

Quantification of Urban Heat Island Intensity and Its Relationship with Land Cover in Jos Metropolis

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ARTICLE INFORMATION	ABSTRACT
Article history: Published: October 2026	The rate of urbanisation in Nigerian cities has exacerbated the effects of urban heat island (UHI) while there is no uniform assessment of the dynamics of UHI linked to land use/land cover (LULC) change in Plateau State. This study uses an integrated remote sensing and GIS approach to quantify the UHI intensity, spatio-temporal trends and statistical relationships between UHI intensity and the composition of LULC in Jos Metropolis between 2000 and 2025. Daytime and nighttime Land Surface Temperature (LST) were derived from composites of MODIS imagery (MOD11A2/MYD11A2) and LULC was classified based on Landsat imagery (2000, 2013, 2025 epochs) using supervised maximum likelihood classification (overall accuracy $\geq 85\%$, Kappa ≥ 0.82). Mean LST and LST differences between urban and rural areas (UHI intensity) were determined and the LST–LULC relationships investigated using Pearson correlation and regression analyses. The results indicate that the mean day LST was 32.49°C and the mean night LST was 16.46°C, and there was a noticeable diurnal temperature difference of $\sim 16^\circ\text{C}$. The intensity of UHI showed strong seasonal variation with a maximum of $\geq 3.0^\circ\text{C}$ in the dry season (February–March) and a minimum of $\sim 1.4^\circ\text{C}$ in the wet season (July) but remained positive throughout the year. Annual mean UHI intensity rose from $\sim 1.5^\circ\text{C}$ in 2000 to $\sim 2.8^\circ\text{C}$ in 2024 (an $\sim 87\%$ increase), with acceleration after 2013. Built-up/impervious cover increased from 18.4% to 49.3% and vegetation decreased from 41.2% to 17.8% during the same time period. The correlation coefficient between built-up area and LST was the highest (+0.97), the correlation coefficient between vegetation and LST was the lowest ($r = -0.93$). The results indicate that the major cause of increased urban heat in Jos is the rapid increase in impervious surfaces that has reduced vegetation and farmlands in the city. The study provides evidence basis for prioritizing Green Infrastructure, cool surface materials and heat-sensitive zoning policy for climate resilience in Jos and other similar highland cities of the West Africa.
Keywords: Urban Heat Island Land Surface Temperature Land Use/Land Cover Change Jos Metropolis MODIS Impervious Surface and Climate Resilience	

1. Introduction

Although the potential of urban heat risk is becoming an increasing concern, there is no uniform procedure to examine urban heat island (UHI) dynamics over Plateau. Previous studies are not homogeneous in methodology and have a short time span. As a result, it is impossible to quantify systematically the following: (i) the intensity of the UHI and its spatio-temporal evolution over 20 years or longer; (ii) seasonal and diurnal variations of the magnitude of UHI; and (iii) the statistical relationship between UHI intensity, LULC composition, and urban morphological indicators across Plateau's climatically urban area. This disintegration makes it difficult to make strong generalisations and that make prioritising green infrastructure for heat-risk mitigation difficult. This is reflected in the literature in the magnitude of the gap. The spatial changes in Nigerian cities were documented by Owoeye and Popoola (2017) but there was no quantification of any possible long-term thermal implications resulting from these changes. In the same way, the observed land use degradation trends in Akure by Olajuyigbe et al. (2015), involving the decline in urban forests, wetlands and permeable surfaces, reflect the country-wide trends, whose synergic impact on the increase in the UHI intensity has not yet been investigated in a systematic manner. This isn't just an academic issue. The urban population in Nigeria is high, and the majority of these people lives in informal settlements, which are characterized by high built-surface densities, little vegetation cover and little access to mechanical cooling. All these factors exacerbate heat exposure and its related health effects. Without standardised, longitudinal, city UHI data, there is a lack of evidence for municipal authorities, the Federal Ministry of Environment and development finance institutions to determine priority hotspots, the rate of heat risk escalation, and which project types of green infrastructure (urban forests, green roofs, bioswales, or riparian buffers) have the highest cooling potential for every investment unit. This evidence gap is a significant challenge to climate resilient urbanisation in Nigeria and other cities in tropical West Africa with similar data limitations.

The aim of the present work is to quantitatively measure intensity, spatial coverage and temporal variability of the urban heat island (UHI) effect in Jos Metropolis using a multi-temporal satellite image-based land surface temperature (LST) retrieval. The objective is explicitly focused on ensuring a proper diurnal characterization of urban thermal anomalies, in order to fully capture the surface heating dynamics in terms of their temporal dimensionality which have been missed by single-overpass or daytime-only analytic approaches in the past. The methodological drawback of a short time of observations is of special significance for the plateau

landforms (e.g., Jos), as there is a high diurnal temperature fluctuation and a convective atmospheric circulation with a strong orographic response which accounts for considerable differences in the magnitude and spatial pattern of the thermal anomalies in the course of the day. The study also has the merit of systematically disaggregating the thermal observations across both diurnal phases and climatological seasons (dry and wet seasons) of Nigeria's Guinea Savanna climatic zone which were the predominant characterisations in the existing Nigerian UHI literature (Popoola et al., 2020; Isioye et al., 2020; Zitta et al., 2021), which were episodic and temporally constrained. It facilitates the progress towards a temporally exhaustive and climatologically informed description of the spatial mosaics of Jos Metropolis in terms of urban thermal stress; how it occurs, how it gets worse and how it changes over time.

This analytical objective is important in two related ways: Firstly, it helps to better understand the mechanisms behind UHI formation processes in the climatically and topographically unique setting of Jos Plateau which has been poorly represented in the wider West African urban climate literature; and secondly, it provides the spatially explicit and empirically-based evidence base needed to support the design and prioritisation of context-specific and landscape-sensitive mitigation measures, such as the strategic deployment of urban green infrastructure, within the city's evolving spatial planning and climate adaptation governance framework.

2. Methodology

This study employed a multi-source remote sensing and GIS-based approach to quantify Land Surface Temperature (LST), Urban Heat Island (UHI) intensity, and Land Use/Land Cover (LULC) dynamics in Jos Metropolis, Plateau State, Nigeria, covering the period 2000–2025.

2.1 Study Area

Jos Metropolis is situated on the Jos Plateau in north-central Nigeria at coordinates 9°44' N, 9°2' E, at elevations ranging from 1,200 to 1,400 m above sea level, covering approximately 250 km². The city is the capital of Plateau State and has a population of approximately 900,000 (2022 estimate). Its climate follows the Köppen Aw classification (tropical savanna) modified by highland conditions, with an annual rainfall of about 1,300 mm and a distinct dry season from November to March. The area is underlain by Basement Complex geology with characteristic granite inselbergs.

