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Three-Decade Expansion of Impervious Surfaces and Intensification of Surface Urban Heat Islands across Six Cities in Southwestern Nigeria

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Abstract
Rapid urban growth replaces vegetated land with impervious surfaces that modify surface energy exchange and intensify urban heat, a concern that is increasingly important in fast-growing African cities. Yet multi-city evidence linking long-term impervious-surface expansion to surface urban heat island (SUHI) development remains limited in southwestern Nigeria. This study quantified changes in impervious cover, vegetation, land-surface temperature (LST), and SUHI intensity across Ibadan, Abeokuta, Lagos Metropolis, Osogbo, Ado-Ekiti, and Akure. Cloud-free Landsat TM, ETM+, and OLI/TIRS scenes were assembled into three dry-season-dominated epochs (1984–1986, 1999–2001, and 2015–2017). Normalized Difference Built-up Index (NDBI), Normalized Difference Vegetation Index (NDVI), single-channel LST retrieval, and urban–rural thermal-hotspot contrasts were used to characterize change. Impervious cover increased in every city; between the first and third epochs, the increase represented approximately 29.8–57.2 percentage points of each city's mapped land area. Mean LST rose from 24.2–26.5 °C in the first epoch to 30.2–33.6 °C in the third. SUHI intensity also strengthened, from 0.1–2.1 °C initially to 0.9–4.8 °C in the most recent epoch, with the largest contrast observed between Lagos Metropolis and Ibereko. The consistent co-occurrence of urban expansion, vegetation loss, and surface warming across six cities extends single-city evidence from Nigeria and underscores the regional planning significance of heat-sensitive land management. Urban growth strategies should protect and expand connected green infrastructure while routine satellite monitoring is used to identify emerging thermal hotspots.

Keywords: impervious surface; land surface temperature; surface urban heat island; NDBI; NDVI; Landsat; urbanization; southwestern Nigeria

I. Introduction

Urbanization is reshaping land surfaces at unprecedented scales, particularly in rapidly growing cities of Africa and Asia. The United Nations projects continued growth in the share and absolute number of people living in urban settlements through 2050, while the IPCC identifies urban expansion, loss of green infrastructure, and heat exposure as interlinked risks for climate-resilient development (United Nations, 2025; IPCC, 2022). This concern is not only climatic: extreme heat is an established public-health hazard, and the World Health Organization emphasizes that city form, housing, vegetation, and access to cooling strongly influence exposure and vulnerability (WHO, 2026).

The physical basis of the urban heat island is well established. Replacing moist, vegetated surfaces with roofs, roads, concrete, and compacted soilsalters albedo, emissivity, aerodynamic roughness, heat storage, and evapotranspiration, thereby redistributing sensible and latent heat fluxes (Oke, 1982; Voogt and Oke, 2003). Satellite thermal remote sensing provides a spatially explicit means to observe this surface expression of urban warming, commonly referred to as the surface urban heat island (SUHI). Across global and regional studies, built-up surfaces generally exhibit higher daytime LST than vegetated or water-covered surfaces, although the magnitude of SUHI varies with climate, season, urban morphology, background environment, and the definition of the rural reference (Peng et al., 2012; Zhou et al., 2014; Nega and Balew, 2022).

Spectral indices derived from Landsat are widely used to characterize these surface changes. The Normalized Difference Built-up Index (NDBI) exploits the relatively stronger short-wave infrared response of built-up surfaces compared with near-infrared reflectance, while the Normalized Difference Vegetation Index (NDVI) provides a long-established measure of photosynthetically active vegetation (Zha et al., 2003; Tucker, 1979). Earlier work has shown that impervious surface

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measures can be particularly informative for interpreting the spatial structure of SUHI because thermal behavior responds directly to the replacement of vegetated and permeable surfaces by built materials (Yuan and Bauer, 2007).

Nigeria provides an important setting for this problem because urban growth is occurring in a warm tropical climate, where additional surface heating directly affects thermal comfort and heat exposure. Previous studies have documented urban thermal change in individual Nigerian cities. Ayanlade (2016) reported that vegetation loss in Lagos was associated with stronger daytime UHI conditions; Ishola et al. (2016) linked changes in Abeokuta's urban biophysical composition to its land-surface thermal field; Adeyeri et al. (2017) found high LST over built-up and bare surfaces in Abuja and a strong positive relationship between NDBI and LST; Daramola et al. (2018) documented long-term land-cover and thermal changes in Ibadan; and Ogunjobi et al. (2018) observed clear thermal consequences of urban growth in Sokoto. Urban expansion studies for Akure similarly show outward development and encroachment into green areas (Owoeye and Ibitoye, 2016).

Despite this evidence, the literature is dominated by single-city analyses or studies using different periods and methodological conventions. A regional comparison conducted within one analytical framework is therefore needed to establish whether the expansion–warming relationship is repeated across multiple state capitals and to quantify how urban–rural surface-temperature contrasts have evolved. This gap is especially relevant in southwestern Nigeria, where six state capitals differ in size, development trajectory, and surrounding land cover but share a broadly humid tropical climate.

Accordingly, this study examines Ibadan, Abeokuta, Lagos Metropolis, Osogbo, Ado-Ekiti, and Akure over approximately three decades. The objectives are to: (i) map and quantify changes in impervious and vegetated surface conditions; (ii) retrieve and compare LST across three observation epochs; (iii) identify thermal hotspots and estimate SUHI intensity relative to selected surrounding rural or peri-urban locations; and (iv) interpret the implications of observed surface change for sustainable urban planning. The working expectation is that cities experiencing greater conversion toward impervious cover will show stronger surface warming and larger urban–rural thermal contrasts. The study is deliberately delimited to daytime Landsat surface conditions and does not attempt to represent the full diurnal atmospheric UHI. This distinction is important because satellite-derived LST and near-surface air temperature describe related but different components of the urban thermal environment (Voogt and Oke, 2003; Stewart and Oke, 2012).

II. Materials and methods

2.1 Study area

The study covers southwestern Nigeria, approximately between 6°00′–9°00′ N and 2°30′–6°00′ E, comprising Oyo, Ogun, Lagos, Osun, Ekiti, and Ondo states. The analysis focuses on their principal urban centres: Ibadan, Abeokuta, Lagos Metropolis, Osogbo, Ado-Ekiti, and Akure. The region experiences a humid tropical climate controlled by seasonal interactions between maritime and continental air masses, with a wet season broadly extending from March to October and a drier season during the remaining months. The selected Landsat acquisitions fall predominantly within the dry-season window, reducing—but not eliminating—seasonal inconsistency among scenes.

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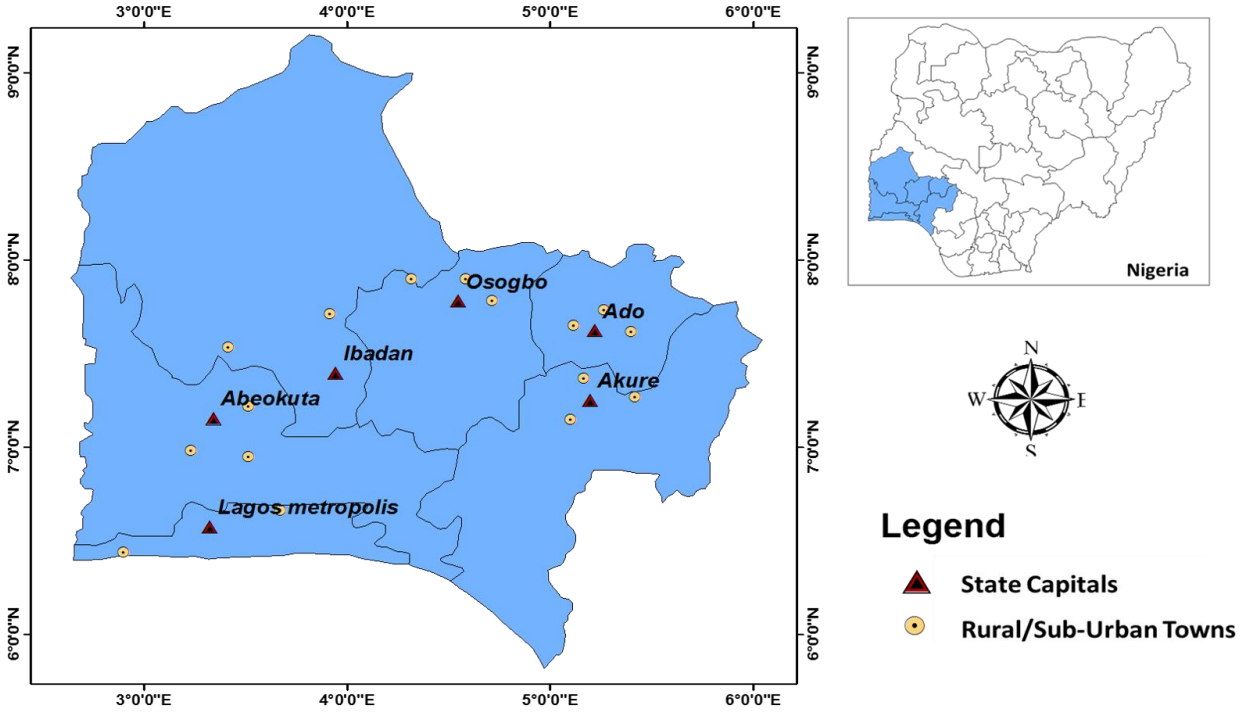

Figure 1. Southwestern Nigeria and the six state capitals examined, together with selected surrounding rural/peri-urban reference towns used in the SUHI analysis.

