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Dynamics of the Urban Heat Island in Lagos Metropolis, Nigeria (1984 to 2013)

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Abstract

Urban Heat Island (UHI) occurs when cities record higher temperatures than surrounding rural areas due to Land Use/Land Cover (LULC) modification and anthropogenic heat. In Lagos metropolis, rapid urbanization has altered LULC, but spatiotemporal UHI dynamics over three decades remain poorly quantified. This study analyzed UHI dynamics in Lagos metropolis from 1984 to 2013 using remote sensing data from Landsat Thematic Mapper (TM) 5, Enhanced Thematic Mapper Plus (ETM+) 7, and Operational Land Imager (OLI) 8 imagery. Land Surface Temperature (LST) was retrieved from thermal bands, and urban–rural extents were delineated through supervised classification from multispectral bands in GIS. UHI zones were identified using mean LST thresholds for each time period. Urban built-up area expanded while rural open land declined, intensifying UHI. Urban LST increased from 24.76°C in 1984 to 28.59°C in 2013, and UHI extent grew from 125.01 km² to 319.38 km², a 155.4% increase. Findings confirm that LULC change driven by urbanization is the primary driver of UHI intensification in Lagos. Mitigation should prioritize increasing urban vegetation and high-albedo roofing. Street canyon design to enhance wind circulation is critical along the Ifako/Ijaye, Oshodi/Isolo, and Lagos Island corridor.

Keywords: Urban Heat Island; Land Surface Temperature; Land use land cover; Lagos metropolis; GIS; Remote Sensing

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1. INTRODUCTION

Global urbanization has accelerated over the past four decades, with 55% of the world's population now residing in cities and projections reaching 68% by 2050 (United Nations Department of Economic and Social Affairs, 2018). This concentration of people and infrastructure alters surface energy balance, modifies radiative properties, and disrupts local climates. Rapid urbanization is expected to worsen issues related to urban climate, bioenergy, and deforestation, as well as competition for environmental resources (Zhou et al., 2016). Among the most documented urban climate effects is the Urban Heat Island (UHI), defined as the surface temperature differential between built-up urban areas and surrounding rural landscapes derived from land surface temperature (LST) (Weng, 2001). UHI arise from the replacement of vegetated, permeable surfaces with impervious materials such as asphalt and concrete. These materials exhibit low albedo, high heat capacity, and reduced evapotranspiration, which increases the storage and re-radiation of solar energy (United States Environmental Protection Agency [US EPA], 2008). As a result, air and surface temperatures in cities can exceed rural temperatures by 2–15°C. Under calm, clear conditions, nocturnal differences can reach 12°C (Ojo, 1982). The intensity and spatial pattern of UHI are governed by urban morphology, building density, anthropogenic heat release, vegetation cover, water bodies, and meteorological conditions (Smargiassi et al., 2009). The consequences of UHI extend beyond thermal discomfort. Elevated temperatures increase energy demand for cooling, degrade air quality, accelerate greenhouse gas emissions, and elevate health risks during heatwaves (Goggins et al., 2012). Urban vegetation and water bodies mitigate these effects by enhancing evapotranspiration and shading, while urban design influences wind flow and heat dispersion (Wichansky et al., 2008). Advances in thermal remote sensing have enabled large-scale monitoring of UHI through LST derived from satellite imagery. Landsat thermal data have been widely applied to quantify UHI in data-scarce regions due to their long temporal record and moderate spatial resolution (Stathopoulou et al., 2007). In Lagos metropolis, urban expansion has been rapid and largely unplanned, resulting in extensive replacement of vegetation and wetlands with built-up areas. Early work by Ojo (1981, as cited in Ojeh et al., 2016) documented spatiotemporal temperature variations using transect measurements. More recent studies employed Geographic Information System (GIS) and remote sensing to classify surface UHI and predict UHI-prone areas (Ramachandra et al., 2012). Ojeh et al. (2016) examined hourly air temperature differences between urban and rural stations. However, few studies have systematically analyzed UHI dynamics over multiple decades using a consistent urban-rural landscape framework linked to LST change.This study addresses that gap by analyzing UHI dynamics in Lagos metropolis from 1984 to 2013 using Landsat imagery. The specific objectives are to: (1) quantify changes in urban-rural landscape, (2) assess changes in urban-rural LST, and (3) map the spatiotemporal evolution of UHI. Unlike prior work, this study explicitly links UHI expansion to changes in urban-rural distance and uses mean LST thresholds to delineate UHI zones for each epoch. The paper is structured as follows: Section 2 describes data and methods, Section 3 presents results on landscape and LST change, Section 4 discusses UHI dynamics and implications, and Section 5 concludes with mitigation recommendations and future research directions.

2. STUDY AREA

Lagos metropolis comprises the contiguous built-up area and surrounding suburbs, including Ojo, Ikotun, Egbe, Agege, Alimosho, Ketu, and Lagos Island, extending to the outskirts of the city on the mainland. Lagos is situated within Lagos State, established in 1967. It served as Nigeria's federal capital until 1991, when the capital was transferred to Abuja, and is located in southwest Nigeria (Ogunleye & Awomosu, 2011). Lagos city lies within geographical coordinates of 507,933.87 m to 574,309.95 m Easting and 740,347.79 m to 706,462.40 m Northing. Figure 1 shows the administrative area and location of Lagos metropolis with inset maps of Lagos State, Nigeria, and Africa. Lagos metropolis comprises sixteen of Lagos State's twenty Local Government Areas. The city recorded 7,937,932 residents in the 2006 national census and was estimated at 13,491,800 in 2022 (Federal Republic of Nigeria Official Gazette, 2009; World Population Review, n.d.). It lies within a wet equatorial climate zone characterized by a bimodal rainfall regime. Peak rainfall occurs from April to July, with monthly means exceeding 300 mm, while minima occur in January, August, and September. Heavy rainfall during peak periods frequently overwhelms the poor surface drainage of the coastal lowlands, resulting in recurrent flooding. Harmattan winds from the Sahara dominate from December to early February. Mean monthly temperatures range from 25°C in July to 29°C in March (Abegunde, 1987).

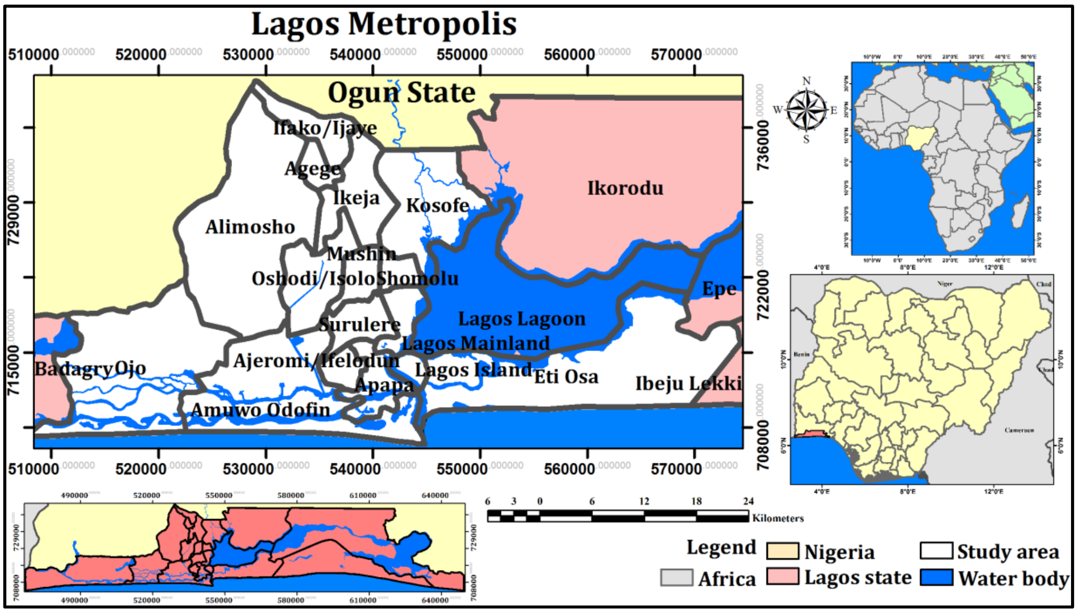

Fig. 1. Lagos Metropolis Administrative Area with inset Maps of Lagos State, Nigeria and Africa for details.

3. METHODOLOGY

This study employed remote sensing and GIS to quantify UHI dynamics in Lagos metropolis from 1984 to 2013.

3.1 Data Sources

Spatial data included Landsat Thematic Mapper (TM) 5, Enhanced Thematic Mapper Plus (ETM+) 7, and Operational Land Imager (OLI) 8 imagery for 1984, 2000, and 2013, acquired from the United States Geological Survey (USGS). This study used mainly spatial data. An administrative vector map of Lagos was obtained from the Guinea Current Large Marine Ecosystem project and the University of Lagos. High-resolution Google Earth Pro imagery was used for accuracy assessment. Ground-truth data were collected using GPS during field surveys.

3.2 Urban-Rural Landscape Analyses

Landsat Bands 4, 5, and 7 were mosaicked, radiometrically corrected, and enhanced for composites (Table 1). Supervised maximum likelihood classification in Idrisi TerrSet 18.31 categorized Land Use/Land Cover (LULC) into built-up area, other land, and water body. Accuracy assessed against Google Earth Pro imagery in IBM SPSS 26 was 80.20% for 1984, 86.40% for 2000, and 86.60% for 2013. Seven landscape classes—urban built-up, suburban built-up, rural built-up, urban open land, captured open land, rural open land, and water body—were delineated using the Urban Landscape Analysis Tool in ArcGIS 10.4.1. Landscape area per epoch and change for 1984–2000 and 2000–2013 were computed in ArcGIS 10.4.1 and Microsoft Excel.

Table 1. Landsat TM 5, ETM+ 7 and OLI 8 sensor and characteristics.

Sensor	Path/Row	Spectral Range (µm)	Bands	Resolution (m)	Time Acquired	Date Acquired
TM 5- Multi Spectral	191/055,056	0.45 - 2.35	3, 4, 5 & 7	30	9:33 AM	12/18/1984
TM 5- TIRS		10.40 - 12.50	6	120		
ETM+ 7- Multi Spectral		0.45 - 2.35	3, 4, 5 & 7	30	9:56 AM	02/06/2000
ETM+ 7-TIRS		10.40 – 12.50	6	60		
OLI 8-Multi Spectral		0.53 - 2.29	3,4, 5 & 7	30	10:04 AM	03/25/2013
OLI 8-TIRS		10.6–12.51	10	100		

Note. TIRS = Thermal Infrared Sensor

3.3 Land Surface Temperature Retrieval

LST retrieval in Idrisi TerrSet 18.31 using USGS protocols (Landsat Missions, 2019). Thermal Bands 6 for TM/ETM+ and 10 for OLI (Table 2) were converted to top-of-atmosphere radiance and at-sensor brightness temperature as follows:

$$L_{\lambda} = \text{offset} + \text{gain} \times DN \quad (1)$$

$$L_{\lambda} = \frac{(L\min - L\max)}{255} \times DN + L\min \quad (2)$$

$$L_{\lambda} = M_L Q_{Cal} + A_L \quad (3)$$

$$T_B = \frac{K_2}{\ln\left[(K_1 / L_{\lambda}) + 1\right]} \quad (4)$$

Where, offset, gain, K_1 and K_2= User defined parameters but K_1= $W/m^2sr^{-1}\mu m^{-1}$ and K_2= Kelvin (K); L_λ= Cell value as radiance ($W/m^2sr^{-1}\mu m^{-1}$); DN= Thermal imagery digital number; Lmax and Lmin= Derived temperature depending on gain status; M_L= Band-specific multiplicative rescaling factor; A_L= Band-specific additive rescaling factor; Q_{cal}= Quantized and calibrated standard product pixel values (DN); T_B= Blackbody temperature(K). From Eqn. 5, emissivity correction was implemented and conversion was applied as follows:

$$T_{LST}(K) = \frac{T_B}{1 + \lambda \times T_B / \rho \times \ln \varepsilon} \quad (5)$$

Where, T_B= Blackbody temperature(K); λ= Wave length of emitted radiance (μm); ρ= ћ × (C/σ) = 1.438×10^{-2} (mK); σ= Boltzman constant= 1.38×10^{-23}JK; C= velocity of Light= $2.998 \times 10^{-8}ms^{-1}$; ћ= Planck's constant= 6.626×10^{-34}Js; ε= Emissivity in the range of 0 to 1; $T_{LST}(K)$= Land Surface Temperature in Kelvin. Surface emissivity corrections were applied per LULC class using coefficients from Snyder et al. (1998) and Stathopoulou et al. (2006) to account for non-uniform emissivity (Ramachandra et al., 2012). LST values were converted from Kelvin to Degree Celsius using

$$T_{LST}(°C) = T_{LST}(K) - 273.15 \quad (6)$$

Where, $T_{LST}(°C)$ = Land Surface Temperature in Degree Celsius and T_{LST} (K) = Land Surface Temperature in Kelvin. The derived LST was used to analyze urban-rural temperature differences for 1984, 2000, and 2013 and to identify UHI areas.

3.4 Urban Heat Island Delineation

UHI zones were defined as areas where LST exceeded the mean urban LST for each epoch. Spatial extent was calculated in km². A transect from Mushin Halt to Imore was used to analyze urban–rural gradients. LST, distance, and landscape class were extracted at 0.88 km intervals to assess changes from 1984 to 2013. Processing was carried out in ArcGIS 10.4.1 and MS Excel 2010.

4. RESULTS AND DISCUSSION

This study analyzes the dynamics of Urban Heat Island in Lagos metropolis from 1984 to 2013 under the following headings: (1) Urban-rural landscape change; (2) urban-rural temperature change; and (3) Urban Heat Island dynamics, 1984–2013.

4.1 Urban-Rural Landscape Change, 1984–2013

Urban-rural landscape maps for 1984, 2000, and 2013 are displayed in Figure 2. Distribution of the urban-rural landscape is tabulated in Table 2. Urban built-up area increased from 242.41 km² in 1984 to 563.28 km² in 2013, primarily at the expense of rural open land, which declined by 233.64 km² between 2000 and 2013. Water body area contracted by 26.28 km² over the period. Table 3 tabulates the urban-rural landscape change from 1984 to 2000 and 2000 to 2013. The replacement of vegetated and permeable surfaces with impervious cover reduced evapotranspiration and shading, altering the local energy balance and creating conditions conducive to UHI development (US EPA, 2008).

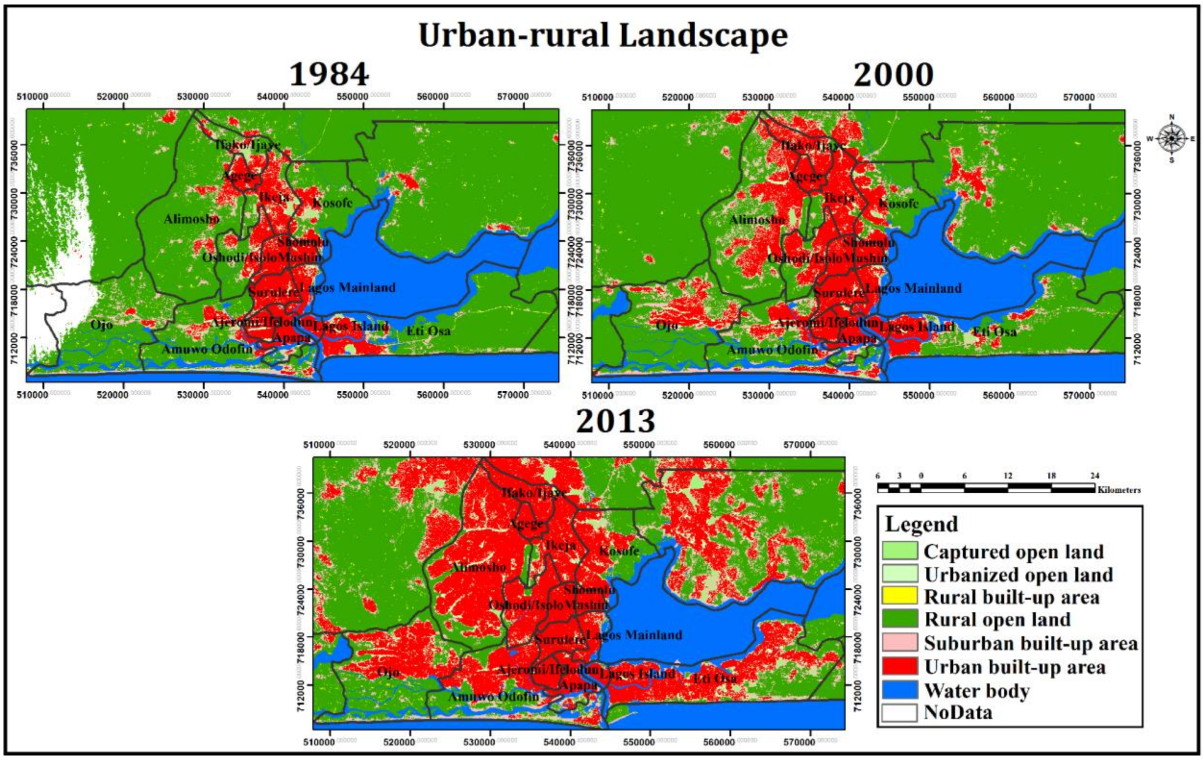

Fig. 2. Urban-rural landscape area of Lagos metropolis in 1984, 2000 and 2013.

Table 2. Urban-rural Landscape Area (km^2) in 1984, 2000 and 2013 for Lagos metropolis.

Category	1984	2000	2013
No Data	24.14	0.00	0.00
Urban built-up area	242.41	296.46	563.28
Suburban built-up area	68.14	69.37	58.74
Rural built-up area	8.14	4.95	3.31
Urbanized open land	169.07	158.04	151.74
Captured open land	13.64	12.62	14.31
Rural open land	354.74	352.03	115.19
Water body	111.54	98.34	85.26

Table 3. Urban-rural Landscape Change (km^2) in Lagos metropolis from 1984 to 2000 and 2000 to 2013.

Category	1984-2000	2000-2013
Urban built-up area	-24.14	-22.39
Suburban built-up area	54.05	270.02
Rural built-up area	1.23	-7.43
Urbanized open land	-3.19	1.56
Captured open land	-11.03	-3.10
Rural open land	-1.01	4.88
Water body	-2.72	-233.64

4.2 Urban-Rural Temperature Change, 1984–2013

Figure 3 shows LST for Lagos metropolis derived from Landsat thermal imagery. Table 4 tabulates minimum, maximum, and mean LST for each landscape category. Mean LST in urban built-up areas rose from 24.76°C in 1984 to 28.59°C in 2013. Rural open land maintained lower temperatures, with a mean of 23.32°C in 2013. The temperature differential between urban and rural zones widened over time, reflecting the thermal impact of urban expansion. Water bodies exhibited the lowest temperature variability due to high heat capacity. Land use and human activity are primary controls on LST variation (Weng, 2001; Wichansky et al., 2008).

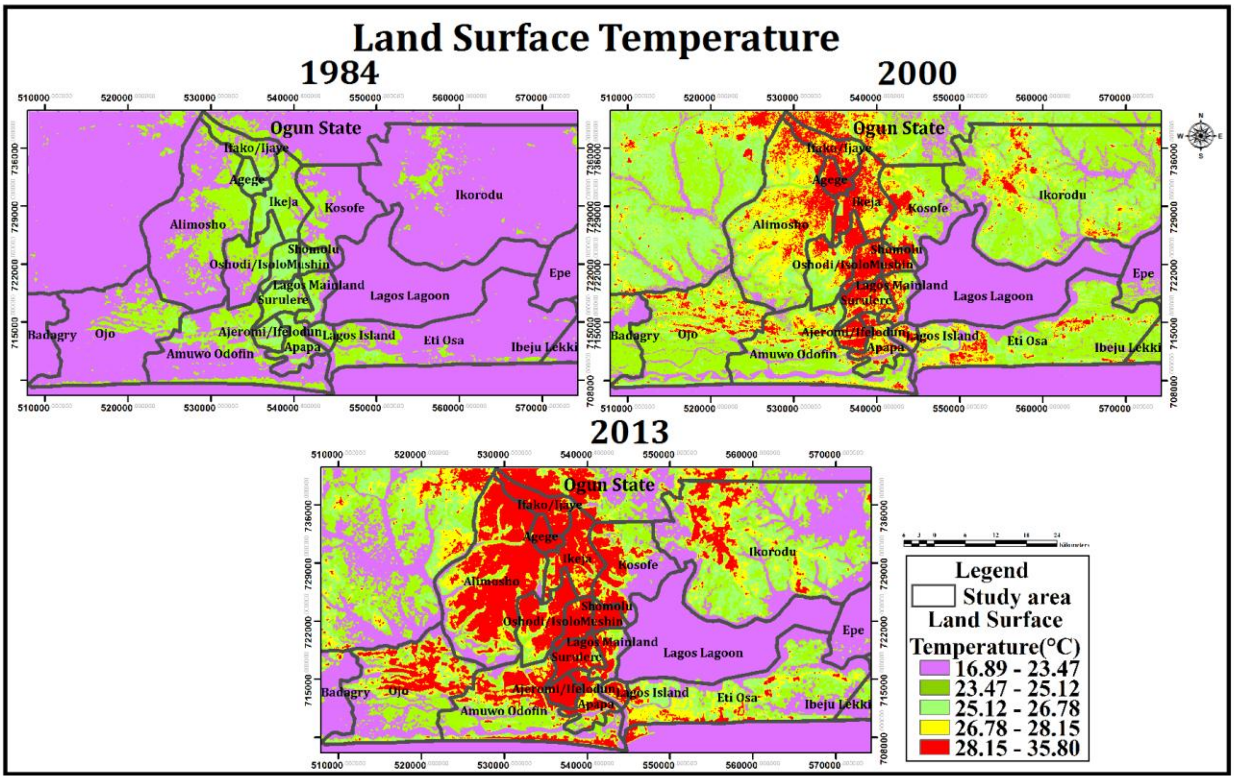

Fig. 3. Land Surface Temperature (LST) of Lagos for 1984, 2000 and 2013.

Table 4. Minimum, maximum and mean Urban-rural Land Surface Temperature (LST) for Lagos metropolis in 1984, 2000 and 2013.

Category	Minimum	Maximum	Mean
		1984	
Urban built-up area	20.20	27.90	24.76
Suburban built-up area	19.30	27.30	23.61
Rural built-up area	20.20	26.80	22.93
Urbanized open land	18.60	27.10	23.43
Captured open land	19.70	26.80	23.07
Rural open land	17.90	26.80	22.02
Water body	18.80	25.50	22.16
		2000	
Category	**Minimum**	**Maximum**	**Mean**
Urban built-up area	22.67	35.80	27.99
Suburban built-up area	22.39	31.13	27.08
Rural built-up area	22.10	30.07	26.91
Urbanized open land	22.10	32.71	26.66
Captured open land	23.23	30.60	25.87
Rural open land	22.10	30.87	24.67
Water body	21.25	27.38	22.91
		2013	
Category	**Minimum**	**Maximum**	**Mean**
Urban built-up area	21.46	33.60	28.59
Suburban built-up area	20.79	32.61	25.37
Rural built-up area	20.79	26.77	23.15
Urbanized open land	20.70	32.48	25.24
Captured open land	20.70	30.14	24.20
Rural open land	20.63	30.33	23.32
Water body	20.78	29.27	22.33

Note. Minimum/Maximum/Mean = °C

4.3 Urban Heat Island Dynamics, 1984–2013

Daytime UHI mapped from LST for 1984, 2000, and 2013 is shown in Figure 4. UHI extent increased from 147.06 km² in 1984 to 332.36 km² in 2013 (Table 5).

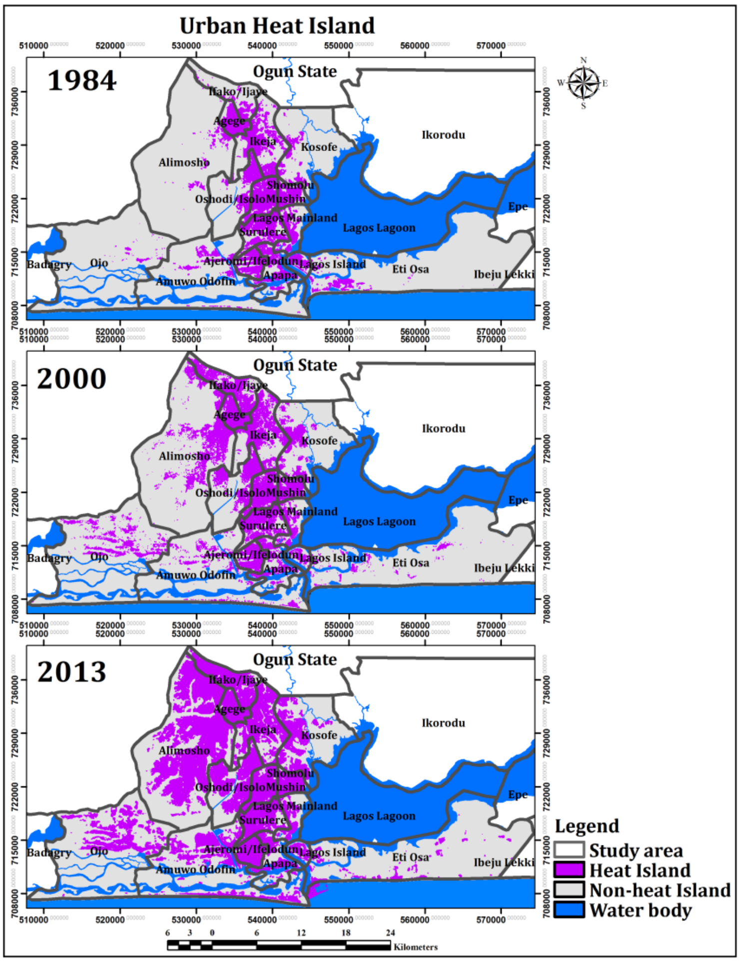

Fig. 4. