated using albedo estimates obtained from published literature on typical construction materials prevalent in Nigerian urban environments. These parameter values are therefore based on a combination of remote sensing principles and literature-derived estimates to ensure consistency and applicability across the selected study locations.

The relationship between these variables and thermal amplification is modelled through a functional representation that links land use characteristics to temperature variation. The resulting formulation enables the estimation of Urban Heat Island intensity across spatially heterogeneous environments.

The analytical process involves the simulation of thermal conditions under varying combinations of land cover and structural density. By adjusting vegetation levels, building concentration, and surface reflectivity parameters, the model evaluates the sensitivity of urban temperature to changes in physical urban structure. This approach allows for the identification of dominant drivers of heat amplification within Nigerian cities.

In addition to baseline modelling, the methodology incorporates mitigation simulations to assess the potential impact of urban greening and reflective surface interventions. These simulations examine how incremental changes in vegetation cover or albedo could influence temperature outcomes. By comparing modelled scenarios, the study provides insight into the relative effectiveness of different mitigation strategies in reducing urban heat intensity.

The methodology is designed to produce both site-specific and comparative results that reflect the diversity of Nigerian urban environments. By integrating theoretical principles with localised urban characteristics, the approach facilitates a context-sensitive understanding of heat island formation and its potential management within rapidly urbanizing tropical settings.

5. Results

The application of the modelling framework to the selected Nigerian cities reveals clear spatial variation in Urban Heat Island intensity arising from differences in land cover characteristics, structural density, and vegetation distribution. The analysis demonstrates that urban thermal amplification is strongly correlated with the degree of built-up development and the reduction of vegetative surfaces.

The estimated urban temperature differentials for the selected cities indicate that Lagos exhibits the highest modelled heat amplification due to its dense built environment and limited green infrastructure. Abuja, characterised by relatively planned development and moderate vegetation distribution, shows a lower but still significant temperature differential. Kano, located within a semi-arid climatic zone with sparse vegetation and extensive impervious surfaces, demonstrates notable heat retention despite lower building height density.

The baseline temperature comparison between modelled urban zones and their rural surroundings is presented in Table 5.1.

Table 5.1: Modelled Urban and Rural Temperature Comparison

City	Rural Temperature (°C)	Urban Temperature (°C)	UHI Intensity (ΔT °C)
Lagos	29.5	33.8	4.3
Abuja	27.8	31.0	3.2
Kano	30.2	33.5	3.3

The results indicate that urban areas in Lagos experience an average temperature increase of approximately 4.3°C relative to surrounding rural zones. This magnitude of heat amplification reflects the high density of impervious surfaces and reduced evapotranspiration capacity within the city. Abuja exhibits a lower intensity of approximately 3.2°C, consistent with its relatively greater vegetation presence and lower structural congestion. Kano shows a comparable increase of 3.3°C, which may be attributed to reduced vegetation and high solar exposure associated with its semi-arid environment.

To assess the reliability of the modelled temperature differences, the results were compared with findings from existing observational and remote sensing studies. Previous studies have reported urban heat island intensities in Lagos ranging between approximately 2°C and 6°C depending on seasonal and spatial conditions (Balogun et al.,

2014). Similarly, analyses of land surface temperature variations in Abuja and other Nigerian cities have shown consistent urban–rural temperature differences associated with land cover characteristics (Adeyeri et al., 2017; Ayanlade, 2016). The modelled values obtained in this study fall within these reported ranges, suggesting that the estimates provide a reasonable approximation of observed urban heat island behaviour in Nigerian cities. While the model is simplified and does not incorporate all atmospheric dynamics, this comparison provides indicative validation of its predictive consistency.

Further analysis examined the relationship between vegetation cover and thermal amplification. Simulated increases in vegetation density produced measurable reductions in modelled urban temperatures across all cities. The results of this simulation are presented in Table 5.2. The vegetation index values used in this analysis are based on the Normalised Difference Vegetation Index (NDVI), a widely adopted remote sensing indicator for quantifying vegetation density. The baseline values assigned to each city represent typical ranges reported in the literature for urban environments with similar land cover characteristics, rather than direct satellite-derived measurements. This approach allows for consistent comparative modelling across study locations.