2.2 Study design and satellite data

The study uses a retrospective, multi-epoch remote-sensing design. Cloud-free Landsat scenes from TM, ETM+, and OLI/TIRS were obtained from the U.S. Geological Survey (USGS) EarthExplorer archive for seven path/row combinations covering southwestern Nigeria. Rather than treating each mosaic as a single calendar year, the revised analysis defines three observation epochs because scenes required to cover the entire region were acquired on different dates: Epoch 1 (1984–1986), Epoch 2 (1999–2001), and Epoch 3 (2015–2017). This formulation is methodologically more accurate than assigning a single nominal year to mosaics composed from multiple acquisitions. Radiometric conversion followed Landsat metadata-based calibration principles described by Chander et al. (2009).

Table 1. Landsat acquisitions used to construct the three analysis epochs.

Path	Row	Epoch 1 (TM)	Epoch 2 (ETM+)	Epoch 3 (OLI/TIRS)
189	055	08 Jan 1986	09 Jan 2001	31 Dec 2017
190	054	17 Dec 1986	13 Nov 2000	05 Feb 2017
190	056	11 Dec 1984	13 Dec 1999	17 Dec 2015
191	054	08 Dec 1986	11 Feb 1999	27 Nov 2017
191	056	18 Dec 1984	06 Feb 2000	08 Dec 2015
192	054	13 Nov 1986	13 Dec 2000	18 Jan 2017
192	055	13 Nov 1986	13 Dec 2000	18 Jan 2017

Scenes were mosaicked by epoch and clipped to the urban study areas using administrative boundaries. Data were projected to a common Universal Transverse Mercator reference system based on WGS 1984. The optical and thermal products were co-registered for spatial comparison. Thermal bands were resampled to 30 m using nearest-neighbour resampling for grid alignment; this operation standardizes pixel geometry but does not create new thermal spatial information beyond the native thermal resolution.

2.3 Impervious-surface and vegetation indices

NDBI was calculated as NDBI = (SWIR1 − NIR)/(SWIR1 + NIR), following Zha et al. (2003). Positive NDBI values were used in the original

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analysis as a proxy for impervious or strongly built-up surface conditions. NDVI was calculated as NDVI = (NIR − Red)/(NIR + Red), following Tucker (1979). The two indices were interpreted jointly because bare soil can sometimes produce NDBI responses similar to built-up land; therefore, the resulting impervious-surface estimates should be understood as an index-based urban-surface proxy rather than a supervised land-cover classification with an independent accuracy assessment.

2.4 Land-surface temperature retrieval

LST was retrieved from Landsat thermal data using the calibrated thermal-radiance/brightness-temperature pathway and an emissivity-corrected single-channel formulation. The general form used was:

LST(K) = T_B / [1 + (λT_B/ρ) ln(ε)]

where T_e is at-sensor brightness temperature, λ is the effective wavelength of emitted radiance, ρ = hc/σ, and ε is land-surface emissivity. Brightness temperature was computed as $T_e = K_2 / \ln(K_1/L\lambda + 1)$, where Lλ is spectral radiance and K_1 and K_2 are sensor-specific thermal calibration constants. For TM/ETM+ scenes, digital numbers were converted to radiance using metadata-based LMIN/LMAX and QCAL terms; for Landsat 8, multiplicative and additive radiance rescaling coefficients from scene metadata were used. These transformations are consistent with standard Landsat radiometric calibration practice (Chander et al., 2009) and the logic of single-channel LST retrieval (Jiménez-Muñoz and Sobrino, 2003; Sobrino et al., 2004). LST in Kelvin was converted to degrees Celsius by subtracting 273.15.

A reproducibility constraint in the archived analytical record is that the exact procedure used to parameterize ε was not documented separately from the LST equation. Consequently, absolute LST magnitudes should be interpreted with appropriate caution, and the most defensible emphasis is on internally consistent spatial contrasts and the repeated direction of change across cities and epochs. Before final journal submission, the authors should recover the emissivity parameterization from the original processing log, if available, and insert it in this subsection.

2.5 Impervious-area quantification and thermal hotspots

For each city, areas with NDBI > 0 were extracted to estimate the mapped extent of impervious/built-up surface. The area of these pixels was summarized in hectares and expressed relative to the mapped city land area. Thermal hotspots were identified from the highest LST zones within each state capital and within selected surrounding rural or peri-urban settlements. The hotspot locations were selected using prior landscape knowledge and inspection of the LST maps, with preference for areas showing limited vegetation and comparatively high thermal response.

2.6 Surface urban heat-island intensity

SUHI intensity was calculated as SUHI = $LST_{urban,max} - LST_{reference,max}$, where $LST_{urban,max}$ is the hotspot LST in the state capital and $LST_{reference,max}$ is the hotspot LST in the selected rural/peri-urban comparison settlement. Positive values indicate a warmer urban hotspot. This hotspot-based metric was retained to remain faithful to the original analysis, but it differs from area-mean SUHI definitions and from Local Climate Zone approaches designed to standardize urban–rural comparisons (Stewart and Oke, 2012). The implications of that choice are addressed explicitly in the limitations section.

III. Results

3.1 Expansion of impervious surfaces

As shown in Figures 2a and 2b, the NDBI maps reveal a clear outward expansion of positive built-up/impervious signatures in all six state capitals. In the earliest epoch, high NDBI values were more strongly concentrated around established urban cores. By the third epoch, positive values had expanded along multiple directions and into peripheral zones, indicating substantial growth of the urbanized footprint.

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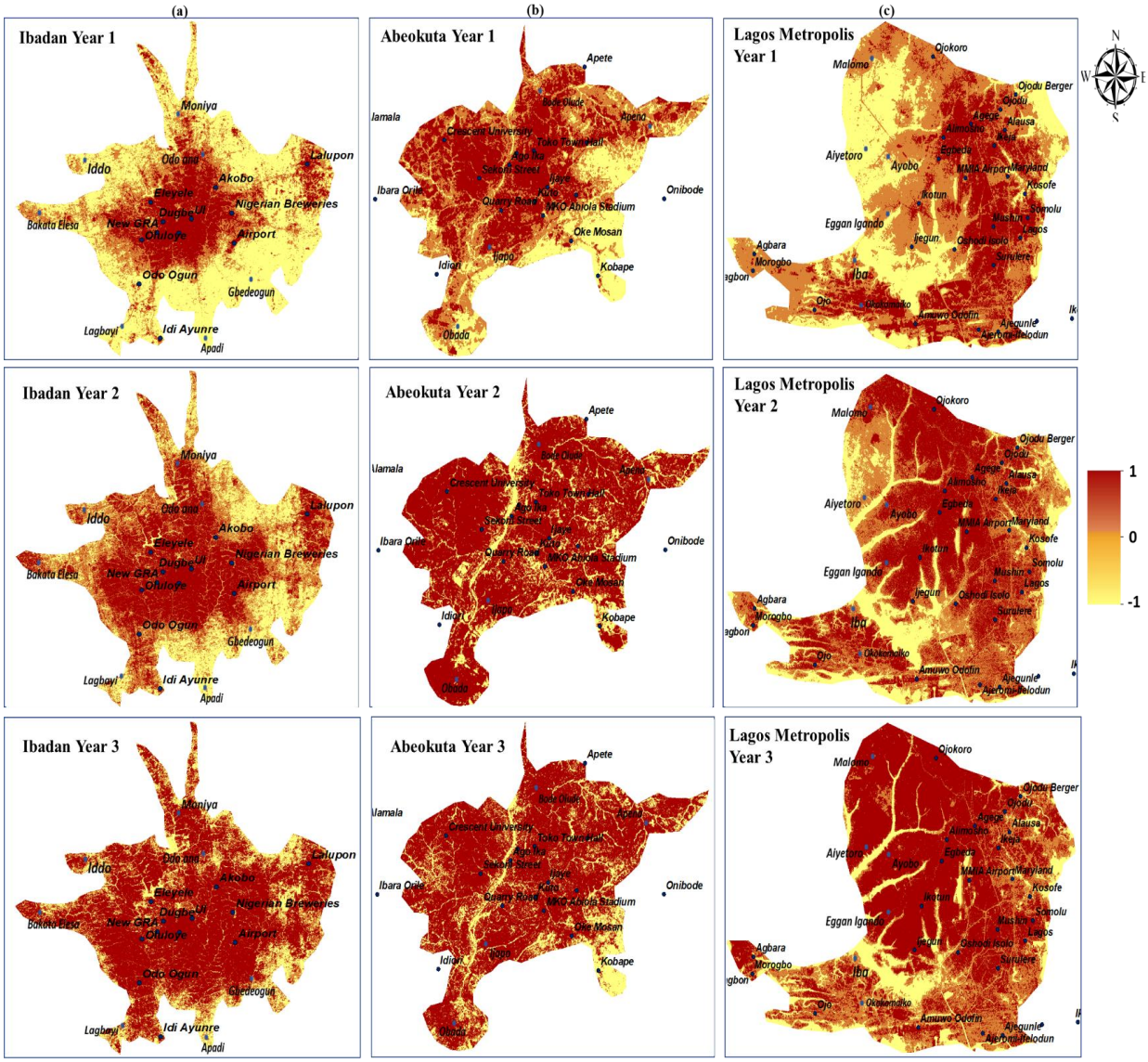

