

# Sokoto Journal of Geographical Studies (SJGS)



*Volume 3, Issue 1, December, 2025 Edition*



# **Sokoto Journal of Geographical Studies (SJGS)**

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## ANALYSIS OF THE IMPACTS OF LAND USES CHANGES ON URBAN HEAT ISLAND AND MITIGATION STRATEGIES USING GIS AND REMOTE SENSING IN BIRNIN KEBBI

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### Abstract

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*The Urban Heat Island (UHI) effect has become a major environmental challenge in rapidly growing cities, particularly in tropical and semi-arid regions. This study examines the spatial distribution, intensity, and mitigation strategies of the UHI phenomenon in Birnin Kebbi, Northwestern Nigeria. Using a mixed-method approach, the research integrates Landsat 8 OLI/TIRS satellite imagery (2014–2024), GIS-based spatial analysis, climatic data, and a survey of 150 residents. Land use/land cover analysis revealed a significant increase in built-up areas from 25% (3,750 ha) in 2014 to 55% (8,250 ha) in 2024, corresponding with a decline in vegetation from 50% (7,500 ha) to 30% (4,500 ha). Land Surface Temperature (LST) values increased from 33.4°C in 2014 to 38.6°C in 2024, with high-density areas such as Gesse Phase I, Bayan Kara, and Badariya recording the highest temperatures. The computed Urban Heat Island Intensity (UHII) ranged between 3.2°C and 6.1°C across the town. NDVI–LST correlation analysis ( $r = -0.62$ ) confirmed that vegetation significantly reduces surface temperature through evapotranspiration and shading. Findings from questionnaire indicate that 72% of residents perceived increasing heat levels, with tree planting and improved ventilation being the most common adaptation strategies. The study concludes that rapid urbanization, reduced green cover, and extensive impervious surfaces drive UHI intensification in Birnin Kebbi. It recommends urban greening, adoption of cool roofing materials, climate-sensitive planning, and public awareness as effective mitigation strategies to enhance urban resilience and thermal comfort.*

**Keywords:** Land Uses Changes, Urban Heat Island, Mitigation Strategies, GIS and Remote Sensing.

### Introduction

Urban Heat Island (UHI) effect refers to the phenomenon where urban areas experience significantly warmer temperatures than their surrounding rural regions (Oke, 1982; Voogt & Oke, 2003). This temperature differential is primarily attributed to anthropogenic modifications of land surfaces and urban activities that alter the local energy balance (Rizwan et al., 2008). The UHI effect is characterized by distinct spatial and temporal patterns, with intensity varying across different urban settings, climatic regions, and seasons. The intensity of the UHI effect is typically measured as the maximum temperature difference between urban and rural area, which can range from 1°C to 10°C or more, depending on the city's size, population density, geographical location, and prevailing weather conditions (Stewart & Oke, 2012). The Urban Heat Island (UHI) effect is a phenomenon where urban areas experience significantly higher temperatures than their surrounding rural landscapes. These thermal gradient results from the replacement of natural landscapes with built environments characterized by heat-absorbing materials, reduced vegetation, the UHI effect has emerged as a critical environmental challenge with far-reaching implications for human health, energy consumption, water resources, and urban sustainability.

Urban areas in hot, arid, and semiarid regions face significant challenges from extreme heat, which the Urban Heat Island (UHI) effect exacerbates (Zhao *et al.*, 2014 and Imran *et al.*, 2019). In Birnin Kebbi, where ambient temperatures regularly exceed 40°C during hot seasons, the additional thermal loading from UHI can create dangerous heat stress conditions for residents, particularly vulnerable populations such as the elderly, children, and those with limited access to cooling resources (IPCC, 2022, WHO, 2018). This issue is compounded by rapid urbanization occurring without adequate consideration of thermal impacts in urban planning and development decisions (Ajibade *et al.*, 2021; Ogundele *et al.*, 2016). According to Arnfield (2003), the UHI effect can be categorized into several types:

- a) Surface Urban Heat Island (SUHI): Refers to the increased surface temperatures in urban areas compared to surrounding rural areas, detectable through remote sensing technology.
- b) Atmospheric Urban Heat Island (AUHI): Consists of the canopy layer heat island (from ground level to rooftop height) and the boundary layer heat island (extending up to 1.5 km above the surface).
- c) Subsurface Urban Heat Island: Pertains to increased temperatures in the ground beneath urban areas.