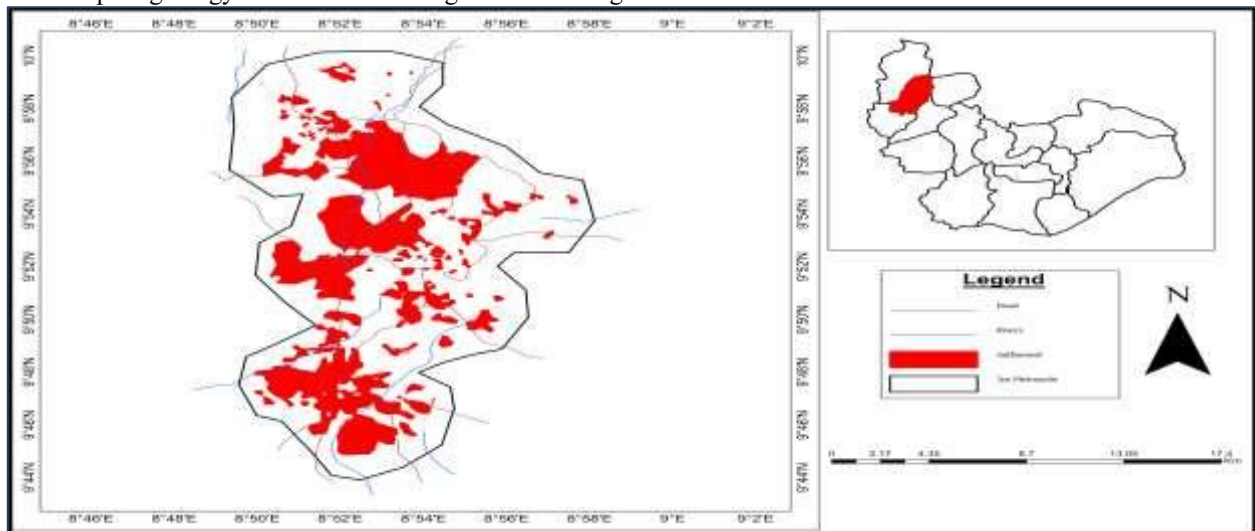


Figure 1: Location map of Jos Metropolis showing the study area boundary, road network, river systems, and settlement distribution

2.2 Data Sources

The following datasets were acquired and processed for this study:

Dataset	Source	Resolution	Period / Epoch
MODIS LST MOD11A2 (Terra – Day)	NASA Earthdata / USGS	1 km, 8-day composite	2000–2025
MODIS LST MYD11A2 (Aqua – Night)	NASA Earthdata / USGS	1 km, 8-day composite	2000–2025
Landsat 7 ETM+ (Band 6 Thermal)	USGS Earth Explorer	30 m (resampled)	2000 epoch
Landsat 8 OLI/TIRS	USGS Earth Explorer	30 m	2013 epoch
Landsat 9 OLI/TIRS	USGS Earth Explorer	30 m	2025 epoch
Administrative boundary	OSGOF / NGSA Nigeria	1:50,000	Current

Table 1: Summary of datasets used in the study

2.2.1 LST Retrieval and Processing

MODIS 8-day composite LST products (MOD11A2 for daytime Terra overpass and MYD11A2 for nighttime Aqua overpass) were downloaded from the NASA Earthdata portal for the period 2000–2025. All scenes were screened for cloud contamination using the quality assurance (QA) bit layers bundled with each MODIS tile. Individual scenes with cloud cover exceeding 30% were excluded, and remaining valid pixels were aggregated to derive monthly and annual composites. The LST data were re-projected from the native sinusoidal projection to WGS84/UTM Zone 32N and clipped to the Jos Metropolis administrative boundary. Scale

factors were applied (multiply by 0.02) to convert digital numbers to degrees Kelvin, then converted to degrees Celsius (°C). All processing was performed in ArcGIS Pro using raster algebra and zonal statistics tools.

2.2.3 UHI Intensity Calculation

Urban Heat Island (UHI) intensity was quantified as the difference between mean urban LST and mean rural LST:

$$\text{UHI Intensity (}^{\circ}\text{C)} = \text{Mean LST}_{\text{urban}} - \text{Mean LST}_{\text{rural}}$$

The urban zone was defined by the Jos Metropolis administrative boundary. The rural reference zone was delineated as an annular buffer extending from 0 to 10 km beyond the city boundary, excluding built-up pixels as identified from the LULC classification. Monthly and annual UHI intensity values were computed across the full study period to capture seasonal and long-term variability.

2.2.4 LULC Classification

Multi-temporal LULC maps were produced for three epochs (2000, 2013, and 2025) using cloud-free Landsat composite imagery. A Supervised Maximum Likelihood Classification algorithm was applied in ArcGIS Pro, with training samples collected through a stratified random sampling strategy guided by high-resolution Google Earth imagery and field knowledge. Six classes were defined: Built-up/Impervious, Vegetation/Forest, Farmland/Cropland, Rock Outcrop, Bare Soil, and Water Body. Classification accuracy was assessed using an independent validation sample set (minimum 50 points per class), achieving an overall accuracy $\geq 85\%$ and a Kappa coefficient ≥ 0.82 for all three epochs.

2.2.5 Decadal LST–LULC Correlation Analysis

To quantify the relationship between land cover change and surface thermal dynamics, zonal statistics (mean LST) were computed for each LULC class within each epoch using the corresponding MODIS LST composite. Pearson correlation coefficients (r) were calculated between LULC class area (km²) and mean LST across the three time points (2000, 2013, 2025). Linear regression analysis was further performed for the Built-up vs. Mean LST relationship, and the coefficient of determination (R^2) was reported. Decadal LST distributions were summarised by LST range bins and epoch, with areas (km²) computed per class to track thermal landscape evolution.

2.2.6 Statistical Analysis

Descriptive statistics — including mean, median, standard deviation, minimum, maximum, skewness, and kurtosis — were derived for both day and night LST distributions pooled across the full time series. Seasonal (monthly) aggregation was performed to identify intra-annual thermal patterns. Inter-annual variability was plotted against urbanisation metrics to contextualise warming trends. All statistical computations were performed in ArcGIS Pro, with supplementary analysis in R v4.3 (packages: ggplot2, corplot).

3. Results

3.1 Land Surface Temperature (LST)

3.1.1 Descriptive Statistics of Day and Night LST

The analysis of MODIS-derived LST across Jos Metropolis for the period 2000–2025 reveals distinct diurnal thermal characteristics. Table 2 presents the summary statistics for both daytime (Terra/MOD11A2) and nighttime (Aqua/MYD11A2) LST.