Figure 2a. NDBI patterns for Ibadan, Abeokuta, and Lagos Metropolis across Epochs 1–3.

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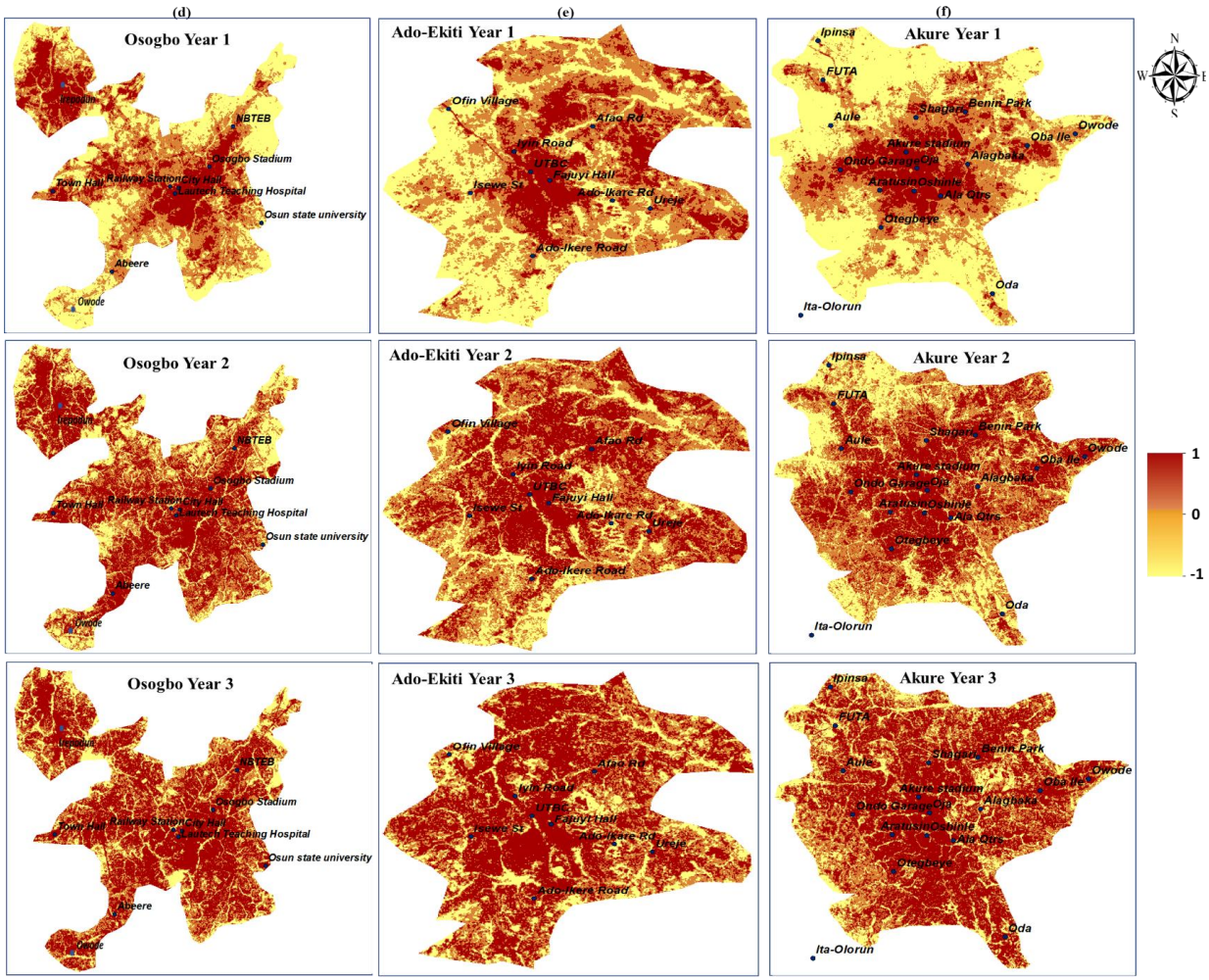

Figure 2b. NDBI patterns for Osogbo, Ado-Ekiti, and Akure across Epochs 1–3.

Table 2. Change in index-derived impervious surface area (ISA) between Epochs 1 and 3.

City	Epoch 1 ISA (10^3 ha)	Epoch 3 ISA (10^3 ha)	Mapped land area (10^3 ha)	Epoch 1 share (%)	Epoch 3 share (%)	Change (percentage points)
Osogbo	2.89	7.70	16.14	17.9	47.7	29.8
Lagos Metropolis	12.41	37.14	69.73	17.8	53.3	35.5
Ibadan	6.72	63.67	99.56	6.7	64.0	57.2
Akure	0.73	10.89	21.02	3.5	51.8	48.3
Ado-Ekiti	0.23	4.93	10.65	2.2	46.3	44.1
Abeokuta	5.22	16.77	20.42	25.6	82.1	56.6

As summarized in Table 2, the magnitude of change was large but spatially uneven. The increase in index-derived impervious coverage ranged from about 29.8 percentage points in Osogbo to 57.2 percentage points in Ibadan. Abeokuta also exhibited a very large increase (56.6 percentage points), while Akure and Ado-Ekiti increased by 48.3 and 44.1 percentage points, respectively. By Epoch 3, estimated impervious coverage exceeded half of the mapped land area in Abeokuta, Ibadan, Lagos Metropolis, and Akure, whereas Osogbo and Ado-Ekiti remained below 50% (Table 2).

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3.2 Vegetation-index change

Figures 3a and 3b show substantial redistribution and fragmentation of vegetated surfaces over the same period. Areas of relatively high NDVI became less continuous within the urban cores as built-up signatures expanded, although local increases in NDVI maxima occurred in some Epoch 3 scenes. These maxima should not be interpreted as evidence of city-wide vegetation gain because the spatial maps show that high-value vegetation became increasingly concentrated in remaining green patches and peripheral zones. The city- and epoch-specific NDVI ranges are summarized in Table 3.

