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Green Infrastructure as a Tool for Mitigating Urban Heat Island Effects and Enhancing Climate Resilience in Abuja Municipal Area Council, Nigeria

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ABSTRACT

Rapid urbanisation in the Abuja Municipal Area Council (AMAC), Nigeria, has intensified the urban heat island (UHI) effect, heightening climate-related risks to human health, infrastructure, and environmental sustainability. This study examined the effectiveness of green infrastructure as a tool for mitigating UHI effects and enhancing climate resilience in AMAC over 30 years (1994–2024). A mixed-methods approach was adopted, integrating multi-temporal remote sensing analysis of land use/land cover (LULC) and land surface temperature (LST) derived from Landsat imagery with long-term meteorological data and a structured social survey. Results indicate a substantial expansion of built-up areas accompanied by severe vegetation loss, leading to a marked increase in surface temperatures and a widening disparity between atmospheric temperature and LST. Ecological indices further reveal spatial polarisation between thermally stressed urban zones and fragmented cooling areas, reflecting limited connectivity and the limited effectiveness of existing green infrastructure. Survey findings corroborate these results, with residents identifying rising heat stress as a significant concern and pointing to governance, funding, and enforcement gaps as key barriers to green infrastructure implementation. The study concludes that while green infrastructure has strong potential to mitigate urban heat and improve climate resilience, its benefits in AMAC remain constrained by weak institutional integration. Strengthening policy frameworks, expanding interconnected green networks, and enhancing stakeholder collaboration are essential for sustainable urban climate adaptation.

KEY WORDS: Green infrastructure, Urban heat island, Climate resilience, Land surface temperature and Urbanisation.

Introduction

Rapid urbanisation and climate change have intensified environmental challenges in cities across the Global South, with the urban heat island (UHI) effect emerging as a significant concern. The UHI phenomenon refers to the condition whereby urban areas experience higher temperatures than surrounding rural areas due to dense built environments, reduced vegetation cover, and extensive use of heat-absorbing materials such as asphalt and concrete (Oke, 1982). In tropical cities, including those in sub-Saharan Africa, elevated urban temperatures exacerbate heat stress, increase cooling energy consumption, degrade air quality, and heighten public health risks, particularly for vulnerable populations (IPCC, 2023). As climate change accelerates the frequency and intensity of extreme heat events, addressing UHI effects has become central to achieving urban climate resilience (Ibrahim et al., 2025).

Green infrastructure (GI) has gained global recognition as a sustainable and nature-based solution for mitigating UHI effects while delivering multiple co-benefits (Tanko et al., 2025). GI encompasses networks of natural and semi-natural elements such as urban forests, parks, street trees, green roofs, green walls, wetlands, and other vegetated spaces integrated into the urban fabric (European Commission, 2013). These systems reduce surface and ambient temperatures through shading and evapotranspiration, enhance carbon sequestration, improve stormwater management, and support urban biodiversity (Gill et al., 2007; Suleiman et al., 2025). Empirical studies demonstrate that cities with well-distributed green infrastructure experience lower land surface temperatures and improved thermal comfort compared to heavily built-up areas (Rupapara, 2025).

In Nigeria, rapid urban growth, population pressure, and unplanned development have intensified the effects of UHI, particularly in major cities such as Abuja (Hafizu et al., 2025). The Abuja Municipal Area Council (AMAC), as the administrative and commercial hub of the Federal Capital Territory, has experienced extensive land-use change characterised by vegetation loss and increased impervious surfaces. Recent geospatial evidence indicates that green and blue spaces within AMAC significantly moderate land surface temperatures, underscoring the cooling potential of green infrastructure in the city (Anyakora et al., 2025). However, the uneven distribution of green spaces and encroachment on natural ecosystems continue to undermine the city's capacity to adapt to climate-induced heat stress.

Beyond temperature regulation, green infrastructure plays a critical role in strengthening urban climate resilience (Magaji et al., 2025). Climate resilience refers to the ability of urban systems to anticipate, absorb, adapt to, and recover from climate-related shocks and stresses (UN-Habitat, 2020; Abubakar et al., 2025). GI contributes to resilience by reducing flood risks, enhancing ecosystem services, improving air quality, and promoting human health and well-being (Abiola et al., 2025). In heat-prone urban environments like AMAC, integrating green infrastructure into land-use planning and development strategies can significantly reduce climate vulnerability while supporting sustainable urban growth (Oluwadare, 2025).

