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Volume 3, Issue 1, December, 2025 Edition

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ABOUT THE JOURNAL

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All correspondence shall be addressed to**:**

Secretary Editorial Board,
Sokoto Journal of Geographical Studies
Department of Geography
Faculty of Social and Management Sciences
Sokoto State University, Sokoto
P.M.B 2134, Along Birnin Kebbi Road, SokotoState-Nigeria

Tel: 080-6950-1786 (Secretary Editorial Board)
Email: sjgs@ssu.edu.ng
Website: https://sjgs.org.ng

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ASSESSING URBAN HEAT ISLAND (UHI) IN IFE CENTRAL LGA, OSUN STATE, USING MULTI-TEMPORAL LANDSAT THERMAL INFRARED IMAGERY

Yusuf, U. G.[1], Dakung, P. D.[2] & Gomwalk, Y. S.[3]

[1]Department of Geography, Sokoto State University, Sokoto
[2]Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]Department of Geography and Planning, University of Jos

Corresponding Author's Email: usman.yusuf@ssu.edu.ng

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Urban Heat Island (UHI) phenomenon is becoming an increasing environmental issue in areas that are urbanizing quickly, as it exacerbates local temperature rises and impacts human health and the stability of ecosystems. This study aimed to assess and map UHI intensity in Ife Central Local Government Area, Osun State, using multi-temporal Landsat thermal infrared imagery. The specific objectives were to (i) assess temporal changes in land cover types between 2015 and 2025, (ii) evaluate UHI intensity over the same period, and (iii) determine the relationship between selected spectral indices (NDVI, NDBI, NDBSI, NDWI, and NDRI) and Land Surface Temperature (LST) to identify the key drivers of UHI. Landsat 8 and 9 OLI/TIRS images and the Local Government Area boundary were processed and analyzed using radiometric calibration, atmospheric correction, supervised land cover classification, NDVI-based emissivity estimation, LST retrieval, and UHI calculation. Correlation analyses between LST and spectral indices were also performed. The results revealed the land cover types in the study area include built-up, vegetation, water bodies, bare land, and rocky surfaces. The results further showed that urban areas increased from 16.4% to 26.1%, while vegetation cover declined from 70.2% to 65.4% between 2015 and 2025. UHI intensity also intensified, with minimum surface temperatures rising from 25.2 °C to 27.3 °C and maximum temperatures from 31.1 °C to 33.9 °C. Correlation analysis indicated that NDBI ((113.95x + 19.28) and NDRI (149.38x + 13.208) had substantial positive relationships with LST (R^2 = 0.52 and 0.66, respectively), while NDVI (-32.236x + 17.072), NDWI (-33.535x + 5.287), and NDBSI (-32.236x + 17.072) were weakly negatively correlated (R^2 < 0.02), highlighting built-up and rocky surfaces as the main contributors to UHI. The study recommends the adoption of sustainable urban planning measures such as expanding green infrastructure, increasing vegetation cover, and promoting heat-mitigating materials to reduce UHI effects and enhance environmental resilience in the area.

Keywords: *Urban Heat Island (UHI), Remote Sensing, Land Surface Temperature (LST), Land Cover, Spectral Indices.*

Introduction

Urban Heat Island (UHI) is a climatic and geographic phenomenon that occurs in urban centers that experience higher temperatures than their rural surroundings due to massive human activities, rapid urbanization, and transformation of land cover over time. This effect is primarily caused by the replacement of natural vegetation with impervious surfaces like asphalt and concrete, including gas emissions, which absorb and retain heat. Consequently, this leads to adverse impacts on human health and the ecosystem as a whole. As global urban growth continues, UHIs have become a major environmental concern because they exacerbate heat-related diseases, alter local climate patterns, and intensify energy consumption for cooling (Zhao *et al*., 2014; Li *et al*., 2017).

Remote sensing techniques, particularly satellite imagery and GIS have become instrumental and efficient for detecting, quantifying, assessing, and mapping UHI intensity through the retrieval of Land Surface Temperature (LST) and analysis of associated land cover (Weng, 2009; Voog & Oke, 200). Landsat satellites, equipped with Thermal Infrared Sensors (TIRS), provide valuable data for retrieving Land Surface Temperature (LST), a critical parameter in UHI studies (Karyati *et al.,* 2022). Spectral indices such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Water Index (NDWI), amongst others further strengthen UHI studies by revealing quantitative relationships between land cover attributes and LST dynamics (Xu, 2006; Awuh*et al*., 2022). For instance, in Bangladesh, Kafy *et al.* (2020), in their study of the prediction of future land surface temperature and its impact on climate change: a remote sensing-based approach in Chattogram City, reported a positive correlation between NDBI and LST and a negative correlation between NDVI and NDWI and LST. In the context of Nigeria, studies have demonstrated the applicability of Landsat data in UHI assessment. Research conducted by Awuh *et al.* (2022) in Abuja Municipal, for instance, revealed that tree canopy significantly contributes to mitigating UHI effects. The study revealed a strong correlation between urban areas and high temperature (Awuh *et al.*, 2022). Similarly, an assessment of UHI by Amusa *et al.* (2022) in Ilorin revealed a correlation between land surface temperature and urban structures, due to population density and human activities. In Osun State, particularly Ile-Ife, Odunsi (2022) found that built-up and open surfaces recorded higher surface temperatures than vegetated and water-covered areas, with maximum temperatures rising over time.

These studies have highlighted the impact of land cover dynamics on LST and UHI. Despite the growing recognition of UHI effects globally, there remains a limited understanding of how rapid urban expansion and land cover changes specifically influence LST and UHI intensity in mid-sized Nigerian cities such as Ife Central Local Government Area (LGA), Osun State**.** While UHI effects have been observed in several Nigerian and international cities, there is insufficient spatiotemporal analysis linking land cover transformations with UHI intensity specifically for Ife Central LGA over the past decade. Addressing this gap is essential for understanding how urbanization and land cover changes drive local climate modifications and for informing sustainable urban planning. Utilizing multi-temporal Landsat thermal infrared imagery, alongside spectral indices such as NDVI, NDBI, and NDWI, offers a robust approach to assess and map UHI intensity, providing critical data for mitigation strategies, including increasing urban vegetation and implementing climate-resilient urban planning measures.

Thus, this paper aims to assess and map Urban Heat Island (UHI) Intensity in Ife Central LGA, Osun State, using multi-temporal Landsat thermal infrared imageries. This aim was set to be achieved by these specific objectives**:**

1. Assess and map out the temporal changes in land cover types in Ife Central LGA between 2015 and 2025.
2. Assess and map out Urban Heat Island (UHI) intensity in the study area between 2015 and 2025.
3. Determine the correlation (relationship) between selected spectral indices (NDVI, NDBI, NDBSI, NDWI, and NDRI) of the land cover and Land Surface Temperature (LST) as of 2025 to decipher the driving parameters of UHI in the study area.