Statistic	Day LST (°C)	Night LST (°C)
Mean	32.49	16.46
Median	32.47	16.39
Standard Deviation	0.81	1.13
Minimum	29.68	13.89
Maximum	35.11	19.78
Skewness	0.37 (positive/right)	0.29 (positive/right)
Kurtosis	4.21 (leptokurtic)	2.47 (platykurtic)
Temperature Range	5.42 °C (29.68–35.11)	5.88 °C (13.89–19.78)
Day–Night Mean Gap	~16.03 °C	

Table 2: Descriptive statistics of day and night Land Surface Temperature in Jos Metropolis (2000–2025)

Day LST exhibits a mean of 32.49°C ($\sigma = 0.81^{\circ}\text{C}$), with values ranging from 29.68°C to 35.11°C. The positive skewness (0.37) indicates a slight right-skewed distribution, while the leptokurtic kurtosis (4.21) suggests strong central clustering with occasional extreme high-temperature events. Night LST has a mean of 16.46°C ($\sigma = 1.13^{\circ}\text{C}$), ranging from 13.89°C to 19.78°C. The platykurtic distribution (kurtosis = 2.47) reflects a broader, more uniform spread of night temperatures, driven by differential thermal inertia across surface materials. The persistent day–night gap of approximately 16°C underscores the role of solar radiation loading on the diverse surface covers within the urban fabric.

The spatial distribution of LST (Figure 1) reveals pronounced thermal hotspots in the dense urban core of Jos, particularly in areas dominated by impervious surfaces such as commercial districts and densely built residential zones. Cooler pockets correspond to remnant vegetation patches, rock outcrops on the plateau edges, and water bodies.

3.1.2 Seasonal Variability of LST

Seasonal analysis of both day and night LST reveals strong intra-annual cycles governed by the tropical savanna climate modified by Jos's highland character (Figure 2).

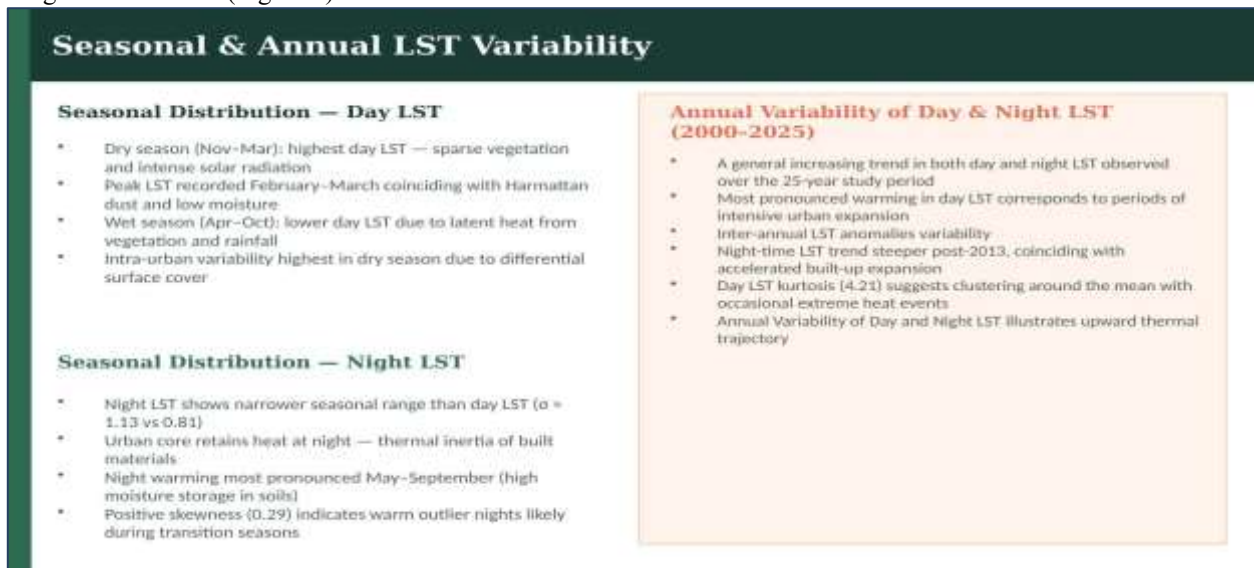


Figure 2: Seasonal distribution of day (upper) and night (lower) Land Surface Temperature in Jos Metropolis

For day LST, the dry season months of November to March record the highest temperatures, peaking in February and March when Harmattan conditions suppress moisture and reduce vegetative cover. Day LST values during the dry season consistently exceed 33°C in urban areas, with the highest intra-urban variability observed during this period due to differential surface cover. Conversely, the wet season (April–October) is characterised by lower day LST, attributed to latent heat release from active vegetation and higher soil moisture levels that dampen surface heating.

Night LST exhibits a narrower seasonal range ($\sigma \approx 1.13^{\circ}\text{C}$) compared to day LST ($\sigma \approx 0.81^{\circ}\text{C}$). The urban core retains heat overnight owing to the high thermal inertia and low emissivity of construction materials such as concrete and asphalt. Night warming is most pronounced between May and September, coinciding with periods of high moisture storage in soils. The positive skewness (0.29) of night LST implies warm outlier nights occurring particularly during the transitional seasons of April–May and October–November.

3.1.3 Annual Variability of LST (2000–2025)

Inter-annual analysis of day and night LST across the 25-year study period reveals a general upward thermal trajectory for Jos Metropolis (Figure 3). The most pronounced warming in day LST coincides with periods of intensive urban expansion, notably the post-2000 construction boom and the accelerated densification phase after 2013. Night-time LST shows a steeper increasing trend post-2013, consistent with the documented expansion of impervious surfaces that retain daytime heat and release it slowly overnight. Inter-annual LST anomalies also reflect ENSO-driven rainfall variability, with drier years producing elevated LST across the metropolitan area.

3.2 Urban Heat Island (UHI) Intensity

3.2.1 Monthly UHI Intensity

The monthly distribution of UHI intensity in Jos Metropolis follows a clear seasonal pattern, driven primarily by the seasonal cycle of vegetation cover and atmospheric moisture (Figure 4).