Despite the growing evidence supporting green infrastructure, its adoption in Nigerian cities remains limited due to weak policy enforcement, competing land-use priorities, insufficient funding, and limited public awareness. Consequently, there is a need for context-specific research that examines the effectiveness of green infrastructure as a tool for mitigating UHI effects and enhancing climate resilience in AMAC. This study seeks to address this gap by

providing empirical insights to inform urban planning policies, climate adaptation strategies, and sustainable development initiatives in Abuja and other rapidly urbanising cities in Nigeria.

Literature Review and Theoretical Framework

Conceptual Review

Green Infrastructure

Green infrastructure refers to a strategically planned and managed network of natural and semi-natural areas designed to deliver a wide range of ecosystem services within urban and peri-urban environments. It includes elements such as urban parks, street trees, green roofs, green walls, wetlands, and urban forests that are deliberately integrated into land-use planning and development processes (European Commission, 2013). Unlike traditional “grey” infrastructure, green infrastructure works with natural systems to regulate temperature, manage stormwater, enhance air quality, conserve biodiversity, and improve human well-being (Benedict & McMahon, 2006). Research has shown that green infrastructure contributes significantly to sustainable urban development by reducing environmental degradation while supporting social and economic benefits, particularly in rapidly urbanising cities (Gill et al., 2007).

Urban Heat Island Effects

The urban heat island (UHI) effect describes the phenomenon whereby urban areas experience higher air and surface temperatures than surrounding rural areas due to human activities and land-use changes. This temperature difference is primarily caused by the replacement of natural vegetation with impervious surfaces such as asphalt, concrete, and buildings that absorb and retain heat, as well as reduced evapotranspiration and waste heat from transportation and energy use (Oke, 1982). The UHI effect intensifies thermal discomfort, increases cooling energy demand, worsens air pollution, and heightens health risks, especially during heatwaves (EPA, 2023). In the context of climate change, UHIs amplify extreme heat events, making urban populations more vulnerable to heat stress and related illnesses (IPCC, 2023).

Climate Resilience

Climate resilience refers to the capacity of human and natural systems to anticipate, absorb, adapt to, and recover from the adverse impacts of climate change while maintaining essential functions and structures (Musa et al., 2025). In urban contexts, climate resilience involves strengthening infrastructure, ecosystems, institutions, and communities to withstand climate-related hazards such as heatwaves, flooding, and droughts (UN-Habitat, 2020). Green infrastructure plays a critical role in enhancing climate resilience by providing nature-based solutions that reduce exposure to climate risks, improve adaptive capacity, and support long-term sustainability (Meerow et al., 2016; Akpan et al., 2025). Building climate-resilient cities is particularly important in developing countries, where rapid urbanisation and limited adaptive capacity increase vulnerability to climate change impacts (IPCC, 2023).

Theoretical Framework

Ecosystem Services Theory (EST)

The **Ecosystem Services Theory** posits that natural ecosystems provide essential services—classified as provisioning, regulating, supporting, and cultural services—that are fundamental to human well-being and sustainable development (Millennium Ecosystem Assessment [MEA], 2005). In urban contexts, green infrastructure delivers critical regulating services, such as temperature regulation through shading and evapotranspiration, air quality improvement, stormwater control, and climate moderation, all of which directly

address urban heat island effects (Bolund & Hunhammar, 1999). By integrating natural elements into urban planning, cities can harness these ecosystem services to reduce climate-related risks and improve adaptive capacity, thereby strengthening climate resilience (Gómez-Baggethun et al., 2013). In rapidly urbanising areas like Abuja Municipal Area Council, the Ecosystem Services Theory provides a strong theoretical foundation for understanding how green infrastructure functions as a cost-effective, nature-based solution to climate change impacts while simultaneously supporting environmental sustainability and human health.

Empirical Evidence

Empirical studies across different geographic contexts consistently demonstrate that green infrastructure (GI) plays a significant role in mitigating urban heat island (UHI) effects and enhancing urban climate resilience. Using geospatial, climatological, and socio-economic datasets, scholars have shown that the presence, distribution, and connectivity of vegetated urban spaces are strongly associated with reduced land surface temperatures (LST), improved thermal comfort, and increased adaptive capacity to climate-induced heat stress.