Materials and Methods

Study Area

Ife Central is one of the thirty (30) Local Government Areas (LGA) of Osun State. It is geographically located at the centre of the State and between latitudes 7^0 26’00” N and 7^0 33’00” N, and longitudes 4^0 29’00” E and 4^0 35’00” E (Figure 1). The LGA is bordered by Ife East to its east, Ife North LGA to its North, and Ife South LGA to its south and west.

Further, the LGA has an approximate landmass of about 110.7 km^2. The LGA is predominantly inhabited by the Yoruba ethnic group, particularly the Ifẹ́ people, who are historically known as the custodians of Yoruba culture and traditions. The people of the area engage in a variety of socio-economic activities. Many are traders, civil servants, transporters, academics, and farmers. The presence of the Obafemi Awolowo University and its adjoining communities also contributes greatly to the economic vibrancy of the area through education, research, commerce, and service-related jobs.

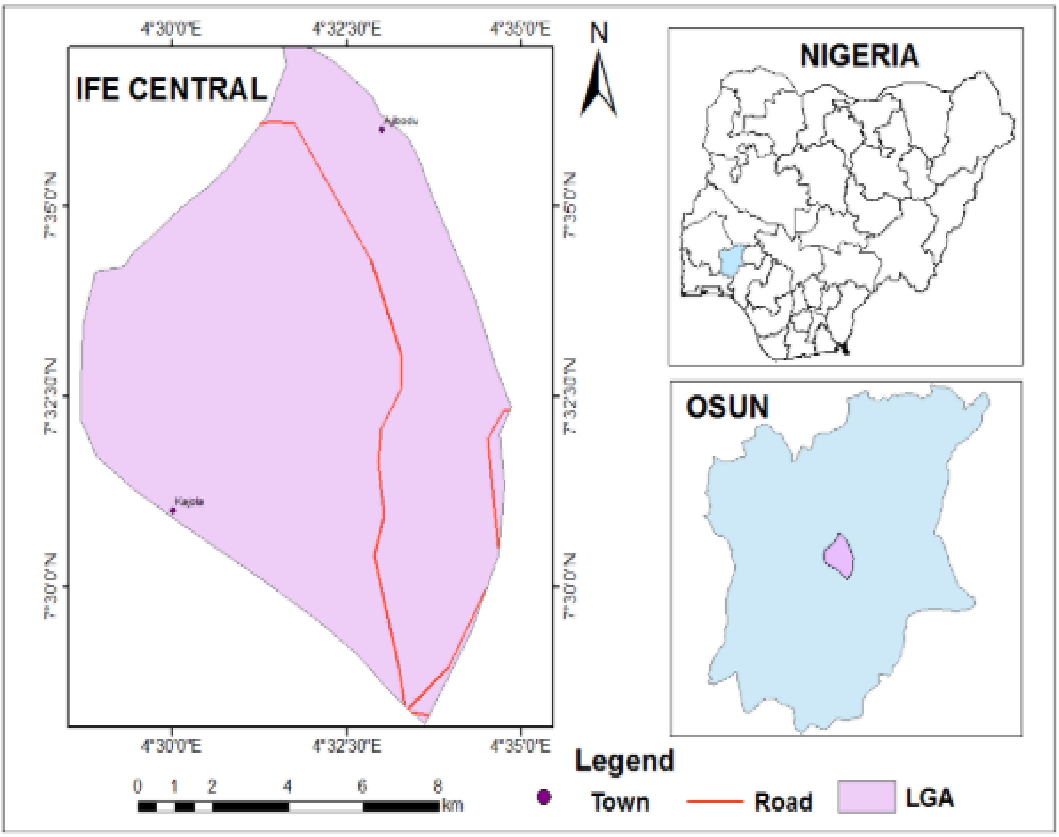

Figure 1: The Study Area

Methods

Data and Sources

The data used for this study consist of multi-temporal Landsat satellite imagery and spatial boundary data. Landsat 8 and Landsat 9 OLI/TIRS images for the years 2015 and 2025 covering the study area were obtained from the United States Geological Survey (USGS) archive (https://glovis.usgs.gov), while the administrative boundary of Ife Central LGA was obtained from the Nigeria Local Government Area (LGA) was derived from the Nigeria Local Government Area (LGA) map. The Landsat images were used to derive land use/land cover classes, land surface temperature, and relevant spectral indices for Urban Heat Island analysis, while the administrative boundary of Ife Central LGA map was used to delineate the study area and clip the satellite imagery for spatial analysis. All datasets were integrated into a spatial geodatabase and processed using ENVI and ArcMap software for analysis.

Data Preprocessing

Prior to analysis, the Landsat images were subjected to standard pre-processing procedures. Atmospheric effects were minimized through cloud and cloud-shadow masking using the Quality Assessment (QA) band based on the CFMask algorithm, ensuring that only clear-sky pixels were used for further analysis. Radiometric calibration was first performed to convert digital number (DN) values to Top-of-Atmosphere (ToA) spectral radiance using the USGS radiometric rescaling algorithm. This conversion is expressed as:

$$L_\lambda = M_L \times Q_{cal} + A_L - O_i \quad \text{(Eq. 1)}$$

Where:

$L\lambda$ = TOA spectral radiance (Watts/(m2*sr*µm))
ML = Radiance multiplicative Band number
AL =Radiance Add Band (No.)
Q_{cal} =Quantized and calibrated standard product pixel values (DN)
O_i = correction value for band 10 is 0.29

The derived ToA radiance was subsequently converted to Top-of-Atmosphere Brightness Temperature (BT) using the inverse Planck function, which transforms thermal radiance into sensor-recorded temperature values expressed in Kelvin. This step accounts for sensor-specific thermal constants and is essential for subsequent Land Surface Temperature (LST) retrieval. The conversion from Kelvin (K) to degrees Celsius (°C) was carried out using the following expression:

$$BT(^\circ C) = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - 273.15 \quad \text{(Eq. 2)}$$

Where:

BT = Brightness temperature (°C)
$L\lambda$ = TOA spectral radiance (Watts/ (m2 * sr * µm)
K1 = Thermal calibration constants specific to the Landsat thermal band
K2 = Thermal calibration constants specific to the Landsat thermal band
ln = Natural logarithm function

Data Processing

Land cover classification was carried out using a supervised image classification approach **b**ased on the Maximum Likelihood Classification (MLC) algorithm. A Level I land cover classification scheme was adopted, focusing on broad and easily distinguishable land cover categories appropriate for medium-resolution Landsat imagery as suggested by Akomolafe *et al*. (2024). The classification scheme comprised five classes: built-up areas, vegetation, water bodies, bare land, and rocky surfaces**.**

Training samples for each land cover class were generated through careful visual interpretation of the Landsat imagery, supported by high-resolution Google Earth imagery and in-depth knowledge of the study area. Homogeneous pixels representing each class were selected to adequately capture intra-class spectral variability. The MLC algorithm assigns each pixel to the land cover class for which it has the highest probability of membership, assuming a normal distribution of spectral values within each class.