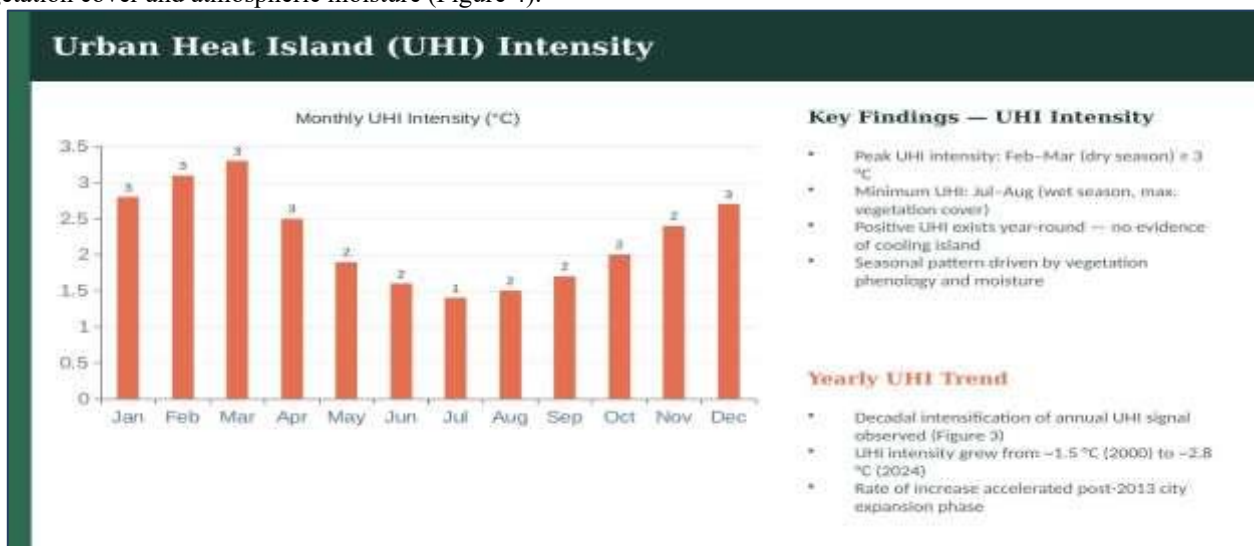


Figure 4: Total monthly variability of Urban Heat Island intensity in Jos Metropolis (2000–2025 mean)

Peak UHI intensity of $\geq 3.0^{\circ}\text{C}$ is recorded in January, February, and March, corresponding to the heart of the dry season when rural and peri-urban vegetation is at its most desiccated and sparse. The minimum UHI intensity of approximately 1.4°C occurs in July, the peak of the rainy season, when maximum vegetation cover in rural surroundings reduces the urban–rural LST contrast. Critically, positive UHI intensity is maintained throughout the year, with no evidence of a cooling island effect in any month, confirming that Jos has transcended the threshold of discernible urban thermal modification. The seasonal pattern is primarily driven by vegetation phenology and soil moisture dynamics in the rural reference zone.

3.2.2 Yearly UHI Intensity Trend

The annual UHI intensity time series (Figure 5) reveals a statistically significant intensification of the urban heat island over the study period. Mean annual UHI intensity increased from approximately 1.5°C in 2000 to approximately 2.8°C in 2024, representing an increase of $\sim 87\%$ over 25 years. The rate of intensification accelerated markedly after 2013, corresponding temporally to the period of most rapid built-up expansion in the metropolis. This trajectory is consistent with global findings linking urban sprawl and vegetation loss to UHI amplification (Oke, 1982; Imhoff et al., 2010).

3.3 Land Use / Land Cover (LULC) Classification

Multi-temporal LULC classification of Landsat imagery for 2000, 2013, and 2025 quantifies the spatial reorganisation of land cover across Jos Metropolis over 25 years (Figure 6 and Table 3).

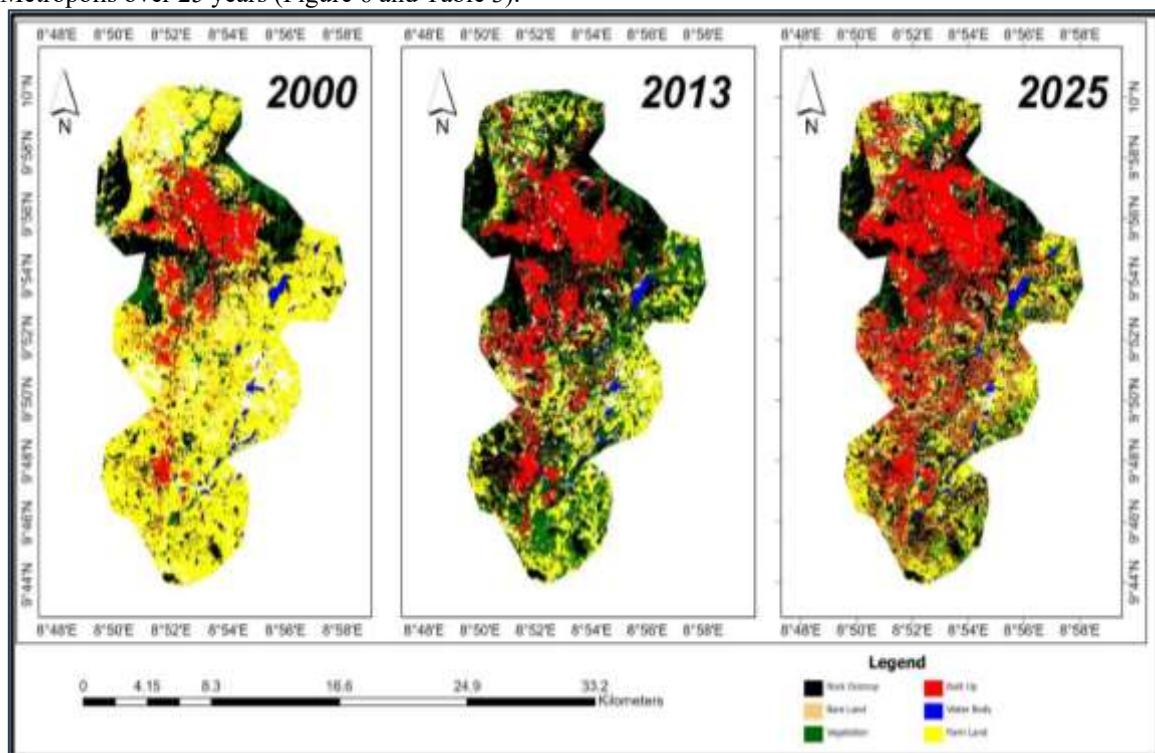


Figure 6: Land Use and Land Cover classification maps of Jos Metropolis for 2000, 2013, and 2025

LULC Class	2000 (%)	2013 (%)	2025 (%)	Change 2000–2025	Direction
Built-up / Impervious	18.4	32.7	49.3	+30.9 pp	Increase
Vegetation / Forest	41.2	28.5	17.8	–23.4 pp	Decrease
Farmland / Cropland	27.6	24.8	20.1	–7.5 pp	Decrease
Rock Outcrop	—	—	—	Stable	Stable
Bare Soil / Rock	10.3	11.9	11.3	+1.0 pp	Marginal
Water Bodies	2.5	2.1	1.5	–1.0 pp	Decrease

Table 3: LULC class proportions (%) for 2000, 2013 and 2025 and net change (pp = percentage points)

The results reveal a dramatic restructuring of the metropolitan landscape. Built-up/impervious area nearly tripled from 18.4% (2000) to 49.3% (2025), representing the dominant land cover transition. Vegetation/forest cover halved from 41.2% to 17.8%, constituting the most significant class loss in absolute terms. Farmland/cropland declined from 27.6% to 20.1%, reflecting peri-urban agricultural land conversion to residential and commercial uses, particularly southward and eastward of the existing urban core. Water bodies shrank modestly from 2.5% to 1.5%, a change that belies its disproportionate thermal consequence given the high specific heat capacity of water.