Globally, remote sensing-based studies provide robust evidence on the cooling effects of green infrastructure. For instance, Gill et al. (2007) observed that increasing urban green cover by 10% could offset predicted increases in surface temperature in UK cities by up to 4°C under future climate scenarios. Similarly, a multi-city analysis by Zhou et al. (2014) found that areas with dense vegetation exhibited significantly lower LST than built-up zones, with urban parks reducing surrounding temperatures by 1–3°C, depending on size and vegetation density. These findings underscore the importance of spatial configuration and scale of green infrastructure in achieving meaningful UHI mitigation.

In rapidly urbanising cities of the Global South, empirical evidence further highlights the vulnerability created by vegetation loss and unplanned development. A study by Li et al. (2019) in Asian megacities revealed that conversion of vegetated land to impervious surfaces led to a sharp increase in surface temperatures, intensifying UHI effects and energy demand for cooling. Similarly, Rupapara (2025) demonstrated that fragmented and poorly connected green spaces provide limited cooling benefits compared to integrated green networks, suggesting that the effectiveness of GI depends not only on quantity but also on ecological connectivity.

African cities exhibit comparable trends. Research in Accra, Ghana, by Owusu-Ansah et al. (2022) showed that neighbourhoods with higher tree canopy cover recorded significantly lower daytime temperatures and improved thermal comfort indices. In Nairobi, Kenya, Onyango et al. (2023) found that urban green spaces reduced LST by up to 2.5°C while also enhancing residents' adaptive capacity to heat stress through improved microclimates and recreational opportunities. These studies highlight the dual role of green infrastructure in both biophysical temperature regulation and socio-environmental resilience.

Empirical evidence from Nigeria strongly supports these global and regional findings. Hafizu et al. (2025) used Landsat-derived LST data to examine urban heat patterns in Abuja. They reported a strong positive correlation between built-up expansion and rising surface temperatures, alongside a negative relationship between vegetation indices and LST. Anyakora et al. (2025) further demonstrated that green and blue spaces within AMAC significantly moderated surface temperatures, with riparian vegetation and urban parks acting as critical cooling zones. Their findings indicate that areas

with dense vegetation recorded LST values several degrees lower than adjacent high-density residential and commercial districts.

Beyond thermal regulation, Nigerian studies also emphasise the role of green infrastructure in enhancing climate resilience. Magaji et al. (2025) observed that urban communities with access to functional green spaces exhibited greater resilience to climate stressors, including heatwaves and flooding, due to improved ecosystem services and social well-being. Abiola et al. (2025) similarly found that green infrastructure reduces flood risk, improves air quality, and enhances public health outcomes, thereby strengthening overall urban resilience. These benefits are particularly relevant in AMAC, where climate risks intersect with rapid population growth and infrastructure pressure.

However, empirical studies also reveal significant constraints to the effectiveness of green infrastructure in Nigerian cities. Oluwadare (2025) noted that weak policy enforcement, inadequate funding, and competing land-use priorities often limit the scale and functionality of urban green spaces. In a socio-institutional assessment of Abuja, Tanko et al. (2025) found that although residents recognise the cooling and health benefits of green infrastructure, implementation remains fragmented due to governance gaps and limited inter-agency coordination. Such institutional challenges reduce the long-term sustainability and resilience potential of GI interventions.

Taken together, the empirical literature demonstrates that green infrastructure is a proven and effective tool for mitigating UHI effects and enhancing urban climate resilience. However, its success depends on strategic planning, adequate spatial coverage, ecological connectivity, and strong institutional support. In the context of the Abuja Municipal Area Council, existing empirical evidence suggests that while green infrastructure can significantly reduce surface temperatures and enhance adaptive capacity, its benefits remain unevenly distributed and constrained by governance and planning limitations. This study builds on existing empirical insights by integrating long-term remote sensing analysis, meteorological data, and social survey evidence to provide a comprehensive, context-specific assessment of the effectiveness of green infrastructure in AMAC.

Empirical and Conceptual Gaps

Despite substantial progress in understanding urban heat islands and green infrastructure, significant empirical and conceptual gaps persist.