Following classification, post-classification refinement was applied to minimize spectral confusion between similar land cover types, particularly between bare land and rocky surfaces. Classification accuracy was evaluated using an error matrix, from which overall accuracy of 86% and the Kappa coefficient of 0.83 were derived to assess the reliability of the classified land cover maps

To further analyze vegetation condition and surface thermal characteristics, several spectral and thermal indices were derived. The Normalized Difference Vegetation Index (NDVI) was computed from the red and near-infrared (NIR) bands of the Landsat imagery to quantify vegetation density and vigor across the study area. NDVI values were subsequently used to estimate Land Surface Emissivity (LSE) based on the NDVI threshold method, accounting for variations in surface materials. It is calculated using the formula:

$$NDVI - \frac{NIR - RED}{NIR + RED} \quad \text{(Eq. 3)}$$

$$NDVI - \frac{\text{Band } 5 - \text{Band } 4}{\text{Band } 5 + \text{Band } 4}$$

Where:

RED = DN values from the RED band
NIR = DN values from the Near-Infrared band

The Land Surface Temperature (LST) was then retrieved by correcting the brightness temperature with the estimated emissivity values using a standard radiative transfer-based approach. The derived LST maps were analyzed in relation to the land cover classes to examine spatial temperature variations associated with different surface types. LSE was estimated using the Normalized Difference Vegetation Index (NDVI) through the calculation of the proportion of vegetation (Pv), which accounts for the fractional vegetation cover in each pixel.

The proportion of vegetation is calculated as:

$$P_v - \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right)^2 \quad \text{(Eq. 4)}$$

Where:

P_v = Proportion of Vegetation
NDVI = DN values from NDVI Image
$NDVI_{min}$ = Minimum DN values from NDVI Image
$NDVI_{max}$ = Maximum DN values from NDVI Image
The Land Surface Emissivity (E) for each pixel was then calculated using the NDVI-based emissivity formula**:**

$$E - 0.004 \times P_v + 0.986 \quad \text{(Eq. 5)}$$

Where:

E = Land Surface Emissivity
P_v = Proportion of Vegetation
0.986 corresponds to a correction value of the equation

This equation accounts for the mixed contributions of vegetation and soil within a pixel, ensuring that the derived LSE values accurately reflect the thermal radiative properties of the land surface.

Finally, Urban Heat Island (UHI) analysis was performed by comparing LST values of built-up areas with those of surrounding non-urban land cover types, particularly vegetation and water bodies. This analysis enabled the identification of UHI intensity and spatial patterns, providing insights into the influence of urbanization and land cover changes on surface thermal behavior within the study area. The UHI intensity was quantified using the standardized approach based on the deviation of Land Surface Temperature (LST) values from the mean LST of the study area:

$$UHI = \frac{LST - LST_m}{SD} \quad \text{(Eq. 6)}$$

Where:

UHI = Urban Heat Islands
LST = Land Surface Temperature
LST_m = Mean temperature of LST
SD = Standard deviation of temperature

Results

Temporal Changes in Land Cover Types in Ife Central LGA between 2015 and 2025

The results of the temporal changes in the extent of the land cover types in the study area are presented in Table 1 and their spatial distribution in Figures 1 and 2, respectively.

Table 1: Spatial Extent of Land Cover Types in the Study Area between 2015 and 2025

Land Cover	2015		2025	
	km²	%	km²	%
Bare Surface	10.8	9.8	7.5	6.8
Rocky Outcrop	3.5	3.2	1.6	1.4
Urban	18.2	16.4	28.9	26.1
Vegetation	77.8	70.2	72.4	65.4
Water Body	0.4	0.4	0.3	0.3
Total	**110.7**	**100**	**110.7**	**100**

The results in Table 1 reveal notable changes in land cover in Ife central LGA between 2015 and 2025. Urban areas increased substantially from 16.4% to 26.1%, indicating rapid urban expansion over the decade. This expansion occurred largely at the expense of vegetation cover, which decreased from 70.2% to 65.4%, reflecting ongoing conversion of natural land cover to built-up areas. Bare surfaces and rocky outcrops also decreased, indicating their transformation into urban and other land uses. Water bodies remained relatively stable with only a slight reduction. This pattern reveals increasing urbanization accompanied by a gradual reduction in natural land covers in the area.