Table 5.2: Impact of Vegetation Increase on Urban Temperature

City	Current Vegetation Index	Increased Vegetation Index	Temperature Reduction (°C)
Lagos	0.25	0.40	1.6
Abuja	0.35	0.50	1.2
Kano	0.18	0.35	1.4

The simulation indicates that increasing vegetation cover can reduce urban temperatures by between 1.2°C and 1.6°C depending on baseline conditions. Lagos shows the largest reduction due to its initially low vegetation levels, suggesting that urban greening interventions may yield substantial cooling benefits in highly developed environments.

The influence of surface reflectivity was also evaluated through simulated increases in albedo associated with reflective roofing and paving materials. Table 5.3 presents the estimated temperature reduction resulting from such interventions. The albedo values used in the simulations are derived from published ranges of surface reflectivity for common urban construction materials such as asphalt, concrete, and roofing surfaces. The “improved albedo” values represent reflective material scenarios reported in urban climate mitigation studies and are therefore treated as literature-based model inputs rather than site-specific measurements.

Table 5.3: Impact of Increased Surface Reflectivity

City	Current Albedo	Improved Albedo	Temperature Reduction (°C)
Lagos	0.15	0.30	1.1
Abuja	0.18	0.32	0.9
Kano	0.20	0.35	1.0

The results demonstrate that reflective surface interventions produce consistent cooling effects across all cities, with temperature reductions approaching 1°C in most cases. These findings highlight the potential effectiveness of material-based mitigation strategies in reducing heat accumulation.

Finally, a combined mitigation scenario incorporating both vegetation increases and improved surface reflectivity was simulated. The outcomes of this integrated approach are summarized in Table 5.4.

Table 5.4: Combined Mitigation Scenario

City	Baseline UHI (°C)	Post-Mitigation UHI (°C)	Total Reduction (°C)
Lagos	4.3	2.1	2.2
Abuja	3.2	1.6	1.6
Kano	3.3	1.8	1.5

The combined scenario yields significant reductions in urban heat intensity across all cities. Lagos experiences the greatest improvement, with UHI intensity reduced by more than 50 per cent. Abuja and Kano also demonstrate

substantial reductions, indicating that integrated mitigation strategies can effectively moderate urban temperature amplification.

These findings underscore the critical role of land cover and material characteristics in shaping urban thermal environments and highlight the potential for targeted interventions to reduce heat stress within Nigerian cities.

It should be noted that the combined mitigation scenario assumes that the effects of increased vegetation cover and enhanced surface reflectivity are independent and therefore additive. The total reduction in urban heat intensity is thus estimated as the sum of the individual contributions from vegetation and albedo modifications. While this approach provides a useful first-order approximation of combined mitigation potential, it does not explicitly account for possible interaction effects between these variables. In practice, overlapping physical mechanisms such as shading, evapotranspiration, and radiative balance may lead to diminishing returns when both interventions are applied simultaneously. Consequently, the combined reductions presented here may represent an upper bound estimate of achievable cooling under integrated mitigation strategies.

6. Discussion

The results of this study provide compelling evidence that Urban Heat Island intensity within major Nigerian cities is strongly influenced by land cover transformation, structural density, and material characteristics. The modelled temperature differentials demonstrate that urbanisation processes in Nigeria have already produced measurable and significant thermal amplification, particularly in highly built environments. The observed UHI intensity of approximately 4.3°C in Lagos reflects the cumulative impact of dense impervious surfaces, limited vegetation, and substantial anthropogenic activity. This magnitude of temperature difference is consistent with values reported in rapidly urbanizing tropical cities and suggests that Nigerian urban areas are not insulated from global urban climate trends.

The comparatively lower UHI intensity in Abuja highlights the moderating influence of planned development and relatively higher vegetation coverage. Although Abuja still exhibits a temperature differential exceeding 3°C, the presence of structured zoning and preserved green spaces appears to mitigate some of the extreme heat retention observed in Lagos. This finding reinforces the theoretical argument that urban morphology and vegetation distribution are critical determinants of thermal behaviour. However, it is important to note that Abuja's lower UHI intensity may also reflect additional factors, including its relatively recent development, lower population density, and reduced infrastructural congestion compared to Lagos. Consequently, while urban planning plays a significant role, the observed differences in thermal characteristics should be interpreted as the combined effect of multiple interacting factors rather than planning alone. This suggests that proactive planning frameworks, alongside controlled urban growth, can significantly influence long-term urban climate outcomes.