At the global level, most urban heat and green infrastructure studies are concentrated in temperate and highly industrialised regions (Europe, North America, East Asia) and rely heavily on advanced simulations and reflective materials (Stewart, 2011; Wong et al., 2021). These models often inadequately represent socio-ecological dynamics such as governance, equity, and public participation, limiting their transferability to tropical African cities.

In Africa and Nigeria, growing interest in urban heat has led to multiple studies on LST and LULC dynamics (Popoola et al., 2022; Adeyeri et al., 2017; Koko et al., 2021). However:

- i. Many studies rely primarily on satellite-derived LST and neglect long-term air temperature trends needed to assess canopy-layer UHI (Mohammed et al., 2023).
- ii. In situ air temperature data over multi-decadal periods are sparse, limiting validation of remote sensing trends (Abur et al., 2018; Yusuf et al., 2023).

- iii. Night-time UHI and residual heat effects, which are critical for human health, are rarely analysed (Suleiman et al., 2025).

For Abuja and AMAC:

- i. Existing studies confirm UHI presence but often cover limited time windows or partial spatial extents (Isioye et al., 2020; Awuh et al., 2021). There is a lack of continuous 30-year LST and air-temperature analysis specifically for AMAC.
- ii. The standard method of defining an “urban–rural” temperature differential is conceptually problematic due to urban sprawl and the difficulty of identifying stable rural reference sites (Stewart & Oke, 2012; Oke, 2006).
- iii. Empirical evidence on green infrastructure’s broader ecosystem services in Abuja, including stormwater management, carbon sequestration, and air quality improvement, remains limited (Shao & Kim, 2022; Unegbu et al., 2024).

There are also important gaps in planning and social dimensions:

- i. Accessible frameworks for translating scientific evidence on green infrastructure into local planning guidelines for Nigerian planners and architects remain underdeveloped (Klemm et al., 2018).
- ii. Qualitative dimensions, such as residents’ awareness, perceptions, and adaptive behaviour, are often overlooked in UHI and GI studies (Adegun et al., 2021; Ahouandjinou, 2025).
- iii. High installation costs, poor maintenance culture, and inadequate technical expertise further hinder GI adoption (Ladan et al., 2023; Abba et al., 2025).

These gaps show that research in Nigeria is expanding but remains fragmented, data-limited, and conceptually narrow. Key unaddressed areas include:

- i. Integration of multi-decadal atmospheric and surface temperature data with LULC transformation metrics.
- ii. Ecological evaluation of green infrastructure cooling efficiency over the years using indices such as the Urban Thermal Field Variance Index (UTFVI) and Ecological Evaluation Index (EEI).
- iii. Inclusion of human perceptions and institutional constraints within resilience assessment frameworks.

This study addresses these gaps by:

- i. Conducting a 30-year geospatial and atmospheric temperature trend analysis for AMAC.
- ii. Applying ecological and thermal indices (e.g., UTFVI, EEI) to evaluate GI efficiency.
- iii. Integrating perceptual and institutional dimensions through resident surveys and policy review.
- iv. Advancing an integrated socio-ecological model combining EST and UET to conceptualise green infrastructure as a dual-function climate mitigation and adaptation mechanism.

This comprehensive approach provides a context-specific empirical foundation and a conceptually unified framework for sustainable, climate-resilient urban planning in AMAC.

Methodology

Research Design

This study adopted a mixed-methods research design integrating quantitative geospatial analysis with a structured social survey to examine the role of green infrastructure in mitigating urban heat island (UHI) effects and enhancing climate resilience in the Abuja Municipal Area Council (AMAC). The mixed-methods approach enables triangulation by combining objective measurements of land-use/land-cover (LULC) and land surface temperature (LST) dynamics with subjective insights from residents and professionals, thereby strengthening the validity and contextual relevance of the findings. Geospatial analysis was conducted using multi-temporal satellite imagery spanning 30 years (1994–2024), while the social survey captured lived experiences and expert perceptions of urban heat stress and green infrastructure performance.