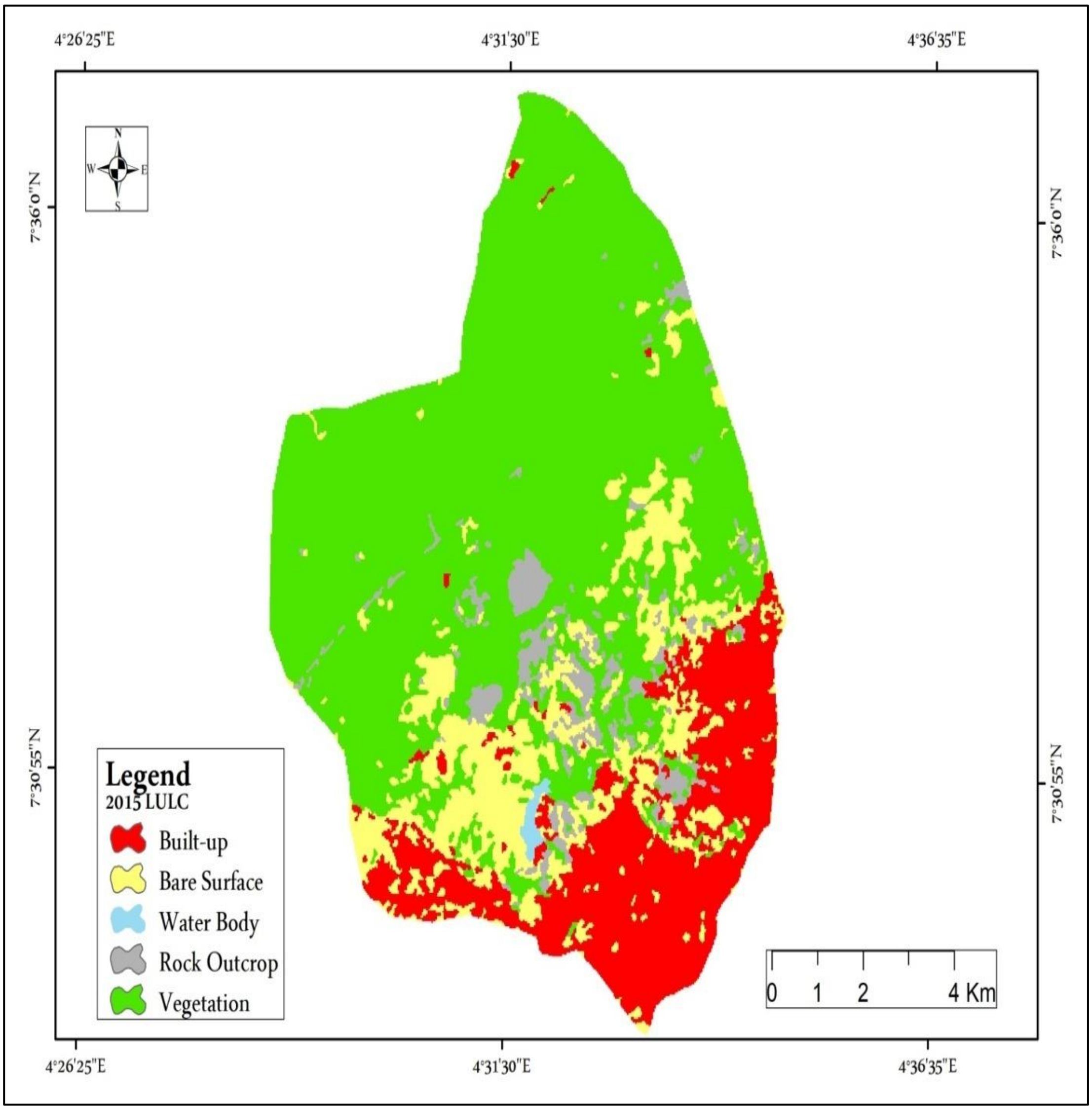

Figure 2: Spatial Extent of Land Cover Types in Ife Central LGA (2015)

The 2015 land-cover map (Figure 2) shows a clear spatial pattern across Ife Central LGA. Vegetation dominates most of the northern and central portions of the area, indicating relatively less disturbed landscapes in those areas. Built-up areas are concentrated mainly in the southern and southeastern parts, forming dense urban clusters that reflect the core settlement and expansion zones of Ile-Ife. Bare surfaces are scattered around the urban fringe, suggesting zones of land clearing, construction, or transitional land use.

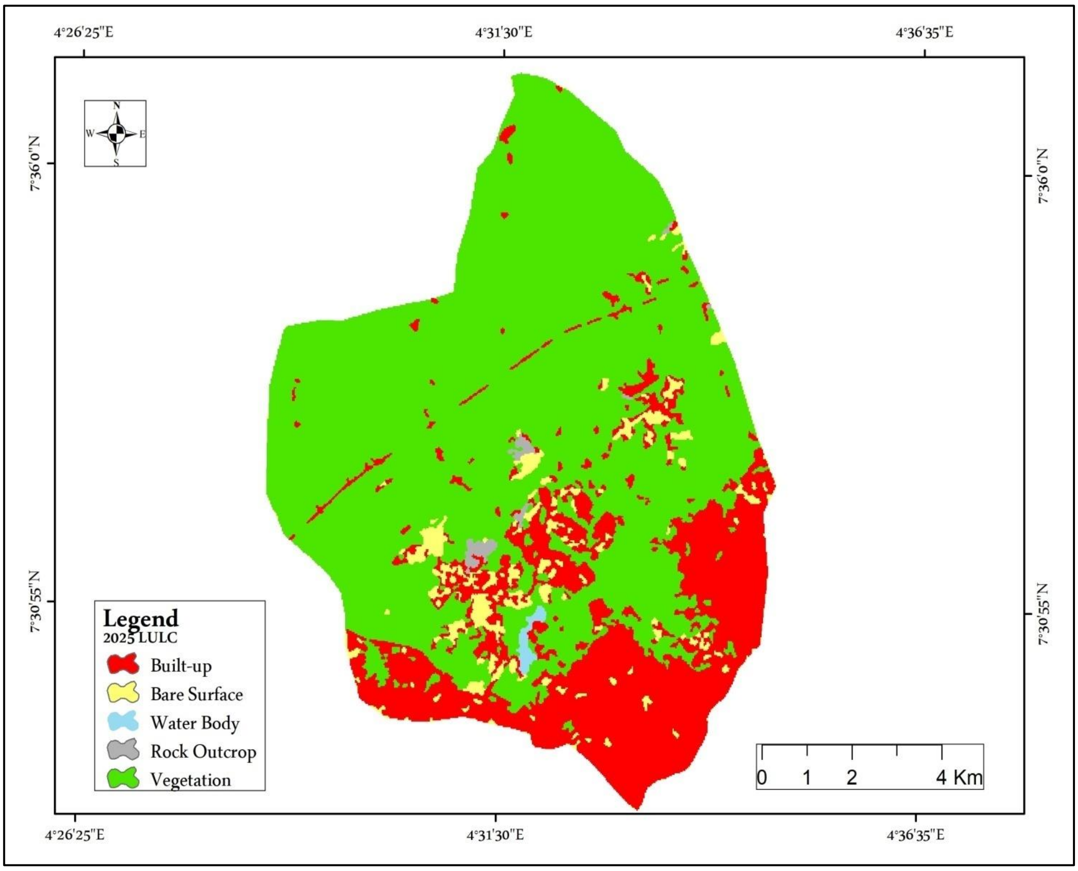

Figure 3: Spatial Extent of Land Cover Types in Ife Central LGA (2025)

The 2025 land-cover map (Figure 3) reveals a pronounced expansion of built-up areas, now extending beyond the southern core into the central and southeastern parts of Ife Central LGA. Urban land cover appears more continuous and compact, indicating intensified urban sprawl and infill development. Vegetation, although still dominant in the northern and peripheral zones, has become more fragmented around the central area due to encroaching development. Bare surfaces are more evident around expanding urban fronts, reflecting active construction and land conversion.

Changes in Urban Heat Island (UHI) Intensity in the Study Area between 2015 and 2025

The results of the changes of UHI intensity in the study area are presented in Table 2 and Figures 4 and 5.

Table 2: Temporal Changes in UHI Intensity in the Study Area

	year	
Temperature	**2015**	**2025**
Min	25.2	27.3
Max	31.1	33.9

Table 2 shows a clear increase in Urban Heat Island (UHI) intensity in the study area between 2015 and 2025. The minimum surface temperature rose from 25.2 °C in 2015 to 27.3 °C in 2025, while the maximum temperature increased from 31.1 °C to 33.9 °C. This warming indicates an intensification of UHI conditions over the decade in the area, associated with the expansion of built-up areas and the reduction of vegetation cover as observed in the land-cover changes.