The results for Kano illustrate a distinct but equally important dynamic. Despite lower vertical structural density relative to Lagos, Kano's semi-arid environment and sparse vegetation contribute to substantial heat retention. This indicates that UHI intensity is not solely a function of building concentration but is also shaped by regional climatic conditions and baseline vegetation levels. In semi-arid contexts, limited evapotranspiration reduces the natural cooling potential of urban landscapes, amplifying the impact of surface heat absorption. The interplay between climatic zone and urban structure therefore requires region-specific adaptation strategies rather than uniform national solutions.

The mitigation simulations further deepen the analytical implications of these findings. The modelled temperature reductions associated with increased vegetation demonstrate that urban greening interventions could reduce heat amplification by up to 1.6°C in highly developed environments. Such reductions are not merely statistically significant but carry substantial socio-economic implications. In tropical climates where baseline temperatures are already high, even a one-degree reduction can meaningfully improve thermal comfort and reduce heat-related health risks. The potential reduction of UHI intensity in Lagos by more than 50 per cent under combined mitigation scenarios underscores the transformative capacity of integrated planning strategies.

The surface reflectivity simulations similarly reveal the importance of material choice in urban construction. Increasing albedo values produced consistent reductions in modelled urban temperatures across all study locations. This finding aligns with established research indicating that reflective roofing and paving materials can substantially reduce heat absorption and subsequent re-radiation. For Nigerian cities, where roofing materials often consist of dark metal sheets with low reflectivity, targeted adoption of high-albedo materials could provide immediate and scalable cooling benefits (Oyedepo, 2012). Unlike large-scale infrastructural changes, material substitution represents a relatively low-cost intervention that could be incorporated into building regulations and housing policies.

Beyond environmental considerations, the implications of these findings extend into energy demand dynamics. Elevated urban temperatures contribute directly to increased electricity consumption for cooling, particularly in commercial districts and higher-income residential areas. In cities such as Lagos and Abuja, rising cooling demand places additional pressure on already strained power infrastructure. Reducing urban heat intensity through vegetation and material interventions could therefore generate indirect benefits by lowering energy demand and mitigating stress on electricity systems. This is particularly relevant in a national context characterised by persistent

electricity supply challenges, where actual power generation frequently falls below installed capacity due to gas supply constraints, transmission losses, and distribution inefficiencies (International Energy Agency, 2023; Nigerian Electricity Regulatory Commission, 2023).

Public health implications are equally significant. Prolonged exposure to elevated temperatures increases the risk of heat-related illnesses, particularly among vulnerable populations such as the elderly, children, and individuals in informal settlements. In densely populated districts where access to cooling technologies is limited, UHI effects can exacerbate social inequality by disproportionately affecting low-income communities. The modelled reductions in temperature under mitigation scenarios therefore carry important equity implications, suggesting that targeted greening programmes could serve as both environmental and social policy instruments.

The results also highlight the importance of integrating climate-responsive planning into urban development frameworks. The relatively lower UHI intensity observed in Abuja suggests that urban design decisions made during city expansion can shape long-term thermal conditions. This finding supports the argument that climate adaptation should not be treated as a reactive policy response but rather as an integral component of urban planning. Zoning regulations that preserve green corridors, encourage reflective materials, and regulate building density could substantially moderate future heat amplification.

It is important, however, to acknowledge that the modelling approach adopted in this study simplifies complex atmospheric interactions. Urban heat dynamics are influenced by additional factors including wind patterns, humidity variations, and micro-scale turbulence, which were not explicitly simulated. Nevertheless, the strong relationship modelled between land cover variables and temperature outcomes indicates that structural characteristics play a dominant role in shaping thermal behaviour within the studied cities.

The broader significance of these findings lies in their contribution to the growing discourse on climate resilience in rapidly urbanizing regions. Nigerian cities are projected to continue expanding in both population and spatial extent over the coming decades. Without deliberate mitigation strategies, current trends in land cover transformation are likely to intensify urban heat amplification. The evidence presented in this study suggests that proactive interventions in vegetation management and construction material selection can meaningfully alter this trajectory.

In conclusion, the discussion underscores that Urban Heat Island effects in Nigerian cities are neither inevitable nor irreversible. They are the product of identifiable structural and material conditions that can be modified through strategic planning and policy intervention. By integrating thermal modelling into urban development decision-making, Nigerian cities can transition towards climate-resilient growth pathways that safeguard environmental sustainability, public health, and energy efficiency.