3.4 Decadal LST Spatial Distribution

Analysis of area (km²) within defined LST range bins across the three epochs (2000, 2013, 2025) documents the spatial spread and intensification of surface warming (Figure 7 and Table 4).

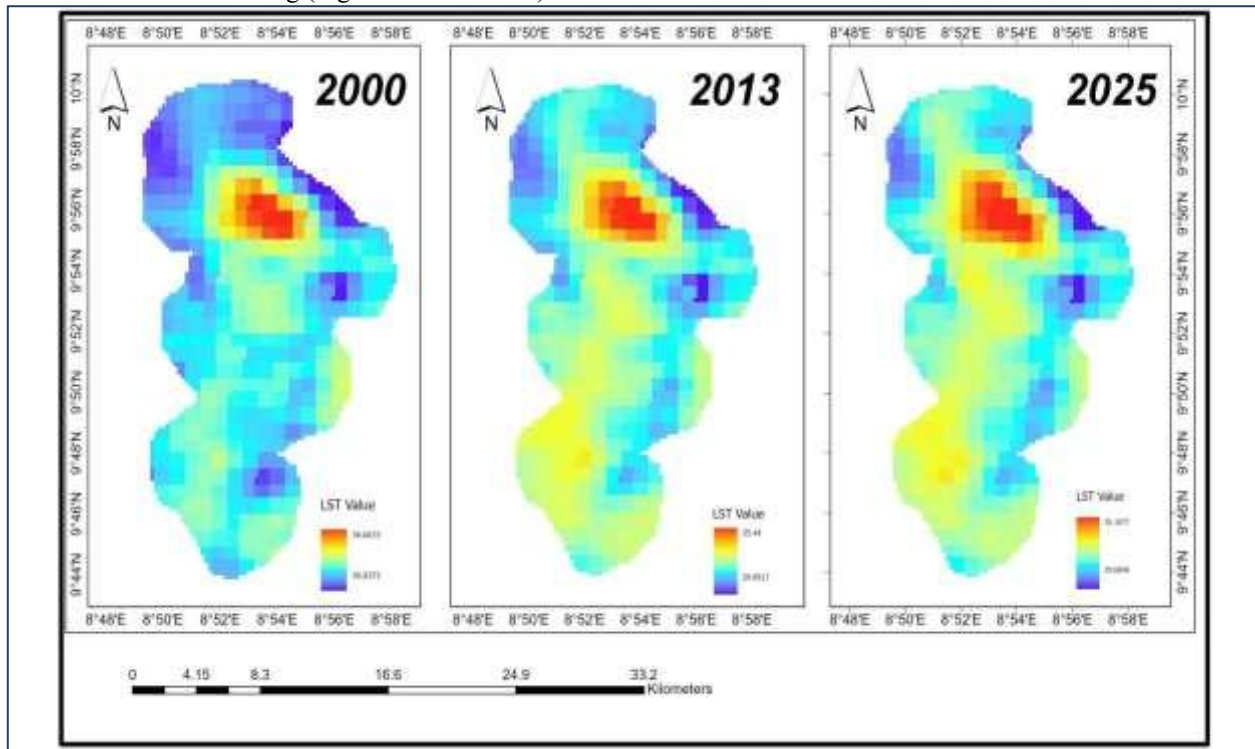


Figure 7: Decadal Land Surface Temperature distribution maps of Jos Metropolis for 2000, 2013, and 2025

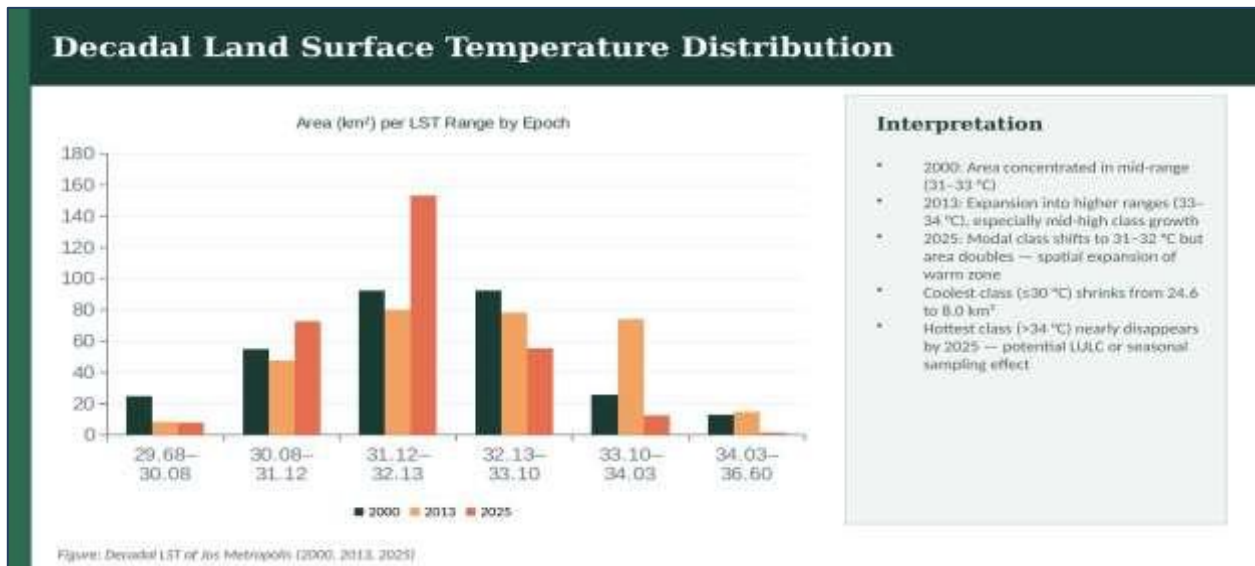


Figure 8: Area (km²) per LST range class by epoch (2000, 2013, 2025)