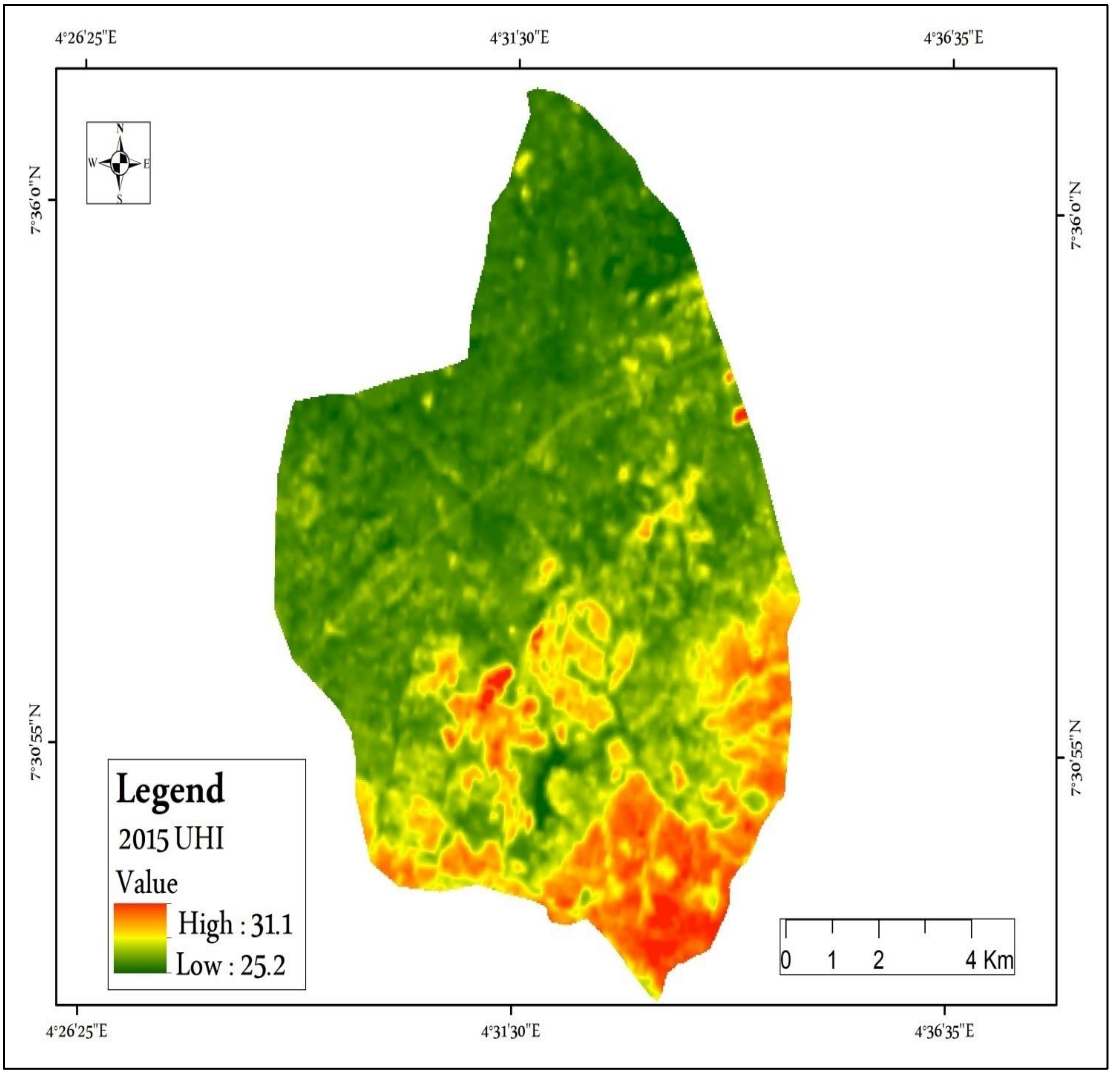

Figure 4: Spatial Distribution of UHI Intensity in the Study Area

The 2015 Urban Heat Island (UHI) map (Figure 4) shows a clear spatial variation in surface temperature across Ife Central LGA. Higher UHI intensities (≈31.1 °C) are concentrated mainly in the southern and southeastern parts of the area, which correspond to densely built-up and bare surface zones. In contrast, lower UHI values (≈25.2 °C) dominate the northern and peripheral areas where vegetation cover is more extensive. This pattern indicates a strong relationship between land cover and thermal conditions, with built-up areas exhibiting higher heat accumulation while vegetated areas help moderate surface temperatures.