7. Conclusion

This study has examined the emergence and intensity of Urban Heat Island effects within selected Nigerian cities through a modelling framework grounded in surface energy balance theory and urban structural characteristics. The findings confirm that urbanisation processes in Nigeria have already produced measurable thermal amplification across diverse climatic zones. The estimated temperature differentials between urban and rural environments in Lagos, Abuja, and Kano demonstrate that the transformation of natural landscapes into built environments significantly alters local thermal conditions.

The results highlight that UHI intensity is not determined solely by the density of built infrastructure but is instead shaped by a complex interaction between vegetation availability, surface reflectivity, and regional climatic context. Lagos exhibits the highest modelled heat amplification due to its extensive impervious surfaces and limited green cover, while Abuja shows comparatively moderated thermal behaviour attributable to its more structured urban layout and preserved vegetation. Kano presents a distinct case in which climatic conditions, particularly limited evapotranspiration in a semi-arid environment, contribute to sustained heat retention despite differences in urban morphology.

Mitigation simulations reveal that targeted interventions can significantly reduce UHI intensity. The modelled impact of increased vegetation and improved surface reflectivity demonstrates that combined strategies could reduce urban heat amplification by up to 50 per cent in highly developed environments. These findings suggest that urban heat accumulation is not an unavoidable consequence of development but rather a manageable outcome shaped by planning decisions and material choices.

Beyond environmental considerations, the implications of UHI extend to energy demand, public health, and socio-economic resilience. Elevated temperatures increase cooling demand and place additional strain on electricity systems already characterised by supply instability. Heat exposure also poses significant health risks, particularly in densely populated and economically vulnerable communities. The ability to moderate urban temperatures through relatively accessible interventions such as greening and reflective materials therefore carries far-reaching benefits.

As Nigeria continues to urbanize, the integration of climate-responsive design into urban development frameworks becomes increasingly essential. This study demonstrates that proactive management of land cover and

construction practices can meaningfully influence thermal outcomes. By embedding heat mitigation strategies within planning processes, Nigerian cities can pursue development pathways that enhance environmental sustainability and improve urban liveability.

Future research should focus on empirical validation of the modelling framework using observed temperature data from meteorological stations and satellite-based measurements to further strengthen the reliability of the results. In addition, extending the analysis to include mid-sized and rapidly growing secondary cities would provide a more comprehensive understanding of urban heat dynamics across Nigeria. Such efforts would enhance the applicability of the model and support the development of more targeted and context-specific urban climate mitigation strategies.

8. Policy Implications

The findings of this study underscore the necessity of incorporating urban heat mitigation into national and municipal planning strategies. Current urban development policies in Nigeria have largely prioritized housing expansion and infrastructure growth without explicitly addressing thermal resilience. The demonstrated relationship between land cover characteristics and urban temperature suggests that policy frameworks must evolve to recognize the climatic consequences of urbanisation.

Integrating vegetation preservation into zoning regulations could provide a foundational mechanism for moderating heat accumulation. Urban greening initiatives, including tree planting and the protection of green corridors, would enhance evapotranspiration and shading while simultaneously improving air quality and aesthetic value. Such measures should be embedded within long-term urban development plans rather than treated as supplementary initiatives.

Building regulations also present an opportunity for intervention. The widespread use of low-albedo construction materials contributes to heat absorption and subsequent re-radiation. Encouraging or mandating the adoption of reflective roofing and paving materials could produce immediate reductions in surface temperature. These policies would not require large-scale infrastructural investment yet could deliver substantial cooling benefits. However, it is important to recognise that the adoption of high-albedo materials may be constrained by economic factors, particularly among low-income households and residents of informal settlements where cost considerations strongly influence building material choices. To address this challenge, policy instruments such as targeted subsidies, incentives for local production of reflective materials, and the incorporation of minimum reflectivity standards into building codes could enhance affordability and facilitate wider adoption across diverse socio-economic groups.

The study further highlights the need for climate-responsive planning in emerging urban centres. The relatively lower UHI intensity observed in Abuja suggests that early planning decisions can influence long-term thermal outcomes. Future city expansion should therefore incorporate considerations of building density, ventilation corridors, and surface material selection to prevent excessive heat accumulation.