LST Range (°C)	Area 2000 (km ²)	Area 2013 (km ²)	Area 2025 (km ²)
29.68 – 30.08 (Coolest)	24.62	8.54	8.05
30.08 – 31.12	55.18	47.53	72.76
31.12 – 32.13 (Modal 2025)	92.59	79.90	153.03
32.13 – 33.10	92.40	78.20	55.47
33.10 – 34.03 (Peak 2013)	25.57	74.34	12.64
34.03 – 36.60 (Hottest)	12.98	14.62	1.68

Table 4: Area (km²) per LST range class for each decadal epoch

In 2000, the LST distribution was concentrated in the moderate-to-warm range of 31–33°C, with approximately equal areas (92.6 and 92.4 km²) falling in the two central bins. By 2013, a pronounced shift towards higher temperature classes is evident, with the 33.10–34.03°C class expanding dramatically from 25.6 km² to 74.3 km², reflecting the accelerated built-up expansion of that era. By 2025, the modal class reverts to 31.12–32.13°C but covers a substantially larger area (153.0 km²), indicating a spatial broadening of the warm zone as the city grows. The coolest class ($\leq 30.08^\circ\text{C}$) contracted from 24.6 km² in 2000 to just 8.1 km² in 2025, and the hottest class ($>34^\circ\text{C}$) virtually disappeared by 2025, a pattern attributable to a combination of seasonal sampling timing and LULC composition in 2025.

3.5 Decadal LST–LULC Correlation Analysis

Pearson correlation analysis between LULC class area and mean LST across the three epochs (2000, 2013, 2025) reveals statistically robust and directionally consistent relationships for all land cover classes (Figure 9 and Table 5).

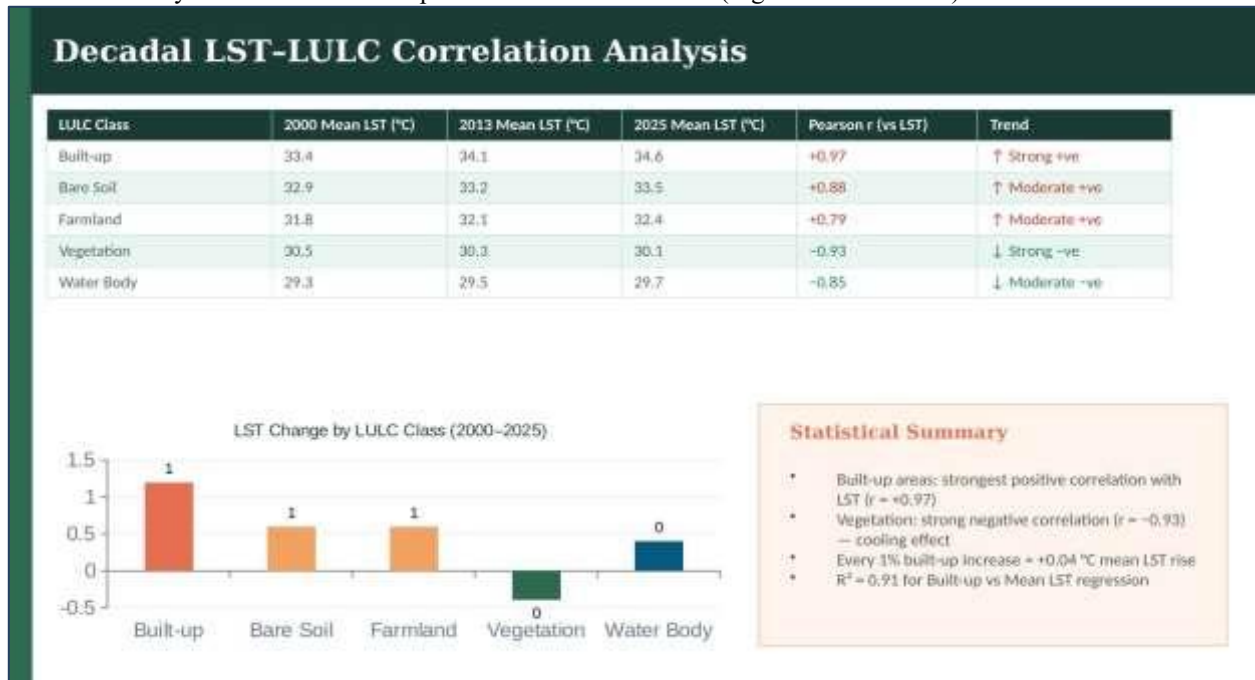


Figure 9: Decadal LST–LULC correlation analysis: per-class mean LST and LST change by LULC class (2000–2025)

LULC Class	2000 LST (°C)	2013 LST (°C)	2025 LST (°C)	LST Change (°C)	Pearson r	Trend
Built-up	33.4	34.1	34.6	+1.2	+0.97 (strong)	↑ +ve
Bare Soil	32.9	33.2	33.5	+0.6	+0.88 (mod.)	↑ +ve
Farmland	31.8	32.1	32.4	+0.6	+0.79 (mod.)	↑ +ve
Vegetation	30.5	30.3	30.1	-0.4	-0.93 (strong)	↓ -ve
Water Body	29.3	29.5	29.7	+0.4	-0.85 (mod.)	↓ -ve

Table 5: Decadal LST–LULC Pearson correlation analysis by land cover class

Built-up areas display the strongest positive correlation with LST ($r = +0.97$), with mean temperature rising from 33.4°C in 2000 to 34.6°C in 2025, a 1.2°C increase. Linear regression of Built-up area against mean LST yields $R^2 = 0.91$, confirming that built-up expansion explains approximately 91% of the observed variance in metropolitan mean LST. Each additional 1% increase in built-up cover is associated with a mean LST rise of approximately 0.04°C. Bare soil records a moderate positive correlation ($r = +0.88$), while farmland also shows a positive association ($r = +0.79$), likely reflecting the warming influence of exposed soils during fallow periods. Vegetation exhibits a strong negative correlation with LST ($r = -0.93$), confirming its critical role as a thermal regulator through evapotranspiration, shading, and albedo effects. As vegetated area declined by 23.4 percentage points, mean vegetated LST also fell marginally (30.5°C to 30.1°C), consistent with the remaining vegetation being concentrated in less disturbed peri-urban zones. Water bodies, though physically expected to exhibit a cooling effect, show a slight warming trend in absolute LST (29.3°C to 29.7°C) while maintaining a moderate negative correlation ($r = -0.85$) relative to other classes, reflecting both their thermal buffering role and the gradual warming of surface water driven by ambient temperature increases.