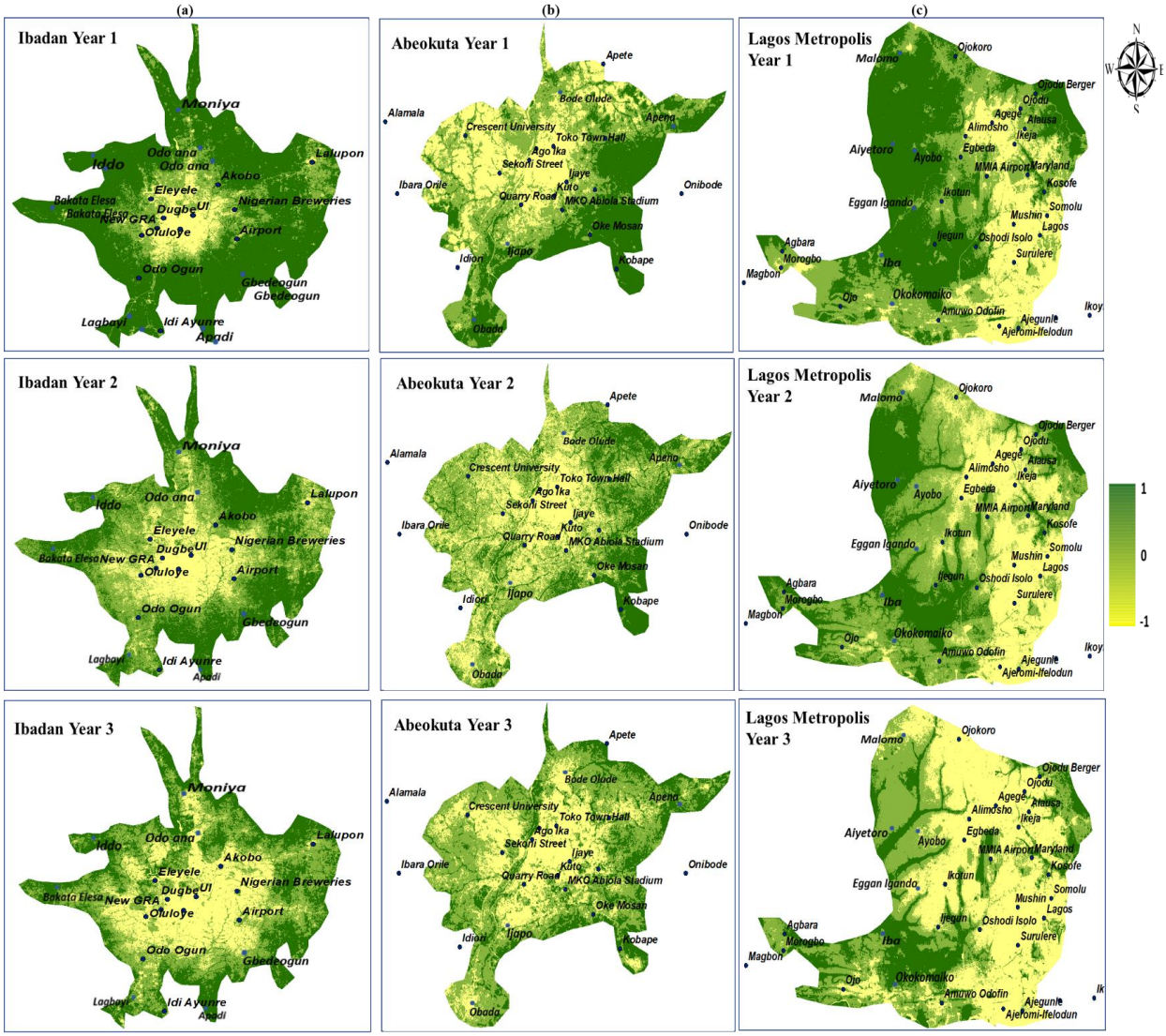

Figure 3a. NDVI patterns for Ibadan, Abeokuta, and Lagos Metropolis across Epochs 1–3.

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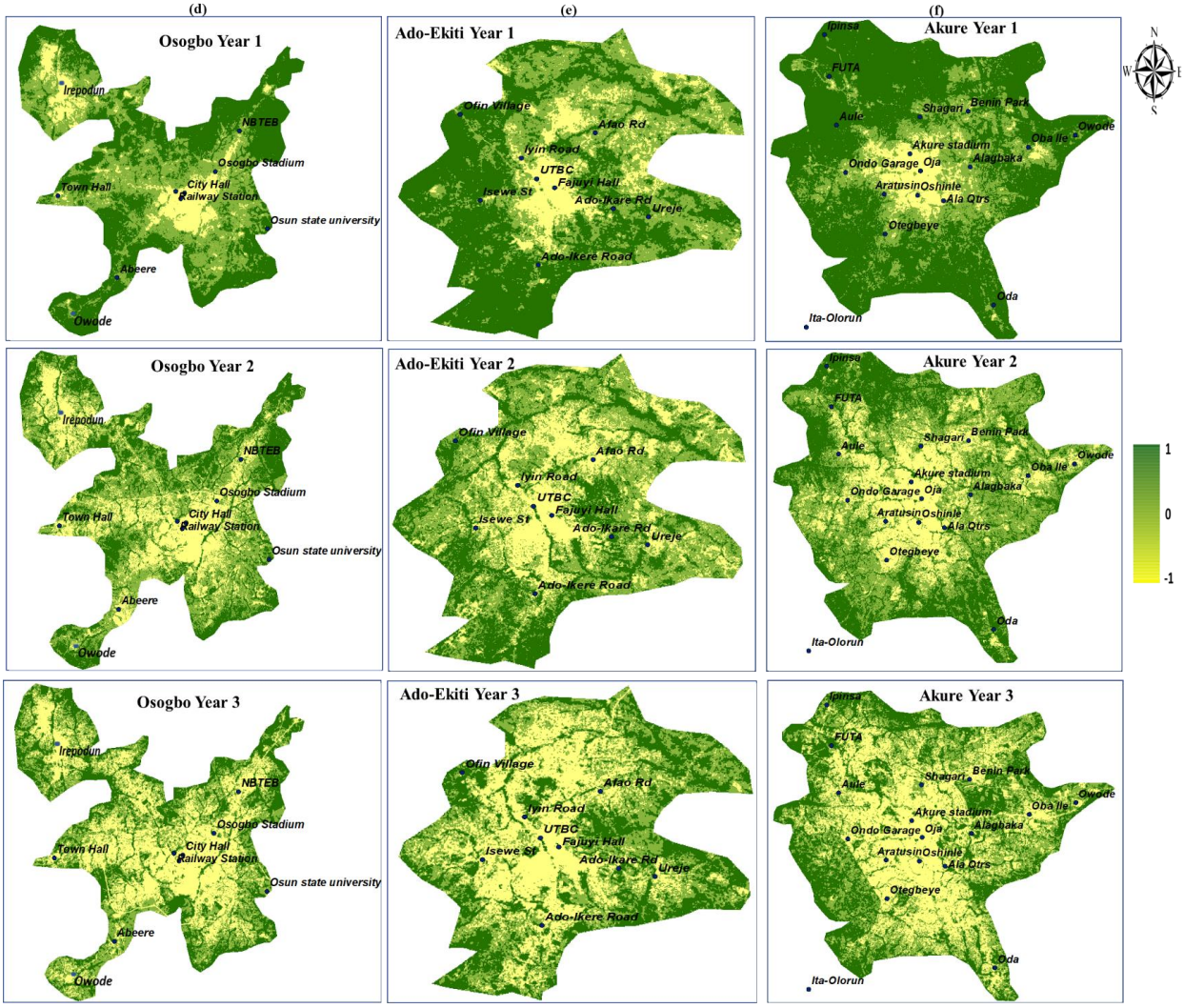

Figure 3b. NDVI patterns for Osogbo, Ado-Ekiti, and Akure across Epochs 1–3.

Table 3. NDVI ranges by city and epoch.

City	Epoch 1 NDVI min	Epoch 1 NDVI max	Epoch 2 min	Epoch 2 max	Epoch 3 min	Epoch 3 max
Ibadan	0.124	0.586	−0.234	0.257	0.039	0.513
Abeokuta	0.150	0.456	−0.220	0.221	0.063	0.422
Lagos Metropolis	0.035	0.482	−0.310	0.122	−0.139	0.640
Osogbo	0.181	0.478	−0.183	0.360	−0.047	0.703
Ado-Ekiti	0.198	0.497	−0.251	0.348	−0.113	0.718
Akure	0.190	0.700	−0.200	0.370	−0.056	0.711

3.3 Land-surface temperature change

As shown in Figures 4a and 4b and summarized in Table 4, mean LST increased in every city between the first and third epochs. The first-epoch means ranged from 24.2 °C in Akure to 26.5 °C in Abeokuta. In Epoch 3, all six cities exceeded 30 °C, ranging from 30.2 °C in Lagos Metropolis to 33.6 °C in Abeokuta. The spatial maps consistently place many of the warmest zones over built-up surfaces, whereas cooler areas are more frequently associated with vegetation and other less-impervious cover (Figures 4a and 4b).