## Causes and Contributing Factors of Urban Heat Islands

### Albedo and Surface Reflectivity

Urban surfaces typically have lower albedo (reflectivity) than natural surfaces, absorbing more solar radiation and subsequently releasing it as heat. Asphalt, for example, has an albedo of 0.05-0.20, compared to vegetation's higher albedo of 0.20-0.30 (Akbari *et al.*, 2001). This reduced reflectivity significantly contributes to higher urban temperatures. Santamouris (2014) demonstrated that decreasing the average albedo of urban surfaces by 0.1 can increase ambient temperatures by approximately 0.3°C.

### Thermal Properties of Construction Materials

Building materials commonly used in urban areas (concrete, asphalt, brick) possess high thermal capacity and conductivity, storing considerable amounts of heat during daytime and releasing it slowly at night (Oke *et al.*, 2017). According to Yang *et al.* (2016), the thermal conductivity of concrete (1.7 W/m·K) significantly exceeds that of natural soil (0.25-0.3 W/m·K), contributing to elevated nocturnal temperatures in built environments.

### Street Canyon Effect

The arrangement of buildings creates "street canyons" characterized by their height-to-width ratio (H/W), significantly influencing urban microclimate (Oke, 1988). Narrow street canyons trap heat through multiple reflections between building surfaces and restrict airflow, intensifying the UHI effect. Nunez and Oke (1977) found that street canyons with H/W ratios exceeding 0.65 experience substantially reduced nocturnal cooling rates compared to more open urban areas.

### Sky View Factor

The sky view factor (SVF), representing the proportion of sky visible from a given point, affects radiation cooling in urban environments. Reduced SVF in dense urban areas impedes longwave radiation loss to the sky, contributing to heat retention (Unger, 2004). Chen *et al.* (2012) established a strong negative correlation ( $r = -0.76$ ) between SVF and nocturnal UHI intensity in high-density Asian cities.

### Anthropogenic Heat Release

Human activities within urban environments release substantial heat, intensifying the UHI effect. Primary sources include:

**Transportation:** Vehicle emissions contribute significantly to urban heat production. Sailor and Lu (2004) estimated that in densely trafficked urban areas, vehicular heat emissions can reach 50-100 W/m<sup>2</sup>.

**Industrial Activities:** Manufacturing processes and industrial operations release heat directly into the urban atmosphere. According to Ichinose et al. (1999), industrial zones in Tokyo contribute up to 400 W/m<sup>2</sup> of anthropogenic heat during peak production periods.

**Building Energy Use:** Heating, ventilation, air conditioning (HVAC) systems, and electrical appliances generate considerable heat. Sailor (2011) calculated that building energy consumption in summer can contribute 20-40 W/m<sup>2</sup> to the urban heat budget in temperate climate cities, with values potentially higher in tropical regions like Nigeria.

### Reduction in Vegetation and Water Bodies

Urbanization typically entails the replacement of natural vegetation and water bodies with impervious surfaces, eliminating crucial cooling mechanisms:

**Evapotranspiration:** Plants cool their surroundings through evapotranspiration. Akbari, *et al.* (2001) estimated that a mature tree can evapotranspire up to 450 liters of water daily, providing cooling equivalent to five room air conditioners operating for 20 hours.

**Shading:** Vegetation provides shade, reducing surface temperatures. Armson, *et al.* (2012) measured surface temperature differences of up to 19°C between shaded and unshaded asphalt surfaces during summer.

**Water Bodies:** Lakes, rivers, and other water features moderate urban temperatures through evaporation and their high specific heat capacity. Theeuwes, *et al.* (2013) found that urban areas within 500m of substantial water bodies experienced UHI intensities approximately 1.3°C lower than similar urban areas without proximate water features.