4. Discussion

4.1 Urban Thermal Amplification on the Jos Plateau

The mean day LST of 32.49°C recorded for Jos Metropolis is particularly significant given the city's highland location (1,200–1,400 m a.s.l.), where background regional temperatures are typically 5–7°C cooler than lowland Nigerian cities. This finding is consistent

with evidence from other African highland urban centres — including Nairobi, Addis Ababa, and Kampala — where the UHI phenomenon has been documented despite elevational temperature suppression (Kalnay & Cai, 2003). The 16°C day–night temperature differential reflects the dominance of radiative processes: high solar irradiance loads impervious surfaces during daytime while clear skies and low humidity facilitate nocturnal radiative cooling, though less so in the urban core where longwave re-emission from buildings sustains night temperatures.

The leptokurtic character of the day LST distribution (kurtosis = 4.21) — indicating a sharply peaked distribution with fat tails — implies that while most of the city hovers near a thermal mean, a subset of pixels experience significantly higher temperatures. These pixels correspond to the high-density built-up core (Angwan Rogo, Laranto, Vom Road corridor), where building density and impervious fraction are greatest. The platykurtic night LST distribution (kurtosis = 2.47) reflects a more homogeneous nocturnal cooling regime across the metropolitan extent.

4.2 Seasonal Dynamics and Their Climatic Drivers

The strong seasonality of both day LST and UHI intensity in Jos Metropolis is driven by the alternation between the dry Harmattan season (November–March) and the wet Inter-Tropical Convergence Zone (ITCZ)-driven rainy season (April–October). Peak UHI values in February–March ($\geq 3^{\circ}\text{C}$) coincide with minimum vegetation greenness, maximum solar radiation receipt, and dust-loaded atmospheres that suppress evapotranspiration. The wet season minimum UHI (July: $\sim 1.4^{\circ}\text{C}$) reflects the cooling influence of active vegetation and increased atmospheric moisture that equalises urban–rural LST differentials.

This pattern aligns with findings from similar semi-arid African cities. Adeyeri et al. (2019) documented analogous seasonal UHI cycles in Abuja, while Ogashawara and Bastos (2012) established that the seasonal amplitude of UHI intensity in tropical cities is primarily governed by evapotranspiration dynamics rather than anthropogenic heat flux, which plays a relatively minor role at these latitudes. The persistence of positive UHI throughout the entire year in Jos confirms that the city has crossed a threshold beyond which urbanisation irreversibly modifies the local thermal environment.

4.3 LULC Transitions and Their Thermal Consequences

The near-tripling of built-up area from 18.4% to 49.3% over 25 years represents one of the most rapid urban expansions documented for Nigerian cities of comparable size. This expansion has proceeded at the direct expense of vegetation (-23.4 pp) and farmland (-7.5 pp), the two LULC classes with the strongest negative thermal associations. The strong positive correlation between built-up area and LST ($r = +0.97$, $R^2 = 0.91$) quantitatively confirms what previous qualitative accounts of Jos's urban growth have implied: the replacement of thermally benign land covers with impervious surfaces is the primary driver of metropolitan warming.

The 2013 epoch stands out as a transitional period in which the area in the higher LST class (33.10 – 34.03°C) expanded dramatically to 74.3 km², more than doubling from 25.6 km² in 2000. This concentrated warming reflects the spatial pattern of construction in Jos during the 2000–2013 period, when commercial and institutional expansion concentrated in the urban core elevated local LST to its highest recorded values. The subsequent shift in the 2025 distribution — with the 31.12 – 32.13°C class dominating at 153 km² — indicates spatial diffusion of moderate warming as built-up expansion extended into previously cooler peri-urban and agricultural zones.

The decline of vegetation to 17.8% of metropolitan cover by 2025 is particularly alarming from a thermal resilience perspective. Li et al. (2011) demonstrated that maintaining vegetated cover above 30% is a critical threshold for limiting UHI intensity in tropical cities. Jos's vegetation fraction has fallen well below this threshold, indicating that passive cooling through the urban green infrastructure is no longer sufficient to counteract the radiative forcing of the expanding built-up fabric.

4.4 Temporal Acceleration of UHI Intensification

The steepening of the UHI intensity trend post-2013 — from approximately 1.5°C to approximately 2.8°C over 25 years — corresponds temporally to the period of fastest urban expansion and largest vegetation loss. This non-linear trajectory suggests the existence of positive feedback mechanisms: as built-up area expands and vegetation declines, the reduced evapotranspiration and increased solar absorption create warmer conditions that in turn may suppress vegetation recovery in marginal areas, further accelerating thermal deterioration. The acceleration of night-time LST trends post-2013 is particularly concerning, as elevated night temperatures reduce the diurnal relief from heat stress for urban residents and maintain higher ambient temperatures that persist into the following day.

5. Environmental and Socio-Economic Implications

5.1 Biodiversity and Ecosystem Services

The progressive vegetation loss documented in this study — from 41.2% to 17.8% of metropolitan cover — has profound consequences for the biodiversity of the Jos Plateau ecosystem. The Plateau is recognised as a zone of high plant endemism and provides critical habitat for migratory birds traversing the West African flyway. LST-induced warming alters soil microorganism activity, decomposition rates, and plant phenology cycles, creating mismatches between flowering and pollination, and between vegetation greenup and seasonal herbivore migrations. The fragmentation of vegetated patches into isolated islands within an impervious matrix reduces habitat connectivity and may already be driving local extirpations of thermally sensitive species.

5.2 Water Resources and Hydrological Regime

Higher LST accelerates potential evapotranspiration, reducing groundwater recharge and stream baseflow — particularly critical during the dry season when Jos residents depend heavily on perennial springs emerging from the Basement Complex aquifer system. The documented shrinkage of water bodies from 2.5% to 1.5% of metropolitan area reduces surface storage capacity and the city's thermal buffering against extreme heat events. The expansion of impervious surfaces simultaneously increases surface runoff intensity, elevating flash flood risk during peak rainy season convective events, while paradoxically deepening dry season water deficits through reduced infiltration and groundwater recharge.

5.3 Urban Liveability, Public Health, and Energy Demand

UHI intensification of $\geq 3^{\circ}\text{C}$ during the dry season materially elevates heat stress exposure for the residents of Jos Metropolis, particularly low-income populations in high-density informal settlements who lack access to air conditioning. Epidemiological studies from comparable African cities associate UHI-driven elevated night temperatures with increased incidence of heat-related morbidity, disrupted sleep, and reduced labour productivity. The 2.8°C annual mean UHI recorded by 2024 represents a physiologically significant burden when superimposed on the background warming trajectory. Elevated urban temperatures also increase the energy demand for cooling, creating feedback loops that raise anthropogenic heat emissions in already stressed power infrastructure. Additionally, higher temperatures and reduced wind speeds in dense urban morphologies increase the retention and concentration of vehicle and industrial air pollutants in the urban canopy layer, amplifying respiratory health risks.

5.4 Climate Change Amplification

The UHI trajectory documented for Jos Metropolis superimposes local anthropogenic warming on the global climate change signal, exposing the city's population to compound heat events of greater frequency and intensity than would be expected from background regional warming alone. The steepening of the night-time LST trend post-2013 points towards a progressive erosion of nocturnal thermal relief that is a hallmark of climate change amplification in rapidly urbanising tropical cities. Under the IPCC's intermediate emissions scenario (SSP2-4.5), regional mean temperatures over Plateau State are projected to increase by $1.5\text{--}2.0^{\circ}\text{C}$ by 2050; the additional UHI component could push peak urban temperatures to levels that compromise outdoor habitability during the dry season.

5.5 Hydro-Meteorological Feedbacks

Urbanisation-driven LST increases alter local atmospheric thermodynamics, intensifying low-level convergence that can modify the spatiotemporal patterns of convective rainfall over and downwind of Jos Metropolis. Evidence from other West African cities indicates that urbanisation can both enhance and displace convective precipitation, contributing to both intensified urban flooding and altered dry-season fog frequency — the latter being ecologically critical on the Jos Plateau. The reduction of moisture recycling from vegetation further suppresses local precipitation recycling, potentially contributing to a drying trend in the plateau's climate.

6. Recommendations

6.1 Urban Greening and Vegetation Restoration

- Mandate minimum green cover ratios ($\geq 25\%$ per development parcel) in the Jos Metropolitan Development Authority (JOMDA) zoning ordinance, with incentive mechanisms for green roof and vertical garden adoption in commercial buildings.
- Establish a metropolitan urban forest programme targeting the restoration of 5,000 ha of degraded vegetated land within the city boundary by 2030, with priority given to peri-urban riparian corridors and open spaces within existing residential zones.
- Enforce a moratorium on the conversion of remaining vegetated patches >0.5 ha within the metropolitan boundary, supported by regular satellite monitoring using the methodology established in this study.

6.2 Cool Surface and Building Materials

- Incorporate mandatory cool roof standards (solar reflectance index ≥ 0.65) into the Nigeria Building Code as enforced by Plateau State for all new construction and major renovations in Jos Metropolis.
- Promote the adoption of permeable and high-albedo pavement materials in road resurfacing programmes managed by the Plateau State Ministry of Works, reducing impervious runoff and surface heat absorption simultaneously.
- Conduct a pilot demonstration of cool pavement technologies in a high-density district (e.g., Terminus Market area) and use LST monitoring to quantify thermal benefits before scaling up.

6.3 Integrated Monitoring and Planning

- Integrate real-time LST and NDVI monitoring dashboards — built on the MODIS and Landsat data pipeline established in this study — into the JOMDA Geographic Information System platform, enabling evidence-based urban heat management.
- Develop a Jos Metropolis Urban Heat Vulnerability Index, combining LST hotspot mapping with demographic and health data, to identify communities at greatest risk and prioritise green infrastructure interventions.
- Conduct decadal LULC and UHI assessments (2030, 2035, etc.) using the replicable methodology developed in this study, with results reported to the Plateau State Climate Change Council.

6.4 Water Resource and Riparian Protection

- Strengthen enforcement of the riparian buffer protection zones (minimum 30 m each bank) along all streams and rivers within Jos Metropolis to preserve critical thermal buffering water bodies and their associated vegetation.
- Incorporate urban wetland conservation into the Jos Metropolis Master Plan revision, recognising documented water body shrinkage and its cumulative thermal and hydrological consequences.

6.5 Policy and Community Engagement

- Mainstream UHI considerations into the Jos Metropolis Master Plan and the Plateau State Climate Change Adaptation Strategy, establishing temperature-sensitive zoning that restricts high-density impervious development in thermally sensitive periurban zones.
- Engage community and religious leaders, who hold significant influence over land management decisions in Jos, in public education programmes on the links between tree removal, urban warming, and public health.
- Develop heat action plans for healthcare facilities, schools, and markets in high-UHI-intensity districts, including cool rest areas, hydration points, and early warning triggers linked to LST thresholds.

7. Conclusion

This study has provided a comprehensive, multi-temporal quantification of Urban Heat Island intensity and its relationship with Land Use/Land Cover dynamics in Jos Metropolis, Plateau State, Nigeria, covering the period 2000 to 2025. Through integrated analysis of MODIS LST time series, Landsat-derived LULC classification, and correlation statistics, the following conclusions are drawn:

- A persistent mean day LST of 32.49°C ($\sigma = 0.81^\circ\text{C}$) and night LST of 16.46°C ($\sigma = 1.13^\circ\text{C}$) were recorded across the study period, with a stable day–night gap of approximately 16°C reflecting the fundamental radiative character of the urban surface energy balance in a highland tropical city.
- UHI intensity in Jos Metropolis follows a strong seasonal cycle, peaking at $\geq 3^\circ\text{C}$ in the dry season (February–March) and declining to $\sim 1.4^\circ\text{C}$ at the height of the wet season (July), with positive UHI maintained year-round. Annual mean UHI intensity intensified from $\sim 1.5^\circ\text{C}$ in 2000 to $\sim 2.8^\circ\text{C}$ in 2024 — an increase of approximately 87% — with the rate of intensification accelerating after 2013.
- Built-up/impervious area expanded from 18.4% to 49.3% of the metropolitan extent over 25 years, while vegetation cover declined from 41.2% to 17.8%. These opposing trajectories have fundamentally reorganised the thermal landscape of Jos, shifting the thermal balance from a moderately warm, vegetation-buffered environment towards an impervious heat island.
- Pearson correlation analysis confirms that built-up expansion is the strongest driver of LST increase ($r = +0.97$, $R^2 = 0.91$), while vegetation loss constitutes the strongest negative thermal regulator ($r = -0.93$). Each additional 1% increase in built-up cover is associated with approximately 0.04°C increase in mean urban LST.
- Decadal LST mapping documents a progressive spatial broadening of the warm zone, with the modal LST class (31.12–32.13°C) more than doubling in area from 92.6 km² (2000) to 153.0 km² (2025), and the coolest class ($\leq 30.08^\circ\text{C}$) contracting from 24.6 km² to 8.1 km².
- The environmental implications are far-reaching, encompassing threats to plateau biodiversity, water resource availability, public health from heat stress, energy demand escalation, and climate change amplification — all of which disproportionately affect the city's most vulnerable populations.

These findings underscore the urgency of integrating thermal environment considerations into urban planning, land use regulation, and climate adaptation strategies for Jos Metropolis. The remote sensing and GIS methodology employed in this study provides a replicable, cost-effective framework that can be applied to other rapidly urbanizing Nigerian and African highland cities. Continued monitoring, combined with targeted green infrastructure investment and heat-sensitive zoning policy, represents the critical pathway towards a thermally resilient Jos Metropolis.

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