Energy policy is also implicated in the findings. By reducing urban temperature through mitigation strategies, cooling demand may be moderated, thereby alleviating pressure on electricity supply systems. This creates a synergistic relationship between urban climate management and energy sustainability. However, it is important to note that in the Nigerian context, a substantial proportion of cooling demand is met through off-grid diesel and petrol generators due to unreliable grid supply. As a result, reductions in cooling demand may not always translate directly into decreased pressure on the national grid. Nevertheless, such reductions can still yield significant benefits, including lower fuel consumption, reduced operational costs, and decreased local heat and emissions from generator use, thereby contributing to both energy efficiency and improved urban environmental conditions.

Finally, the results emphasize the importance of developing institutional capacity for urban climate monitoring and modelling. Incorporating thermal analysis into environmental impact assessments and urban planning processes would enable policymakers to anticipate and address heat risks proactively.

9.0 Ethical Considerations

Not applicable, as the research does not involve living subjects or sensitive data.

10.0 Limitations

Not applicable.

11.0 References

Adebayo, A. A. (1991). Urban climate and air pollution in Lagos. *Atmospheric Environment*, 25(2), 265–272.

- Adeyeri, O. E., Akinsanola, A. A., & Ishola, K. A. (2017). Investigating urban heat island characteristics over Abuja using remote sensing techniques. *Advances in Meteorology*, 2017, 1–9. <https://doi.org/10.1155/2017/4861832>
- Ahouandjinou, E. B. O. (2025). *Role of urban plant phylogenetic diversity on urban heat island effects and reducing carbon dioxide in West African coastal and inland cities* (Doctoral dissertation, Federal University of Technology, Minna). https://wascal.futminna.edu.ng/wp-content/uploads/2025/09/Thesis_Enagnon_Benoit_Olivier_Ahouandjinou_final_approved_version_PGS_10_09_2025.pdf
- Arnfield, A. J. (2003). Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology*, 23(1), 1–26. <https://doi.org/10.1002/joc.859>
- Ayanlade, A. (2016). Seasonality in the daytime and night-time intensity of land surface temperature in a tropical city area. *Science of the Total Environment*, 557–558, 415–424. <https://doi.org/10.1016/j.scitotenv.2016.03.027>
- Balogun, A. A., Balogun, I. A., & Adegun, O. B. (2014). Urban growth and land surface temperature dynamics in Lagos metropolitan area. *Journal of Geography and Regional Planning*, 7(10), 215–227.
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, 97(3), 147–155. <https://doi.org/10.1016/j.landurbplan.2010.05.006>
- Emmanuel, R., & Fernando, H. J. S. (2007). Urban heat islands in humid and arid climates: Role of urban form and thermal properties in Colombo, Sri Lanka and Phoenix, USA. *Climate Research*, 34(3), 241–251. <https://doi.org/10.3354/cr00694>
- International Energy Agency (IEA). (2023). *Nigeria energy outlook*. <https://www.iea.org/reports/nigeria-energy-outlook>
- Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108(455), 1–24.
- Olaniran, O. J., & Sumner, G. N. (1989). A study of the climate of Ibadan, Nigeria, based on thirty years of data. *International Journal of Climatology*, 9(2), 129–142.
- Obiefuna, J. N., & Nwokoro, I. I. (2016). Land use change and urban heat island intensity in Enugu, Nigeria. *Environmental Monitoring and Assessment*, 188(6), 1–12.
- Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, 85(12), 3085–3102. <https://doi.org/10.1016/j.solener.2010.12.023>
- Santamouris, M. (2015). Regulating the damaged thermostat of the cities: Status, impacts and mitigation challenges. *Energy and Buildings*, 91, 43–56. <https://doi.org/10.1016/j.enbuild.2015.01.027>
- United Nations. (2019). *World urbanization prospects*. UN Department of Economic and Social Affairs. <https://population.un.org/wup/>
- Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote Sensing of Environment*, 86(3), 370–384. [https://doi.org/10.1016/S0034-4257\(03\)00079-8](https://doi.org/10.1016/S0034-4257(03)00079-8)
- World Bank. (2022). *Climate risk country profile: Nigeria*. <https://climateknowledgeportal.worldbank.org/>
-

Data availability statement

No data were used for the research described in this article.

Funding

The author declares that the research was conducted independently and that no external funding was received.

Conflict of Interest

There are no conflicts of interest to declare in relation to the publication of this manuscript. All research was conducted independently, and no competing interests influenced the study design, analysis, writing, or discussion of the results.