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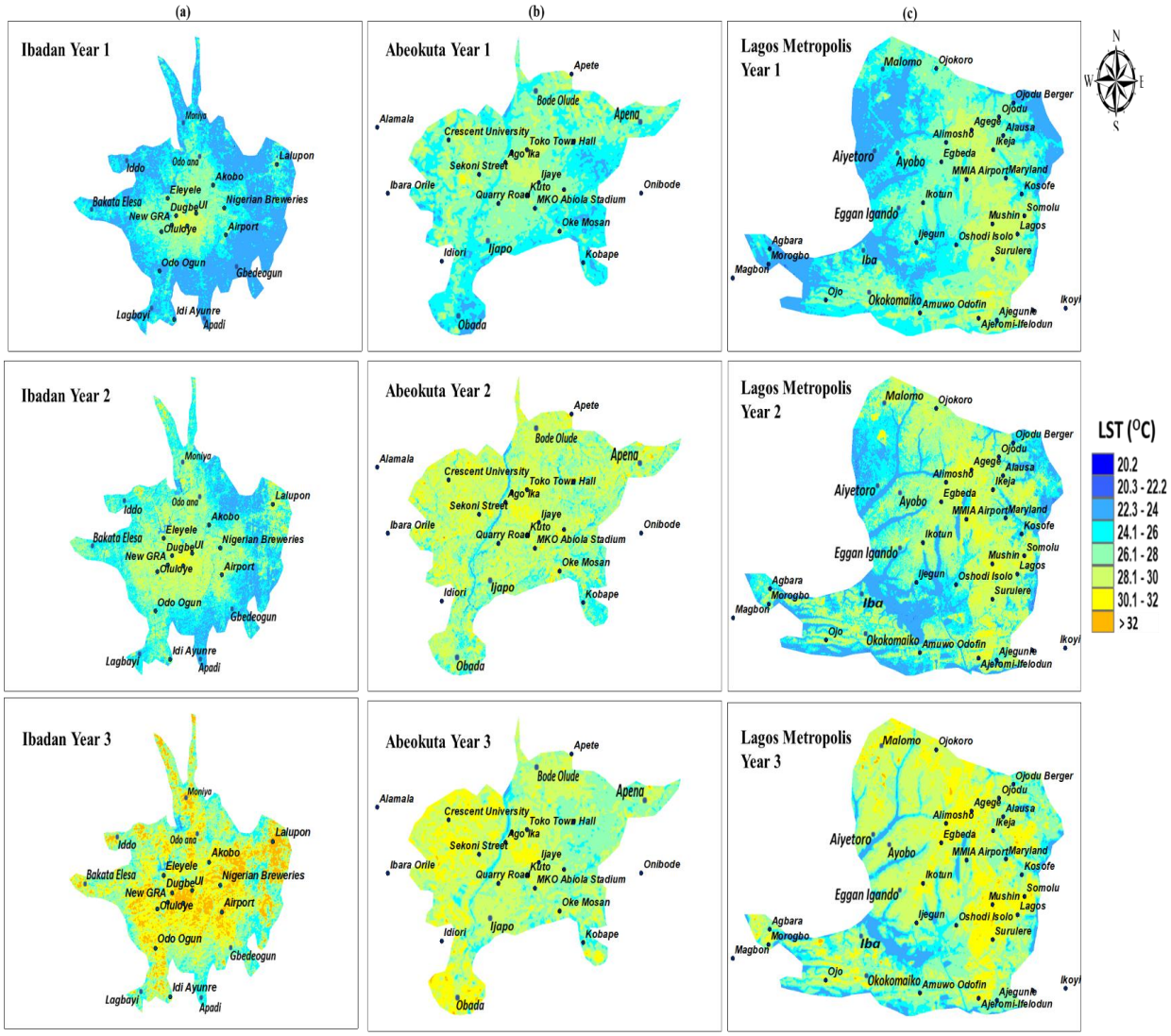

Figure 4a. LST patterns for Ibadan, Abeokuta, and Lagos Metropolis across Epochs 1–3.

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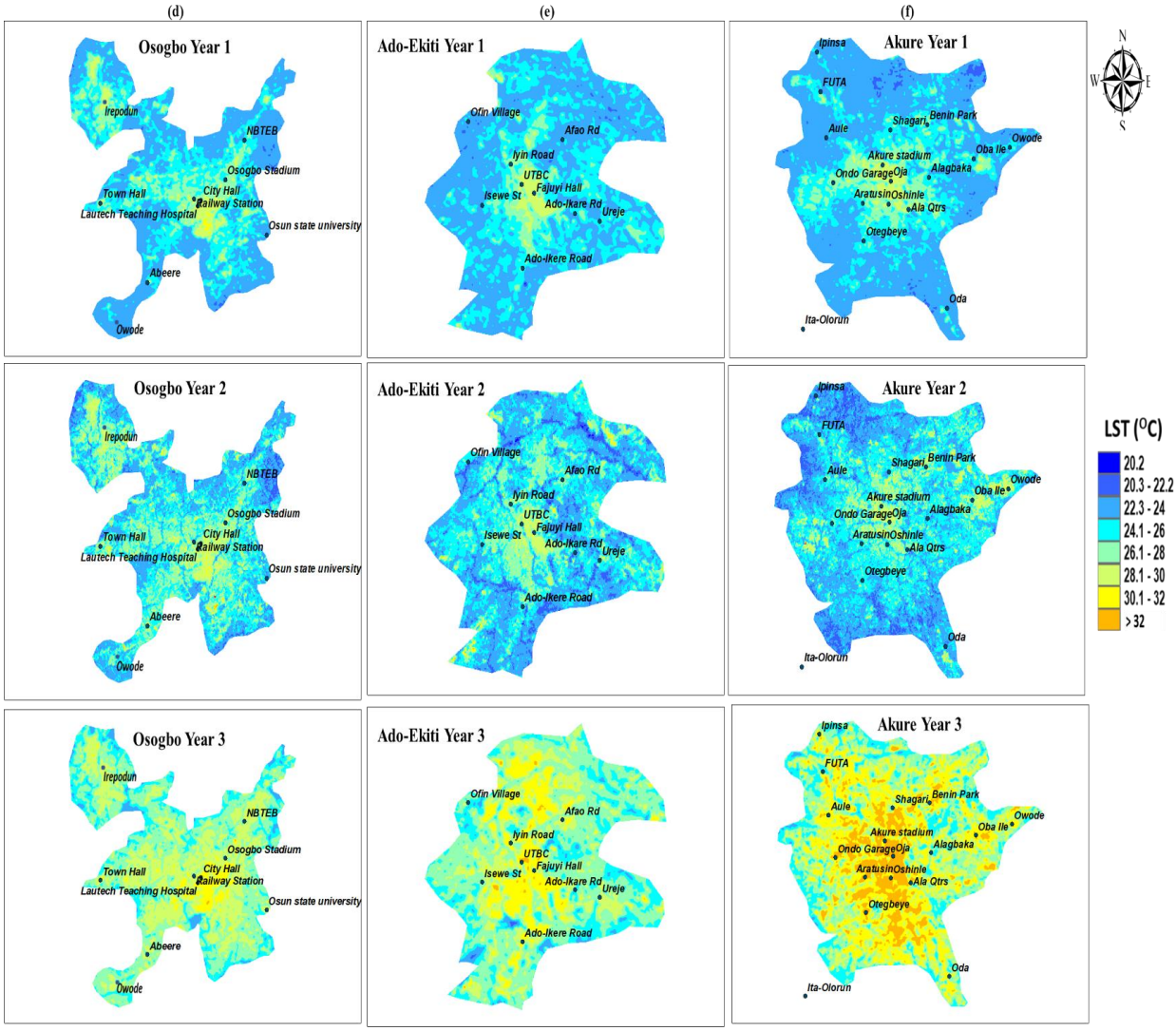

Figure 4b. LST patterns for Osogbo, Ado-Ekiti, and Akure across Epochs 1–3.

Table 4. Mean LST by city and epoch.

City	Epoch 1 mean LST (°C)	Epoch 2 mean LST (°C)	Epoch 3 mean LST (°C)	Epoch 1→3 change (°C)
Ibadan	24.9	26.3	31.9	7.0
Abeokuta	26.5	28.3	33.6	7.1
Lagos Metropolis	26.1	27.5	30.2	4.1
Osogbo	24.7	25.2	31.3	6.6
Ado-Ekiti	24.5	24.5	31.2	6.7
Akure	24.2	24.4	31.6	7.4

Table 4 shows that the largest first-to-third-epoch increase in mean LST occurred in Akure (7.4 °C), followed by Abeokuta (7.1 °C), Ibadan (7.0 °C), Ado-Ekiti (6.7 °C), and Osogbo (6.6 °C). Lagos Metropolis showed the smallest increase (4.1 °C), although it remained characterized by extensive high-temperature built-up zones (Figures 4a and 4b). Because observations are based on single-date scenes assembled into multi-year epochs, these values represent scene-specific surface conditions rather than climatological annual means.

3.4 Thermal hotspots and SUHI intensity

Figures 5a–5c show that thermal hotspots were concentrated mainly in dense urban cores and

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highly developed commercial or residential zones. In Ibadan, warm zones included the University of Ibadan–Bodija–Dugbe axis; in Abeokuta, hotspots occurred around Ago Ika, Kuto, and Ijaye; Lagos hotspots included Oshodi-Isolo, Surulere, and Mushin; Osogbo hotspots were associated with the central urban area; Ado-Ekiti hotspots were concentrated around the central built-up zone; and Akure's warmest urban zones included Oja Oba and adjacent high-activity areas. The selected surrounding settlements generally exhibited lower hotspot temperatures than their associated state capitals (Figures 5a–5c).

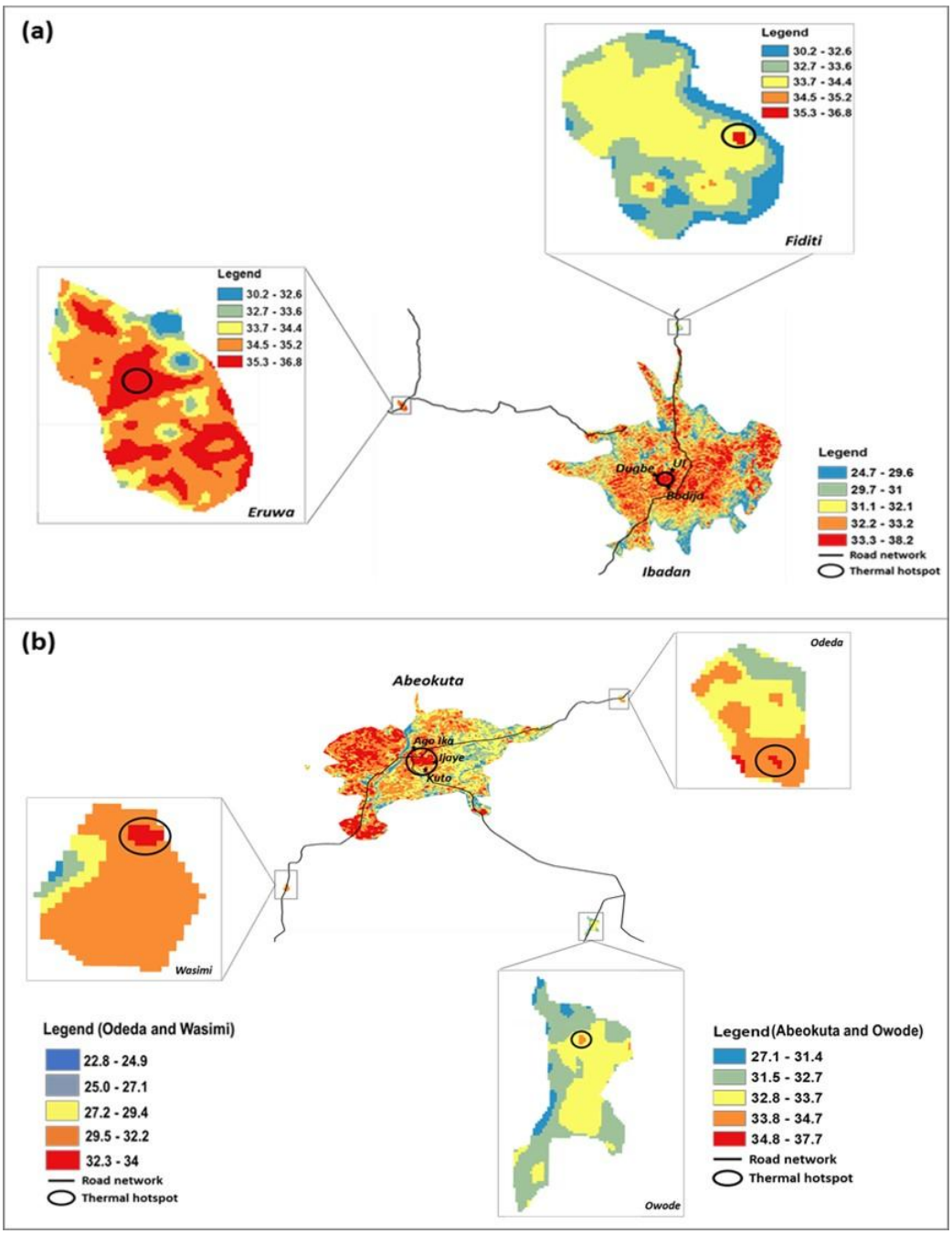

Figure 5a. Example Epoch 3 LST hotspot maps for Ibadan and Abeokuta and their selected surrounding reference settlements.

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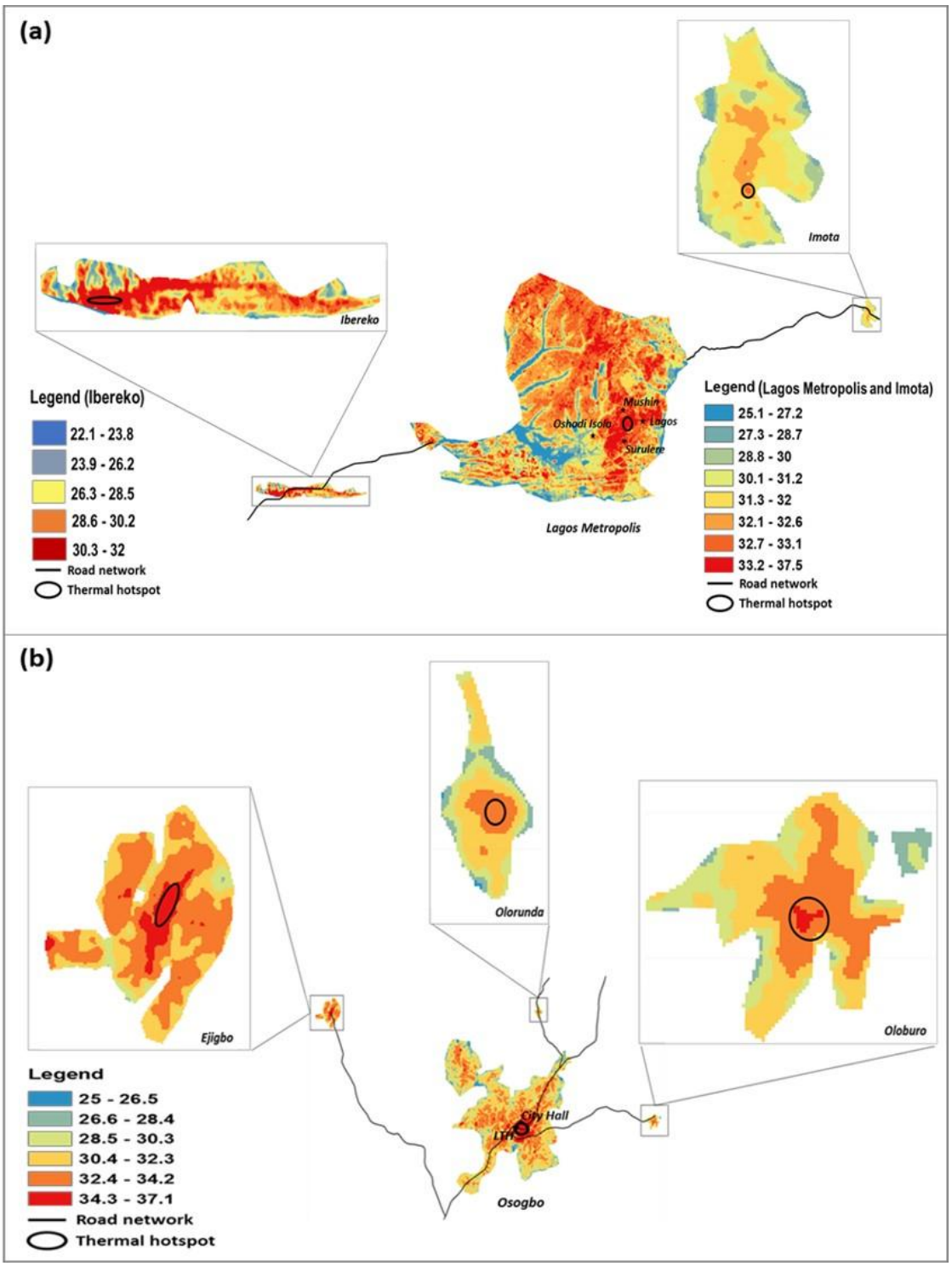

Figure 5b. Example Epoch 3 LST hotspot maps for Lagos Metropolis and Osogbo and their selected surrounding reference settlements.

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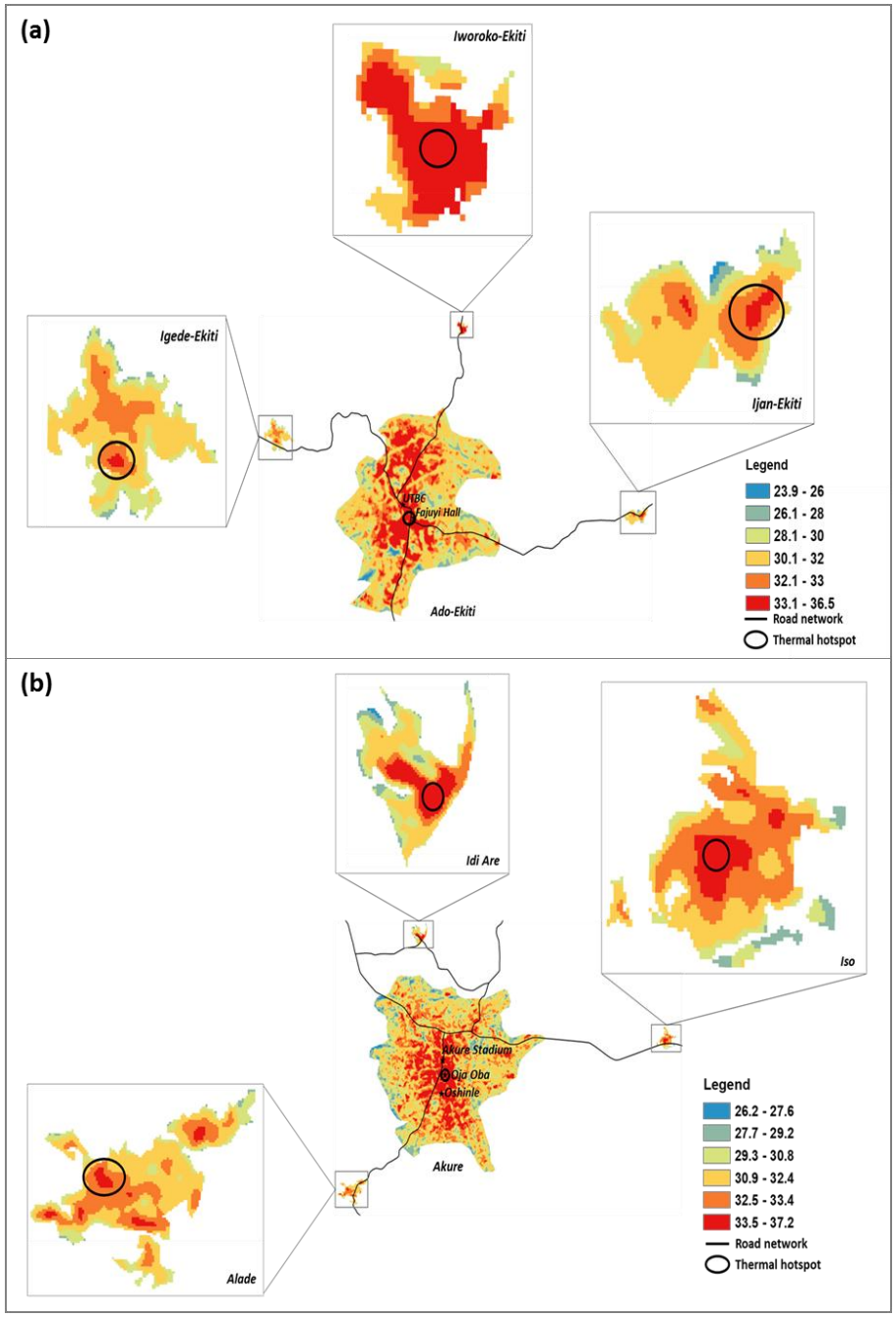

Figure 5c. Example Epoch 3 LST hotspot maps for Ado-Ekiti and Akure and their selected surrounding reference settlements.

Table 5. Surface urban heat-island intensity derived from urban and rural/peri-urban hotspot contrasts.

Urban centre	Reference settlement	Epoch 1 SUHI (°C)	Epoch 3 SUHI (°C)
Lagos Metropolis	Imota	1.3	3.7
Lagos Metropolis	Ibereko	0.5	4.8
Ibadan	Fiditi	0.3	1.2
Ibadan	Eruwa	0.4	2.2
Osogbo	Olorunda	1.9	3.5
Osogbo	Oloburo	1.4	1.7

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Osogbo	Ejigbo	1.0	1.2
Akure	Idi Are	0.1	0.9
Akure	Alade	0.9	1.6
Akure	Iso	0.1	1.3
Abeokuta	Owode	2.1	2.3
Abeokuta	Odeda	1.8	2.5
Abeokuta	Wasimi	1.7	3.8
Ado-Ekiti	Ijan-Ekiti	1.0	2.1
Ado-Ekiti	Igede-Ekiti	0.8	2.0
Ado-Ekiti	Iworoko-Ekiti	0.4	1.5

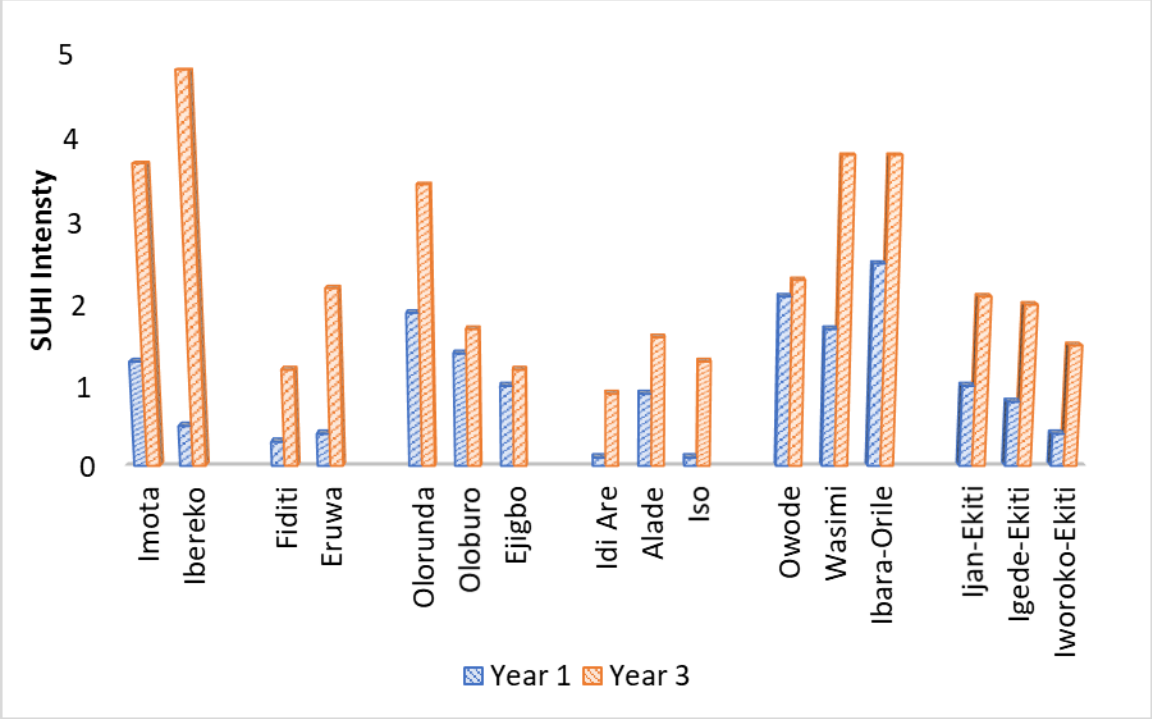

Figure 6. SUHI intensity for the selected urban–reference settlement pairs in Epochs 1 and 3.

As shown in Table 5 and Figure 6, all urban–reference pairs retained positive SUHI values, and every pair showed a larger contrast in Epoch 3 than in Epoch 1. The range widened from 0.1–2.1 °C in Epoch 1 to 0.9–4.8 °C in Epoch 3. The strongest third-epoch contrast occurred between Lagos Metropolis and Ibereko (4.8 °C), followed by Abeokuta–Wasimi (3.8 °C), Lagos–Imota (3.7 °C), and Osogbo–Olorunda (3.5 °C). The smallest third-epoch contrast was Akure–Idi Are (0.9 °C) (Table 5; Figure 6).

IV. Discussion

4.1 Regional consistency of urban expansion

The most important regional result is not simply that each city expanded, but that the same directional pattern emerged across six urban systems with different sizes and development histories. Figures 2a and 2b show positive NDBI signatures expanding outward from older cores, while Table 2 indicates that the index-derived impervious share increased by roughly 30–57 percentage points between the first and third epochs. This provides a cross-city context for local studies that previously documented rapid land conversion in Akure and other Nigerian cities. Owoeye and Ibitoye (2016), for example, reported outward and weakly controlled expansion of Akure into adjoining settlements; the spatial pattern observed here is consistent with that trajectory. Similar long-term urban growth has been linked to major changes in surface thermal characteristics in Abeokuta, Ibadan, Lagos, and Sokoto (Ishola et al., 2016; Daramola et al., 2018; Ayanlade, 2016; Ogunjobi et al., 2018).

The revised interpretation avoids treating the NDBI threshold as a perfect impervious-surface

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classifier. NDBI is sensitive to built surfaces, but bare or dry soil can also produce positive responses, particularly in tropical dry-season imagery. Nevertheless, the magnitude, contiguity, and directional expansion of the positive-NDBI zones shown in Figures 2a and 2b, together with the large changes quantified in Table 2 and their spatial association with known urban development, support their use as a comparative indicator of urban surface expansion. A future high-resolution validation using contemporary land-cover data would allow the index-derived areas to be converted into more defensible impervious fractions.

4.2 Surface warming and the role of land-cover conversion

As shown in Figures 4a and 4b and Table 4, mean LST increased in all six cities, and the spatial pattern repeatedly placed high temperatures over strongly built-up zones. This agrees with the physical expectation that impervious materials store and re-radiate more sensible heat while reducing evapotranspirative cooling relative to vegetated surfaces (Oke, 1982; Voogt and Oke, 2003). A systematic review of recent remote-sensing studies similarly found that built-up land most consistently occupies the warmest LST class across diverse environments, with vegetation and water generally cooler (Nega and Balew, 2022).

The Nigerian literature provides particularly strong contextual agreement with the patterns shown in Figures 4a and 4b and quantified in Table 4. In Abuja, Adeyeri et al. (2017) reported a positive relationship between NDBI and LST and identified built-up and bare areas as thermal hotspots. In Abeokuta, Ishola et al. (2016) showed that changes in urban biophysical composition between 1984 and 2014 altered the surface thermal field. Daramola et al. (2018) documented comparable land-cover and thermal changes in Ibadan between 1984, 2000, and 2016, while Ogunjobi et al. (2018) linked urban expansion to temporal LST changes in Sokoto. The present multi-city analysis therefore does not represent an isolated local response; it shows that the same surface-transition signal is repeated across the major cities of an entire geopolitical region.

The absolute LST increases reported in Table 4 should, however, not be interpreted as a pure urbanization effect. Scene acquisition dates differ within each epoch, atmospheric conditions vary among dates, sensors changed from TM to ETM+ to OLI/TIRS, and the historical processing record does not fully document emissivity parameterization. These factors can influence absolute retrieved temperatures. The strongest conclusion is consequently the repeated spatial coincidence of built-up expansion (Figures 2a and 2b) and hotter surfaces (Figures 4a and 4b), together with the consistent direction of mean LST and SUHI change across all six cities (Tables 4 and 5; Figure 6), rather than attribution of the full multi-degree increase solely to land-cover conversion.

4.3 Intensification of the surface urban heat island

As shown in Table 5 and Figure 6, the urban–reference hotspot contrasts intensified for every city–settlement pair. This is consistent with global evidence that SUHI is driven by the interaction of urban form, land cover, climate, and the surrounding background environment (Peng et al., 2012; Zhou et al., 2014). Lagos displayed the largest third-epoch contrast, reaching 4.8 °C relative to Ibereko (Table 5; Figure 6). Ayanlade (2016) independently found that reduced vegetation cover in Lagos altered surface thermal and aerodynamic processes and intensified UHI conditions, lending support to the direction of the present result.

Table 5 also demonstrates that the variation among reference settlements is instructive. For example, Ibadan's contrast with Fiditi (1.2 °C) was smaller than with Eruwa (2.2 °C), while Osogbo's contrast ranged from 1.2 °C to 3.5 °C depending on the comparison settlement; the same variation is visually apparent in Figure 6. Such differences demonstrate that SUHI magnitude is not a fixed property of a city; it depends materially on the thermal characteristics of the reference landscape. Stewart and Oke (2012) developed the Local Climate Zone framework precisely to reduce ambiguity arising from inconsistent urban and rural site definitions. Future extensions of this work should therefore replace hotspot-only comparisons with area-based LCZ or standardized urban–rural reference classes.

4.4 Planning significance and heat mitigation

The practical significance of the findings lies in the alignment of three signals: expanding impervious cover (Figures 2a and 2b; Table 2), contraction or fragmentation of vegetated surfaces (Figures 3a and 3b; Table 3), and stronger surface-temperature and SUHI contrasts (Figures 4a–6; Tables 4 and 5). These changes matter because urban form can amplify local heat exposure beyond background climate warming, and the IPCC identifies urban green infrastructure and nature-based solutions as important components of heat-risk reduction (IPCC, 2022). The health relevance is reinforced by WHO guidance that extreme heat can

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worsen cardiovascular, respiratory, renal, and other health risks and that urban design can either increase or reduce exposure (WHO, 2026).

Evidence from within the study region also indicates that greening can produce measurable thermal benefits. Balogun and Daramola (2019) found urban green areas in Ibadan to be approximately 1–2 °C cooler within surrounding buffer zones, illustrating the mitigation value of connected vegetation rather than isolated ornamental planting. The present study therefore supports planning measures that protect mature tree cover, preserve and connect parks, introduce shaded pedestrian networks, limit unnecessary surface sealing, and use heat-sensitive materials and development controls in new urban expansion areas. Satellite-based monitoring can provide a repeatable screening tool for identifying rapidly warming districts that require more detailed field or public-health investigation.

4.5 Limitations and directions for further research

Several limitations define the strength of inference. First, each regional mosaic combines Landsat acquisitions from a two- to three-year epoch rather than a single date, and although the scenes are predominantly dry-season, meteorological conditions are not identical. Second, NDBI > 0 was used as an index-based proxy for impervious surface without an independent classification accuracy assessment; confusion with bare soil is therefore possible. Third, thermal-band resampling to 30 m standardized the analysis grid but did not improve native thermal spatial resolution. Fourth, the SUHI metric is based on selected maximum-temperature hotspots and is sensitive to the choice of rural/peri-urban reference. Fifth, the archived workflow does not preserve a separate description of the emissivity parameterization used in the LST equation. These constraints do not erase the repeated regional pattern, but they limit causal and climatological interpretation of the absolute temperature differences.

Future work should use Landsat Collection 2 Level-2 surface-temperature products or another fully documented atmospheric/emissivity correction workflow, adopt consistent seasonal composites, validate impervious fractions against high-resolution imagery, and quantify uncertainty. A Local Climate Zone design, spatially matched urban–rural samples, statistical trend testing, and fusion with population or heat-health exposure data would substantially strengthen policy relevance. Where contemporary high-resolution imagery is available, object-based mapping of tree canopy and sealed surfaces could also reveal which forms of urban growth most strongly modify local thermal conditions.

V. Conclusions and recommendations

This study set out to determine whether long-term urban surface change and thermal intensification occurred consistently across the six state capitals of southwestern Nigeria. Using three Landsat observation epochs spanning approximately three decades, it combined NDBI, NDVI, LST retrieval, impervious-area summaries, and urban–reference hotspot comparisons within one regional framework.

The results provide a consistent answer to the research problem. Impervious-surface signatures expanded in every city, corresponding to increases of approximately 29.8–57.2 percentage points of mapped city area between the first and third epochs (Figures 2a and 2b; Table 2). Mean LST rose from 24.2–26.5 °C to 30.2–33.6 °C (Figures 4a and 4b; Table 4), while all urban–reference pairs displayed stronger SUHI contrasts in the latest epoch (Table 5; Figure 6). Third-epoch SUHI intensity ranged from 0.9 to 4.8 °C, with the largest contrast observed between Lagos Metropolis and Ibereko. Although the magnitude of absolute temperature change is affected by sensor, date, atmospheric, emissivity, and reference-site uncertainties, the repeated co-occurrence of expanding built surfaces and stronger surface heating across all six cities is robust at the comparative level.

The central practical implication is that urban growth policy in southwestern Nigeria should treat heat as a land-use planning issue rather than only as a meteorological concern. Development control should protect remaining green infrastructure, require meaningful tree and shade provision in new growth areas, reduce unnecessary soil sealing, and prioritize thermal-risk screening in dense commercial and residential districts. Routine Earth-observation monitoring should be institutionalized so that urban planners can identify emerging hotspots before they become entrenched features of the city.

The study is limited by multi-date epoch mosaics, index-based impervious mapping, native thermal-resolution constraints, hotspot-based SUHI reference selection, and incomplete documentation of emissivity parameterization. Future research should therefore use standardized seasonal composites and fully reproducible Landsat Level-2 surface-temperature workflows, validate impervious and vegetation fractions with high-resolution data, and evaluate urban heat within Local Climate Zones

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or similarly standardized urban-form classes. The broader conclusion is clear: where impervious urban surfaces expand while vegetated cooling capacity contracts, surface heat intensifies. Managing the geography of urban growth is therefore a practical component of managing future heat risk in southwestern Nigeria.

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Declarations

Conflict of interest: The authors declare no conflict of interest.

Data availability: Source Landsat data are publicly accessible through the U.S. Geological Survey EarthExplorer archive. Derived outputs should be deposited by the authors in an appropriate repository or made available in accordance with the target journal's policy.

Ethics statement: This study used remotely sensed and geospatial data and did not involve human participants or animals.