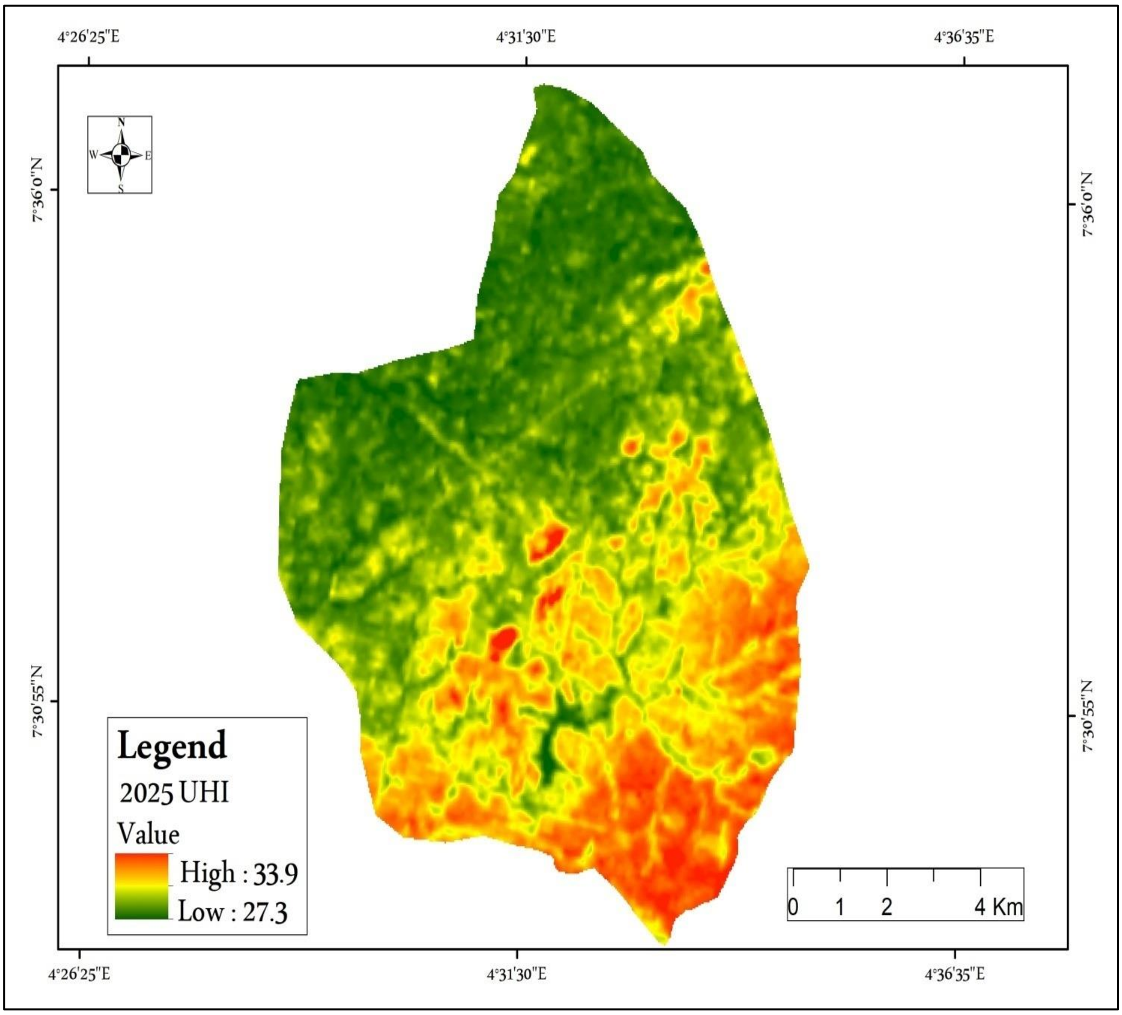

Figure 5: Spatial Distribution of UHI intensity in the Study Area

The 2025 Urban Heat Island (UHI) map shows a clear spatial variation in surface temperature across Ife Central LGA. Higher UHI intensities (≈31.1 °C) are concentrated mainly in the southern and southeastern parts of the area, which correspond to densely built-up and bare surface zones. In contrast, lower UHI values (≈25.2 °C) dominate the northern and peripheral areas where vegetation cover is more extensive. This pattern indicates a strong relationship between land cover and thermal conditions, with built-up areas exhibiting higher heat accumulation while vegetated areas help moderate surface temperatures.

Correlation between Selected Spectral Indices of the Land Cover and Land Surface Temperature (LST) as of 2025

The results of the correlation between the selected spectral indices (Normalized Difference Vegetation Index [NDVI], Normalized Difference Built-up Index [NDBI], Normalized Difference Bare Surface Index [NDBSI], Normalized Difference Water Index [NDWI], and Normalized Difference Rock Index [NDRI]) and LST are presented in Figures 6–10, respectively.

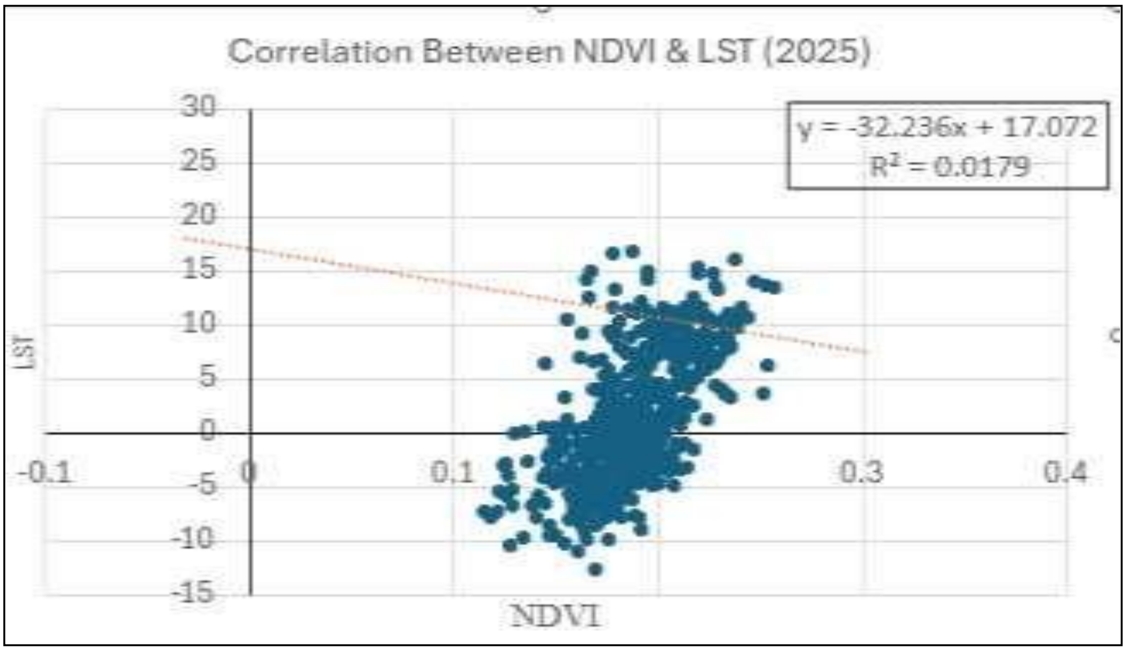

Figure 6: NDVI vs. LST

Figure 6 indicates a weak inverse relationship between NDVI and land surface temperature (LST), as shown by the negative regression equation (−32.236x + 17.072). The very low coefficient of determination (R^2 = 0.017) suggests that variations in vegetation cover explain only about 1.7% of the changes in surface temperature.

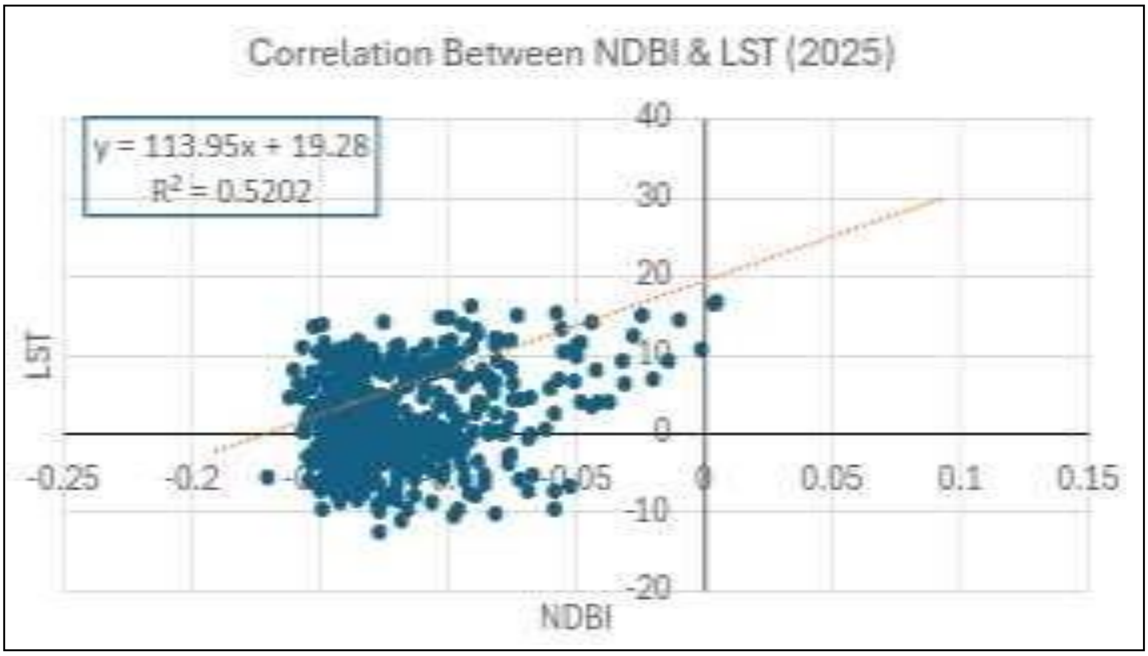

Figure 7: NDBI vs. LST

Figure 7 shows a moderate positive relationship between the Normalized Difference Built-up Index (NDBI) and land surface temperature (LST), as indicated by the regression equation (113.95x + 19.28) and a coefficient of determination of 0.52. This suggests that increases in built-up surfaces are associated with higher surface temperatures, with about 52% of the variation in LST explained by changes in NDBI.

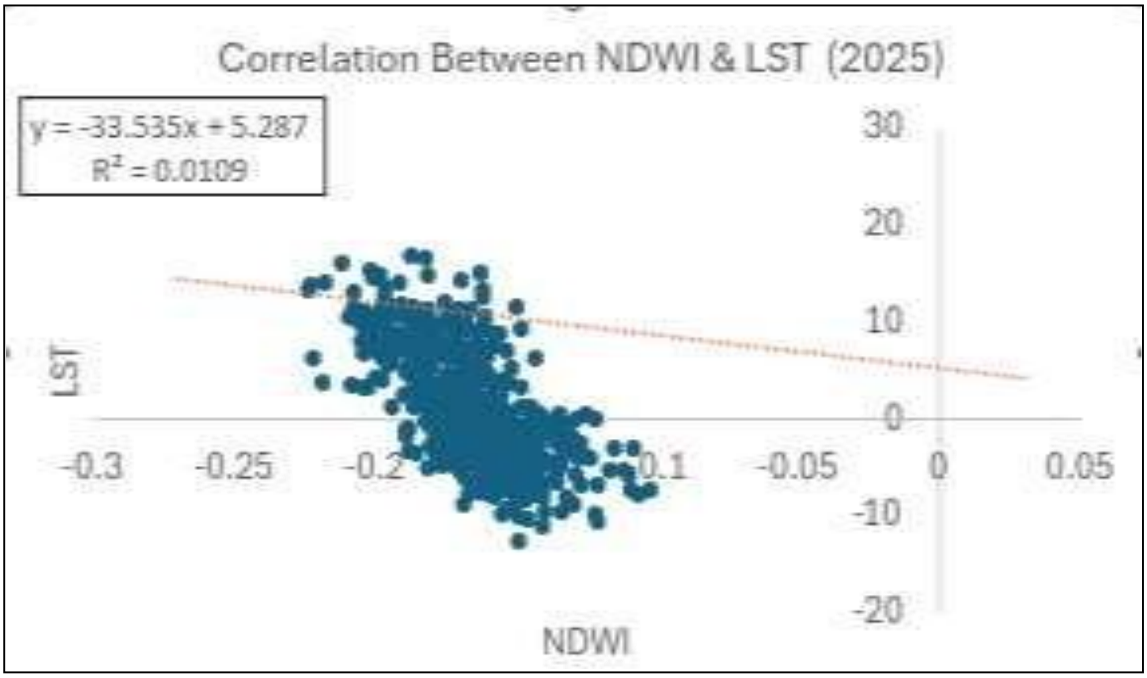

Figure 8: NDWI vs. LST

Figure 8 shows a weak inverse relationship between the Normalized Difference Water Index (NDWI) and land surface temperature (LST), as indicated by the negative regression equation (−33.535x + 5.287). However, the very low coefficient of determination ($R^2 \approx 0.011$) suggests that NDWI explains only about 1% of the variation in LST.

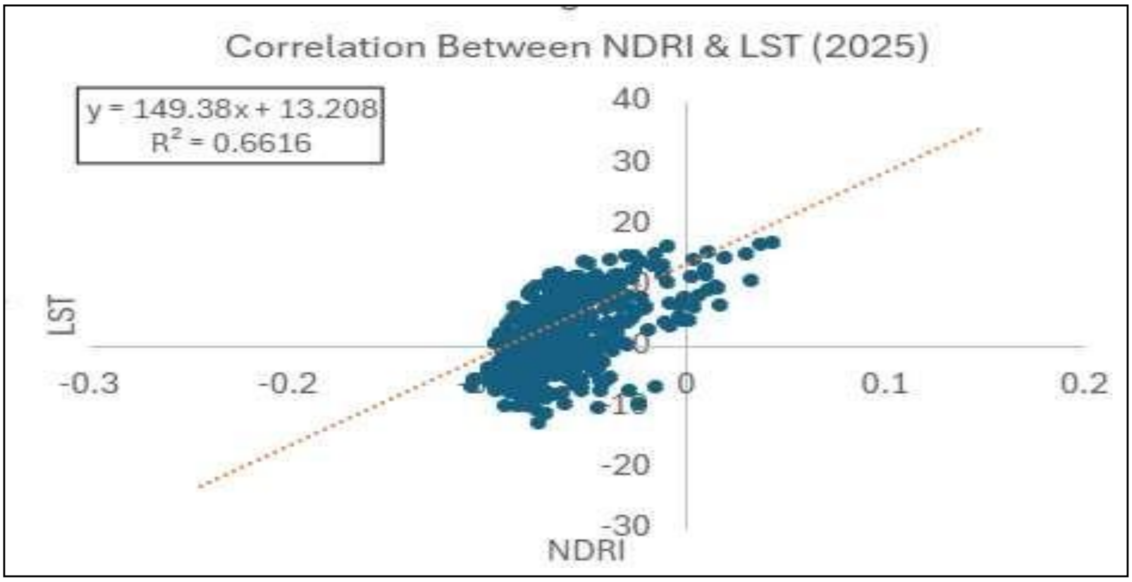

Figure 9: NDRI vs. LST

Figure 9 indicates a moderate to strong positive relationship between the Normalized Difference Rocky Index (NDRI) and land surface temperature (LST), as shown by the regression equation (149.38x + 13.208) and a coefficient of determination of 0.66. This suggests that increases in rocky or exposed surface areas are associated with higher surface temperatures, with about 66% of the variation in LST explained by changes in NDRI.