Study Area

The study was conducted in the Abuja Municipal Area Council (AMAC), the administrative and economic core of Nigeria’s Federal Capital Territory (FCT). AMAC is located between latitudes 8°40’N and 9°20’N and longitudes 7°10’E and 7°40’E, covering approximately 1,769 km² within the FCT’s total land area of about 7,315 km² (Balogun, 2001). Bwari Area Council bounds it to the north, Kuje Area Council to the south, Gwagwalada Area Council to the west, and Nasarawa State to the east. The area encompasses the Federal Capital City districts of Garki, Wuse, Maitama, and Asokoro, as well as rapidly expanding satellite settlements such as Karu, Nyanya, and Lugbe, which are critical for assessing urban expansion and heat dynamics.

AMAC experiences a tropical wet-and-dry climate (Köppen classification Aw), characterised by a rainy season from April to October and a hot, dry season from November to March. The terrain consists of undulating plains interspersed with inselbergs, notably Aso Rock, with elevations ranging from approximately 70 to 760 m above sea level (Musa et al., 2019). Historically dominated by a forest–savanna mosaic, the area has experienced extensive vegetation loss due to rapid urbanisation, resulting in increased impervious surfaces and fragmented green spaces, such as Millennium Park, which now function as limited ecological buffers (Okoye & Martins, 2023).

Reconnaissance Survey

A reconnaissance survey was conducted prior to data collection to obtain preliminary insights into microclimatic conditions, urban morphology, and logistical considerations within selected districts (Garki, Wuse, Maitama, and Asokoro). This survey facilitated observation of temperature variations, shading patterns, and green space distribution, informed the refinement of research instruments, and guided sampling decisions. Relevant institutions, including the Abuja Geographic Information System (AGIS), the Nigerian Meteorological Agency (NiMet), and Abuja Development Control, were also visited to support data acquisition and validation.

Population and Sample Size

The study population comprised residents of AMAC, urban planners, and environmental professionals affected by or involved in managing UHI-related challenges. Based on a projected 2024 population of approximately 3.6 million, the sample size was initially estimated using the Krejcie and Morgan (1970) formula, which recommended a sample of 384 respondents. However, due to logistical and resource constraints, a purposive sample of 150 respondents was adopted. Following data cleaning, 135 valid responses were retained and proportionally distributed across

AMAC to ensure adequate representation of diverse urban experiences.

Data Sources and Collection

The study employed geospatial and meteorological datasets supported by primary survey data. Multi-temporal satellite imagery was obtained from the United States Geological Survey (USGS), including Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI/TIRS, and Landsat 9 OLI/TIRS for the years 1994, 2000, 2006, 2012, 2018, and 2024. These datasets were selected for their suitability in LST retrieval and LULC classification. Historical air temperature records spanning 1990–2024 were sourced from NiMet to validate satellite-derived temperature trends and provide ground-based climatic context.

Remote Sensing and Geospatial Analysis

Satellite imagery underwent standard preprocessing procedures to ensure temporal and spatial consistency. Geometric correction was applied by projecting all spatial datasets to the Universal Transverse Mercator (UTM) Zone 32N using the Minna Datum. Radiometric correction was performed to minimise atmospheric and sensor-related distortions. Relevant spectral bands were stacked to generate false-colour composite images, which were subsequently clipped to the AMAC boundary using the “Extract by Mask” tool in ArcGIS. Image enhancement techniques were applied to improve visual interpretation and classification accuracy.

Statistical Analysis

Quantitative analyses were conducted using SPSS version 26.0. Linear regression analysis was applied to NiMet temperature records to identify long-term warming trends and assess statistical significance over the 30 years. Pearson’s correlation analysis was used to examine the relationship between LST and key LULC variables, particularly vegetation cover and built-up density, to determine the strength and direction of associations.

Accuracy Assessment

Classification accuracy was assessed to evaluate the reliability of LULC outputs across all study years. Accuracy assessment measures the agreement between classified images and independent reference data (Congalton & Green, 2019). Validation datasets included field verification points from the reconnaissance survey, high-resolution imagery from Google Earth Pro and Sentinel-2 archives, and geospatial datasets from AGIS and the Office of the Surveyor-General of the Federation. A confusion matrix was generated to compute overall accuracy, producer’s accuracy, user’s accuracy, and the kappa coefficient. Interpretation followed Landis and Koch’s (1977) thresholds, while acceptable accuracy levels adhered to established remote sensing standards (Foody, 2002; Congalton & Green, 2019).

Ethical Considerations and Data Presentation

Ethical approval was obtained prior to data collection, and informed consent was secured from all participants. Participation was voluntary, anonymity was ensured, and data were securely stored. Findings were presented using tables, charts, graphs, and thematic maps generated in ArcGIS to illustrate spatial and temporal patterns of LULC, LST, and climate indices across AMAC.

Data Presentation and Analysis of Results

This section presents and analyses empirical findings on the role of green infrastructure in moderating the urban heat island effect and enhancing climate resilience in the Abuja Municipal Area Council (AMAC) between 1994 and 2024. The analysis integrates long-term atmospheric temperature records, satellite-derived land surface temperature (LST), land-use and land-cover (LULC) dynamics,

ecological indices, and residents’ perceptions. The results are organised according to the study’s objectives, progressing from climatic trends to surface thermal patterns, landscape transformation, ecological performance, and the socio-institutional dimensions that influence the implementation of green infrastructure. Interpretation is guided by ecosystem services and urban ecology perspectives, ensuring coherence between biophysical evidence and human experience.

Atmospheric Temperature Trends in Abuja (1994–2024)

Table 4.1 Annual Atmospheric Temperature Profile for Abuja (1994–2024)

| Year | Max Temp (°C) | Min Temp (°C) | Avg Temp (°C) |
|------|---------------|---------------|---------------|
| 1994 | 33.3 | 21.1 | 27.2 |
| ... | ... | ... | ... |
| 2024 | 33.6 | 22.1 | 27.9 |

Source: Author’s Analysis (2025), using Nigerian Meteorological Agency (NiMet) data

Table 4.1 reveals a clear long-term warming signal in Abuja, characterised by asymmetric temperature change. While maximum daytime temperatures fluctuate only slightly within a narrow range, minimum (night-time) temperatures show a persistent upward trend, increasing by approximately 1.0 °C over the 30 years. This pattern confirms progressive nocturnal heat retention, a defining characteristic of urban heat island development. The steady rise in average temperature is therefore driven primarily by elevated nighttime conditions rather than by extreme daytime peaks, indicating reduced nocturnal cooling capacity in the urban environment.

Land Surface Temperature (LST) Dynamics in AMAC (1998–2024)

Table 4.2 Summary of Land Surface Temperature Statistics in AMAC

| Year | Maximum LST (°C) | Mean LST (°C) | Minimum LST (°C) |
|------|------------------|---------------|------------------|
| 1998 | 32.2 | 32.2 | 32.2 |
| 2000 | 36.0 | 32.7 | 29.7 |
| 2006 | 37.9 | 32.8 | 26.2 |
| 2012 | 36.3 | 34.2 | 31.6 |
| 2018 | 43.5 | 34.2 | 21.4 |
| 2024 | 47.1 | 37.0 | 20.7 |

Source: Author’s Analysis (2025), Landsat thermal data

Table 4.2 demonstrates a pronounced escalation in surface thermal conditions across AMAC. Maximum LST increased by approximately 15 °C between 1998 and 2024, confirming intense surface warming beyond atmospheric trends. The widening gap between maximum and minimum LST values reflects increasing spatial thermal heterogeneity, with built-up zones acting as heat reservoirs while residual vegetated areas provide limited cooling. The sharp rise in mean LST by 2024 indicates cumulative thermal

stress and confirms that surface urban heat island intensity has intensified significantly over time.

Land Use and Land Cover (LULC) Dynamics (1994–2024)

Table 4.3 Land Use and Land Cover Distribution in AMAC (km²)

| Year | Cropland | Vegetation | Bare Surface | Water Body | Built-up |
|------|----------|------------|--------------|------------|----------|
| 1994 | 453.73 | 1110.52 | 51.86 | 5.78 | 128.83 |
| 2000 | 461.12 | 1094.95 | 59.96 | 3.80 | 130.89 |
| 2006 | 227.00 | 289.70 | 1038.55 | 2.60 | 192.85 |
| 2012 | 733.15 | 579.61 | 42.67 | 3.20 | 392.07 |
| 2018 | 493.95 | 383.92 | 514.62 | 2.43 | 486.57 |
| 2024 | 498.41 | 140.45 | 383.83 | 2.20 | 725.82 |

Source: Author’s Analysis (2025), Landsat imagery

Interpretation:

Table 4.3 reveals a fundamental transformation of AMAC’s landscape. Vegetation declined catastrophically from over 63% of land area in 1994 to just 8% by 2024, while built-up land expanded more than fivefold. The spike in bare surfaces in 2006 indicates extensive land clearing preceding construction, a process that significantly increases surface heat exposure. By 2024, built-up areas dominate the landscape, confirming that urban expansion has

occurred mainly at the expense of ecological assets critical for thermal regulation.

Table 4.4 Average Annual Rate of Change in LULC (1994–2024)

| Class | Change (km ²) | Rate (km ² /year) |
|--------------|---------------------------|------------------------------|
| Cropland | +44.68 | +1.49 |
| Vegetation | −970.07 | −32.34 |
| Bare Surface | +331.97 | +11.07 |
| Water Body | −3.58 | −0.12 |
| Built-up | +596.99 | +19.90 |

Source: Author’s Analysis (2025)

Table 4.4 highlights the velocity of ecological loss relative to urban growth. Vegetation loss occurs at a rate far exceeding built-up expansion, indicating that land clearing systematically precedes development. This imbalance produces extensive bare surfaces that intensify surface heating. The rapid expansion of built-up land underscores sustained development pressure, while the decline in water bodies signals growing hydrological stress. Together, these trends explain the sharp rise in LST observed in earlier sections.

Relationship Between LULC, LST, and Air Temperature

Table 4.5 Combined LULC, LST, and Air Temperature Indicators

| Year | Built-up (km ²) | Vegetation (km ²) | Air Tmax (°C) | LST Max (°C) | Thermal Gap (°C) |
|------|-----------------------------|-------------------------------|---------------|--------------|------------------|
| 2000 | 130.89 | 1094.95 | 33.1 | 36.0 | +2.9 |
| 2006 | 192.85 | 289.70 | 33.0 | 37.9 | +4.9 |
| 2012 | 392.07 | 579.61 | 32.4 | 36.3 | +3.9 |
| 2018 | 486.57 | 383.92 | 32.9 | 43.5 | +10.6 |
| 2024 | 725.82 | 140.45 | 33.6 | 47.1 | +13.5 |

Source: Author’s Analysis (2025), combined NiMet, LST, and LULC data

Interpretation:

Table 4.5 confirms a strong inverse relationship between vegetation cover and surface temperature intensity. While atmospheric temperatures remain relatively stable, surface temperatures rise dramatically with increasing built-up density. The widening thermal gap between air temperature and LST illustrates that urban materials absorb and retain heat far beyond the effects of atmospheric moderation. The temporary cooling observed in 2012 coincides with partial vegetation recovery, empirically validating green infrastructure as an effective surface-level cooling mechanism.

Ecological Performance of Green Infrastructure (EEI and UTFVI)

Table 4.6 EEI and UTFVI Distribution in AMAC (2004–2024)

| Year | Excellent (%) | Worst (%) | Mean UTFVI (Excellent) | Mean UTFVI (Worst) |
|------|---------------|-----------|------------------------|--------------------|
| 2004 | 48.82 | 50.02 | −0.836 | +0.816 |

| Year | Excellent (%) | Worst (%) | Mean UTFVI (Excellent) | Mean UTFVI (Worst) |
|------|---------------|-----------|------------------------|--------------------|
| 2014 | 42.18 | 56.66 | −0.947 | +0.704 |
| 2024 | 44.99 | 53.74 | −0.844 | +0.706 |

Source: Author’s Analysis (2025)

Table 4.6 reveals extreme ecological polarisation in AMAC. Over half of the landscape consistently falls within the “Worst” ecological category, actively generating heat, while cooling surfaces remain spatially fragmented. The absence of intermediate ecological classes demonstrates a binary urban structure lacking connective green networks. Although minor recovery is observed in 2025, the dominance of thermally degraded land confirms limited resilience against escalating urban heat stress.

Resident Perceptions of Urban Heat and Green Infrastructure

Table 4.7 Perception of Urban Heat Island Severity

| Perception | Percentage |
|------------------|------------|
| Very serious | 45 |
| Somewhat serious | 41 |
| Not a problem | 0 |
| Unsure | 14 |

Source: Author's Field Survey (2025)

Table 4.7 demonstrates strong convergence between empirical evidence and lived experience. An overwhelming majority of respondents perceive urban heat as a serious challenge, which aligns with satellite-derived and meteorological findings. The absence of responses denying the problem underscores the immediacy of heat stress within daily urban life in AMAC.

Table 4.8 Barriers to Green Infrastructure Implementation

| Barrier | Percentage |
|------------------------|------------|
| Lack of political will | 65 |
| Insufficient funding | 56 |
| Weak enforcement | 52 |
| Limited awareness | 52 |
| Technical constraints | 41 |

Source: Author's Field Survey (2025)

Table 4.8 identifies governance failures as the dominant constraint on the effective delivery of green infrastructure. Respondents overwhelmingly attribute inadequate cooling outcomes to political and institutional limitations rather than technical feasibility, reinforcing the argument that urban heat in AMAC is as much a governance issue as an environmental one.

Discussion of Findings

The findings of this study reveal a strong, consistent relationship between rapid urban expansion, declining green infrastructure, and increasing thermal stress in the Abuja Municipal Area Council (AMAC). Empirical evidence from long-term meteorological records and satellite-derived land surface temperature (LST) data shows that while atmospheric temperatures have increased moderately over the last three decades, surface temperatures have risen sharply, particularly in densely built-up areas. The pronounced widening gap between air temperature and LST confirms the intensification of the urban heat island (UHI) effect, primarily driven by extensive vegetation loss and the proliferation of impervious surfaces. Land use and land cover analysis further demonstrates that urban growth in AMAC has occurred predominantly at the expense of natural vegetation, which declined drastically over the study period. This transformation has weakened the city's natural cooling capacity, validating the critical role of green infrastructure in regulating urban microclimates and mitigating surface heat accumulation.

In addition, the ecological and socio-perceptual findings underscore significant limitations in the current capacity of green infrastructure to enhance climate resilience in AMAC. Ecological indices reveal a spatial polarisation between thermally stressed built-up zones and fragmented cooling areas, indicating the absence of a coherent, interconnected green network capable of delivering widespread cooling benefits. Survey responses further corroborate these results, as residents overwhelmingly perceive urban heat as a serious and escalating problem, while identifying weak political commitment, inadequate funding, and poor enforcement of planning regulations as significant barriers to effective green infrastructure implementation. Collectively, these findings suggest that urban heat stress in AMAC is not solely an environmental outcome but also a governance challenge. Without deliberate policy reforms, sustained investment, and integrated urban planning that prioritises green infrastructure, AMAC's capacity to withstand and adapt to increasing climate-related heat risks will remain severely constrained.

Conclusions and Recommendations

Conclusion

This study concludes that the intensification of the urban heat island (UHI) effect in the Abuja Municipal Area Council (AMAC) is strongly linked to rapid urban expansion, extensive vegetation loss, and the dominance of impervious surfaces over the past three decades. Empirical evidence from meteorological records, land surface temperature analyses, and land-use/land-cover dynamics demonstrates that surface temperatures have increased at a much faster rate than atmospheric temperatures, indicating localised heat amplification driven by land transformation rather than by broader climatic variability alone. The findings further confirm that green infrastructure plays a critical role in moderating urban thermal conditions and enhancing climate resilience; however, its effectiveness in AMAC remains limited due to spatial fragmentation, inadequate coverage, and weak institutional support. As a result, the city's natural capacity to regulate heat and adapt to climate stressors has been significantly compromised.

Recommendations

Based on these findings, the study recommends mainstreaming green infrastructure into urban planning and development frameworks in AMAC through enforceable policies that prioritise urban greening, ecosystem restoration, and nature-based solutions. Strategic investments should focus on expanding interconnected green networks—such as urban parks, street trees, green corridors, and green roofs—particularly in high-density and thermally stressed neighbourhoods. Strengthening institutional capacity, improving funding mechanisms, and enhancing coordination among planning authorities are also essential to ensure effective implementation and maintenance of green infrastructure. Additionally, public awareness and community participation should be encouraged to foster stewardship of urban green spaces. By adopting an integrated and governance-driven approach to green infrastructure development, AMAC can significantly reduce urban heat stress, improve environmental quality, and strengthen its long-term climate resilience.

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