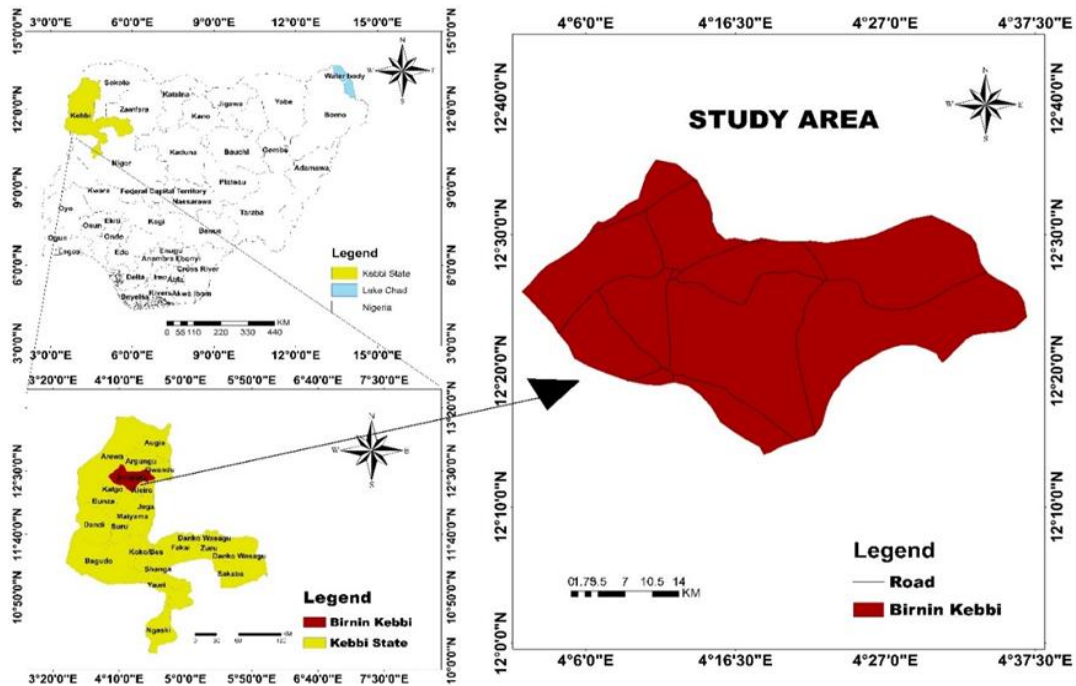
While UHI effects have been extensively studied in many large metropolitan areas globally (Oke, 1982 and Li, *et al.*, 2019), medium-sized cities in developing regions such as Birnin Kebbi remain understudied despite their increasing vulnerability to heat stress (Adelekan, 2010, Akukwe & Ogbodo, 2015). The absence of spatially explicit data on UHI patterns in Birnin Kebbi hampers effective urban planning and the implementation of targeted mitigation measures. Moreover, limited understanding exists regarding how local urban morphology, land use patterns, and socioeconomic factors interact to influence the distribution and intensity of UHI across different neighborhoods of the city.

Birnin Kebbi, the capital city of Kebbi State in Northwestern Nigeria, is experiencing rapid urbanization in recent decades. The city is particularly vulnerable to heat-related stresses. Its geographical location in the Sahel region, prevailing high temperatures, and increasing urban development creates conditions conducive to pronounced UHI effects. Despite these concerns, research examining the spatial characteristics, intensity, and mitigation options for UHI in Birnin Kebbi remain sketchy despite its importance in climate adaptation planning strategies in the region. Therefore, this research tends to address these gaps by conducting a spatial analysis of the UHI effect in Birnin Kebbi and developing mitigation strategies.

## Study Area and Research Methodology

### Study Area

Birnin Kebbi is the capital of Kebbi State in northwestern Nigeria. It is located approximately on Latitude 12.4539° N and Longitude 4.1975° E (Figure 1). Placing it within the Sudan Savanna region of the country. This positioning offers the town strategic importance in terms of regional connectivity, as it is close to the borders of Niger Republic to the north and Benin Republic to the west. Birnin Kebbi is also located along key road networks that link it to other major cities such as Sokoto and Argungu, further boosting its role as a regional hub.



**Figure 1: Locational Map of Birnin Kebbi**

Birnin Kebbi experiences a tropical savanna climate (Köppen climate classification Aw), characterized by distinct wet and dry seasons. The rainy season typically lasts from May to October, with the heaviest rainfall occurring in August and September. During this period, the town receives an average annual rainfall of about 800-1000 mm. The dry season spans from November to April, marked by lower humidity and higher temperatures, with the hottest months being March and April, where temperatures can soar above 40°C (104°F). The harmattan winds, blowing from the Sahara Desert, often bring dusty and dry conditions during the peak of the dry season (Climate-Data.org, 2024).

### Research Methodology

The total population of Birnin Kebbi is estimated to be around 445,671 people as projected from the last population census of 2006. Therefore, the target population for the purpose of this research was 156 households of Birnin Kebbi and some institutional representatives which include health workers and physical planners which serve as the sample size of the study. The sample size of 156 respondents selected for the questionnaire survey was statistically adequate for research, following Yamane's (1967) formula for finite populations, with a margin error of 0.08 as follows:

$$n = \frac{N}{1 + N(e^2)}$$

Where: n= sample size

N= population size

e = margin of error. Therefore,

$$n = 445671 / (1 + 445671 * 0.0064)$$

$$n = 445671 / (1 + 2852.29)$$

$$n = 445671 / 2852.29 = 156$$

$$n = 156$$

A stratified random sampling technique is employed to ensure that respondents are drawn proportionally from different residential density areas, i.e., High-density zones (e.g., inner-city residential areas), Medium-density zones (transitional neighborhoods) and Low-density zones (newer layouts and peri-urban areas). This stratification enables comparison of UHI effects across socio-economic classes and land-use patterns.

The study relies on a combination data source to achieve its objective; using structured questionnaires and Landsat 8 OLI/TIRS imagery (2014, 2019, 2024) Administrative maps, topographic sheets, and urban development reports as primary and secondary sources respectively as well as climatic data for the period of 10 years obtained from the Nigerian Meteorological Agency (NiMet), Birnin Kebbi. Data presentation and analysis was done using descriptive statistics which include frequencies, percentages, and charts. While correlation analyses (Inferential Statistics) were used to determine the relationship between Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST).

## Results and Discussions

### The Spatial Distribution of Land Surface Temperatures Across Birnin Kebbi Using Remote Sensing Data

Table 1 presents the spatial distribution of Land Surface Temperature across Birnin Kebbi in 2024. The results indicate that high-density urban zones such as Gesse Phase I (41.8°C), Gesse Phase II (40.9°C), and Bayan Kara (39.7°C) recorded the highest temperatures. In contrast, vegetated and peri-urban areas including Makera (33.7°C), Dukku (33.5°C), and Kalgo (32.8°C) exhibited significantly lower temperatures. This distribution clearly demonstrates the influence of land use patterns and surface characteristics on thermal variations within the metropolis.

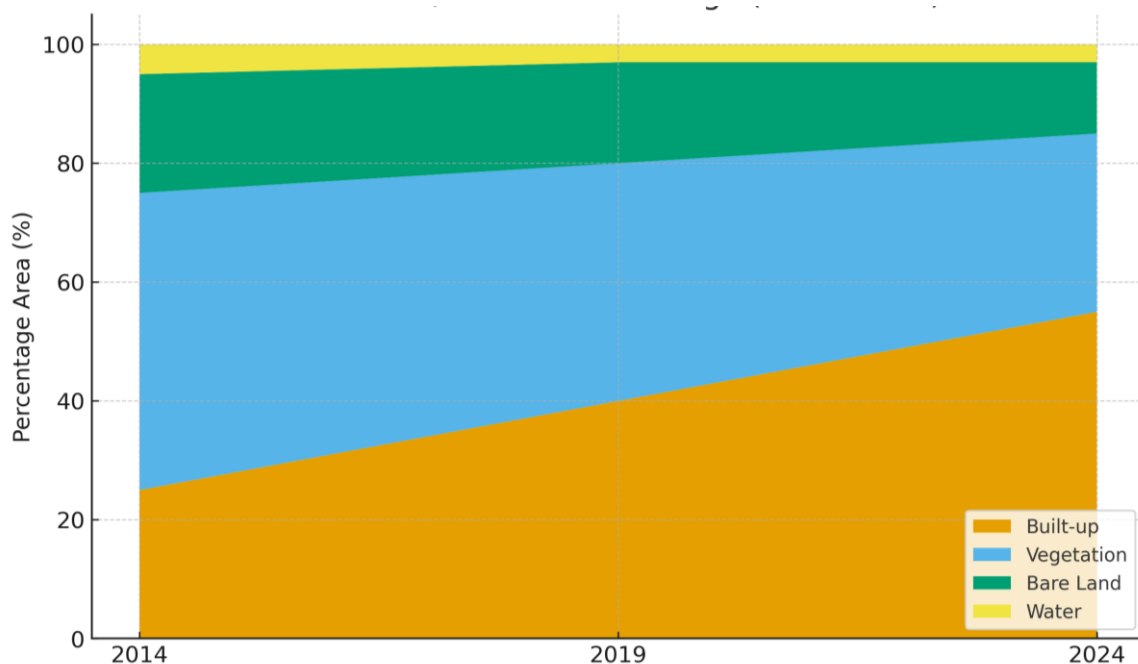
**Table 1: Spatial Distribution of Land Surface Temperature (LST) Across Birnin Kebbi (2024)**

S/N	Location / Zone	Land Use Type	Mean LST (°C)
1	Gesse Phase I	High-density residential	41.8
2	Gesse Phase II	High-density residential	40.9
3	Bayan Kara	Commercial / mixed-use	39.7
4	Badariya	Residential / mixed-use	39.4
5	Rafin Atiku	Medium-density residential	37.6
6	Tudun Wada	Medium-density residential	36.9
7	Federal Polytechnic Axis	Institutional	36.4
8	Police Line Area	Residential/Administrative	35.8
9	Fadama Area	Low-density / peri-urban	34.1
10	Makera	Vegetated / semi-rural	33.7
11	Dukku	Vegetated / semi-rural	33.5
12	Kalgo (Periphery)	Rural/vegetated	32.8

Source: Nimet, Birnin Kebbi Station and Field Work (2024)

## Land Use Classification

The supervised classification of Landsat imagery for 2014, 2019, and 2024 revealed Four main categories: Built-up areas, Vegetation, Bare land, and Water bodies. Over the ten-year period, a steady expansion in built-up areas was observed, particularly within the central and southern parts of Birnin Kebbi. This expansion corresponds with a reduction in vegetative cover, suggesting that urban growth is progressively replacing natural surfaces with impervious materials. Figure 2 illustrates the temporal pattern of land-cover transformation, showing a clear shift from predominantly vegetated land in 2014, where vegetation occupied about 60% (9,000 ha) of the landscape to a more urbanized environment by 2024, with built-up areas expanding from 25% (3,750 ha) to 55% (8,250 ha). This represents a 120% increase in development and a corresponding 41.7% reduction in vegetation cover over the ten-year period. The findings of this study reveal a clear pattern of rising surface temperatures in Birnin Kebbi over the ten-year period examined. The spatial analysis demonstrates that as the built-up area expanded, vegetative and open spaces declined significantly. This land use transformation has altered the city's surface energy balance, increased heat storage and reducing evapo-transpiration rates. The dominance of concrete and asphalt materials in construction contributes to heat absorption during the day and slow release at night, which intensifies nighttime temperatures a key characteristic of the Urban Heat Island phenomenon.



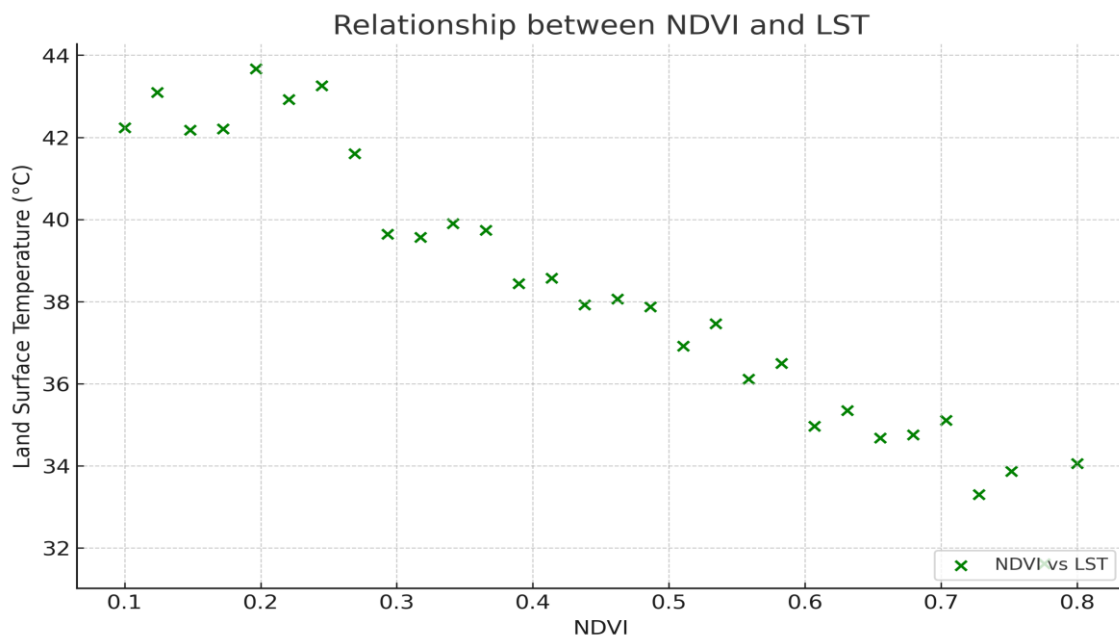
**Figure 2: Land Use Change (2014–2024)**

## Land Surface Temperature (LST) and Vegetation Relationship

The retrieved Land Surface Temperature (LST) data from the thermal band of Landsat 8 indicated a progressive rise in average surface temperature across the study period. Mean LST values increased from 33.4°C in 2014 to 38.6°C in 2024 (Source: Landsat 8 Operational Land Imager/Thermal Infrared Sensor [OLI/TIRS] Level-1 Data, United States Geological Survey – USGS Earth Explorer), highlighting the intensification of urban heat within the city. The Normalized Difference Vegetation Index the NDVI analysis revealed a clear inverse relationship between vegetation density and surface temperature, where areas with high NDVI values representing dense vegetation corresponded to significantly lower LST values, while built-up and sparsely vegetated areas with low NDVI values exhibited higher temperatures due to reduced

evapotranspiration and increased heat absorption. Areas with dense vegetation recorded lower LST values, confirming the cooling influence of vegetative cover on local microclimate (Figure 3).

The analysis of NDVI values across the city further confirmed that vegetation plays a critical role in mitigating urban heat. Areas with dense vegetative cover like: dukku and Makera recorded considerably lower surface temperatures than built-up or bare areas Such as Badariya Gesse Phase I and Gesse Phase II. This is because vegetation enhances shade and promotes evapotranspiration, which cools the surrounding environment. The decline in NDVI values between 2014 and 2024 indicates a continuous reduction in green spaces, which directly correlates with the recorded increase in LST. This situation underscores the environmental cost of unregulated urban expansion.

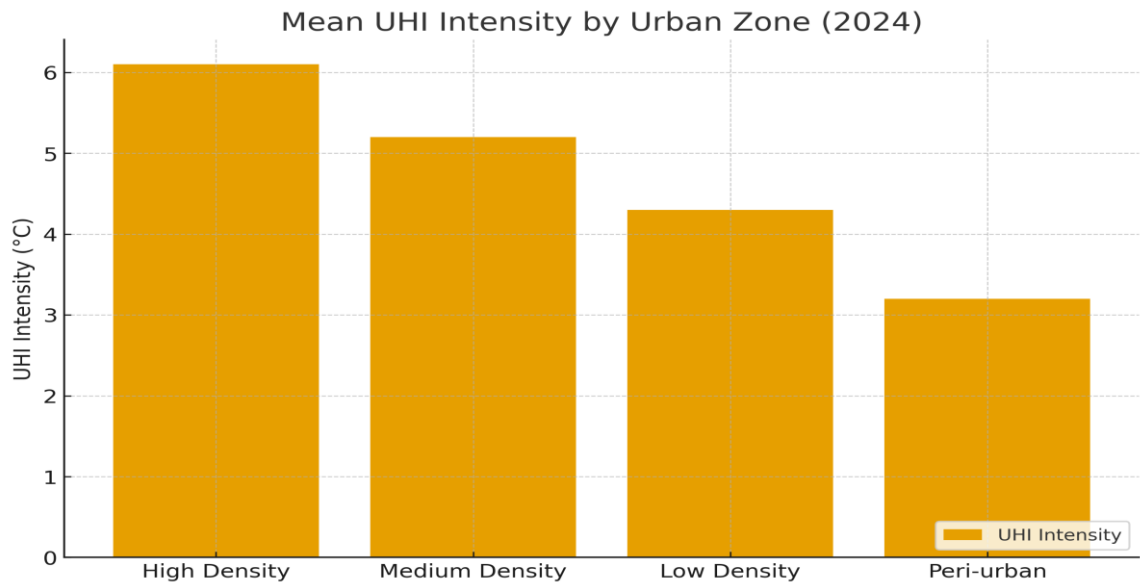


**Figure 3: Relationship between NDVI and LST in Birnin Kebbi (2024)**

### Urban Heat Island (UHI) Intensity

#### Urban Heat Island Intensity (UHII)

Urban Heat Island Intensity (UHII) was determined by comparing the mean LST of built-up areas with vegetated and peri-urban zones. The calculated UHII ranged between 3.2°C and 6.1°C, with higher intensity observed in densely populated neighborhoods such as Gesse, Bayan Kara, and Badariya. Conversely, peripheral areas such as Kalgo exhibited lower UHI values due to larger vegetative and open spaces. These findings confirm that surface modification and density of built-up areas strongly influence local temperature distribution. The computed Urban Heat Island Intensity (UHII) values, which ranged between 3.2°C and 6.1°C, reflect the existence of localized heat pockets across Birnin Kebbi. The high-density core areas such as Gesse (6.1°C), Bayan Kara (5.8°C), and Badariya (5.6°C) exhibited the most elevated UHI values due to the concentration of impervious surfaces, limited green areas, and high building density (Figure 4). In contrast, peripheral communities such as Kalgo (3.2°C), Makera (3.4°C), and Dukku (3.5°C) recorded lower intensities (see Table 1) because of their extensive vegetative cover and open spaces, which help moderate surface temperatures. These findings confirm that urban morphology and land surface characteristics are the dominant determinants of spatial heat variation within the metropolis.

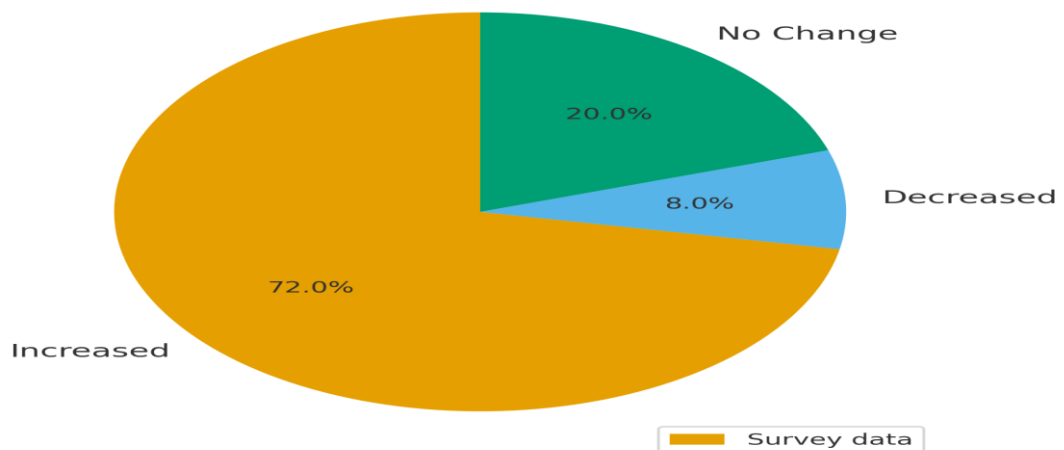


**Figure 4: Mean UHI Intensity by Urban Zone (2024)**

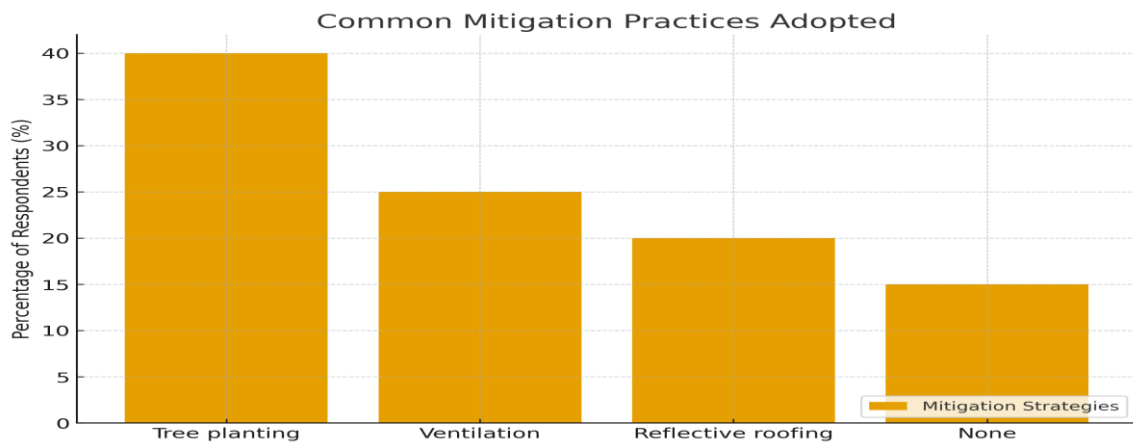
### Residents’ Perception on Urban Heat and Mitigation Strategies

The analysis of the 156 administered questionnaires revealed that 72% of respondents perceived an increase in ambient temperature within the past decade. Respondents identified reduced tree cover, expansion of built-up areas, and poor ventilation as major contributors to heat buildup in the city. Regarding mitigation, tree planting (40%), improved ventilation (25%), and reflective roofing (20%) were among the most adopted strategies, while 15% of respondents reported no adaptation measures (Figure 5). The residents’ perception data complement the spatial findings, showing that most respondents have experienced noticeable warming in recent years. The perception of increased temperature by 72% of respondents aligns with observed thermal changes from satellite-derived data. Tree planting emerged as the most common household-level mitigation practice, indicating a strong local awareness of the cooling benefits of vegetation. However, the relatively low adoption of reflective roofing materials and poor building ventilation in some areas such as Badariya, Tudun Wada, and parts of Rafin Atiku highlights the need for broader environmental education and improved housing standards (Figure 6).

### Respondents’ Perception of Temperature Change



**Figure 5: Respondents’ Perception of Temperature Change**



**Figure 6: Common Mitigation Practices Adopted by Residents**

In general, the study findings emphasize that the intensification of the UHI effect in Birnin Kebbi is primarily linked to loss of green infrastructure, and changes in land surface characteristics. This has direct implications for human comfort, energy consumption, and public health, particularly during the dry season when heat stress levels are highest. Therefore, sustainable urban planning practices that prioritize vegetation conservation, green space development, and climate-sensitive design should be integral to future city expansion policies.

**Table 2: Pearson Correlation Matrix for NDVI and LST (2024)**

Variables	NDVI	LST (°C)
NDVI	1.000	-0.62
LST (°C)	-0.62	1.000

**Vegetation–Temperature Relationship:** The correlation coefficient ( $r = -0.62$ ) indicates a strong inverse relationship between NDVI and LST across the study area (Table 2). This confirms that areas with dense vegetation (high NDVI) consistently exhibit lower surface temperatures, while sparsely vegetated and built-up areas with low NDVI recorded higher temperatures.

**Conclusion and Recommendations**

This study has provided a spatial analysis of the Urban Heat Island effect in Birnin Kebbi. The results show that rapid urbanization and declining vegetation cover are the major drivers of increased surface temperatures. The observed temperature differentials across land use categories demonstrate how human-induced changes alter the local climate. The findings also highlight the importance of vegetation in regulating urban microclimate and reducing heat intensity. In conclusion, mitigating the UHI effect in Birnin Kebbi requires coordinated efforts between government agencies, urban planners, and the local community. Implementing green infrastructure, promoting sustainable urban design, and encouraging climate-sensitive policies will contribute significantly to improving urban livability and resilience against extreme heat events.

Based on the findings and conclusions of this research, the following recommendations are made which include urban greening and tree planting, improved urban planning and zoning as well as public awareness and environmental education:

1. The Kebbi State Urban Planning Board should incorporate UHI mitigation into city master plans, with emphasis on green space preservation.
2. Government agencies should promote policies that mandate the use of cool roofing materials and green landscaping in new constructions.
3. Public enlightenment campaigns should be intensified to educate residents on environmentally friendly building practices and the benefits of vegetation.

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