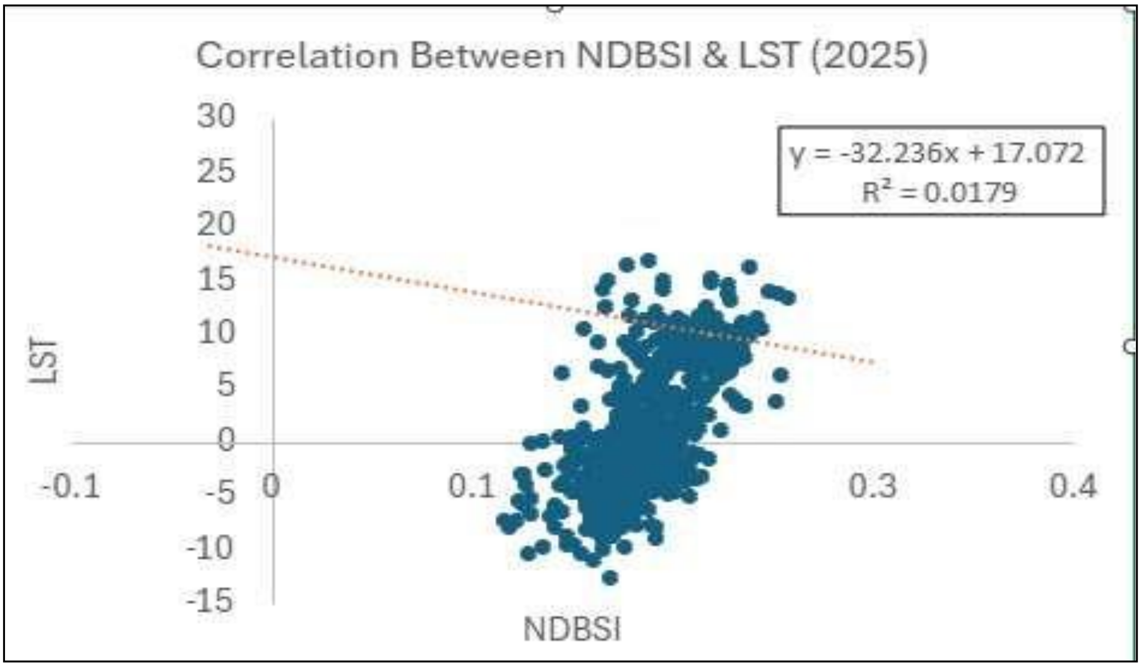

Figure 10: NDBSI vs. LST

Figure 10 indicates a weak inverse relationship between the Normalized Difference Bare Soil Index (NDBSI) and land surface temperature (LST), as shown by the negative regression equation (−32.236x + 17.072) and the very low coefficient of determination ($R^2 = 0.0179$). This implies that changes in bare soil surfaces account for less than 2% of the variation in LST.

Discussion

The results of the temporal changes of land cover types in Ife Central LGA indicate significant land cover transformations in Ife Central LGA between 2015 and 2025, characterized by a marked expansion of urban areas from 16.4% to 26.1%. This rapid urban growth aligns with trends observed in other Nigerian cities, as reported by Ajala *et al*. (2024), who noted that urban metamorphosis in Ile-Ife has been largely driven by population growth, infrastructural development, and increased economic activities, often at the expense of vegetative cover. Similarly, Oyeniyi *et al*. (2024), in their study of Akure and Osogbo, found that urban expansion between 2014 and 2023 led to a substantial reduction in vegetation cover and a corresponding increase in built-up areas, highlighting the common pattern of urban sprawl in mid-sized Nigerian cities.

The decrease in vegetation from 70.2% to 65.4% in Ife Central is particularly significant, as it reflects the ongoing conversion of natural land cover into urbanized environments. This loss of green cover is consistent with global observations linking urban expansion to environmental modifications. For instance, Ma & Dong (2023) demonstrated in Zhengzhou, China, that reduction in vegetation cover intensifies the surface urban heat island (SUHI) effect, suggesting that the vegetative losses in Ife Central could have similar implications for local microclimate and thermal comfort. Das &Angadi (2020) also reported that LULC transformations in

Barrackpore, India, directly corresponded with rising land surface temperatures, reinforcing the ecological consequences of replacing vegetation with impervious surfaces.

The decline of bare surfaces and rocky outcrops in Ife Central suggests that previously uncultivated or marginal lands are increasingly being absorbed into urban expansion. This observation resonates with the findings of Mekonnen *et a*l. (2024) in Gondar, Ethiopia, where similar land conversions contributed to urban heat intensification and highlighted the role of both physical geography and human development in shaping urban landscapes.

The results of the temporal changes in UHI intensity in the study area reveal a notable increase between 2015 and 2025. The minimum surface temperature rose from 25.2 °C to 27.3 °C, while the maximum increased from 31.1 °C to 33.9 °C. This trend indicates that the study area is experiencing intensified warming over the decade, likely driven by the substantial expansion of urban areas and the concomitant reduction in vegetation cover. These findings are consistent with studies across Nigeria and globally. For instance, Ochei & Ogunfuyi (2023) reported that urbanization in Ondo State led to rising surface temperatures, with built-up expansion and vegetation loss identified as the main drivers of increased UHI intensity. Similarly, Odunsi & Rienow (2024) found that Abeokuta's economic growth and urban cluster development were closely linked to elevated UHI effects, emphasizing how urbanization-induced land cover changes exacerbate local warming.

In Enugu, Nigeria, Ofordu *et al*. (2022) observed that UHI intensity was closely tied to urban growth patterns, with areas of dense built-up land showing significantly higher temperatures than vegetated or open areas. These studies reinforce the pattern observed in Ife Central, where urban expansion and vegetation reduction have directly contributed to elevated surface temperatures.

The observed increase in both minimum and maximum temperatures suggests that UHI effects in Ife Central are not only becoming more pronounced but may also persist longer into the night, as minimum temperatures typically reflect nocturnal heat retention. This aligns with general UHI behavior documented in both tropical and subtropical urban environments, where impervious surfaces absorb heat during the day and release it slowly at night, increasing the thermal load on residents (Odunsi & Rienow, 2024; Ofordu *et al*., 2022).

The results of the correlation between the selected spectral indices of the land cover and LST confirms that built-up and rocky surfaces are the primary drivers of elevated LST in Ife Central, while vegetation, water bodies, and bare soil play minor roles in regulating surface temperature. These results highlight the need for strategic urban planning interventions, including increased vegetation cover, urban green spaces, and reflective or permeable materials in built-up areas to mitigate SUHI effects, in line with recommendations from the reviewed literature (Makinde & Agbor, 2019; Koko *et al*., 2021; Ofordu *et al*., 2022; Rauf & Pasra, 2020).

Conclusion and Recommendations

The study reveals that rapid urban expansion in Ife Central LGA is driving significant environmental and thermal changes, intensifying the Urban Heat Island effect. Built-up and rocky surfaces are the main contributors to elevated surface temperatures, while vegetation and water bodies offer limited mitigation. These insights underscore the urgent need for evidence-based urban planning policies that prioritize green infrastructure, sustainable land use, and climate-adaptive building practices. Implementing such strategies is crucial for reducing heat stress, enhancing urban resilience, and promoting sustainable development in rapidly urbanizing areas.

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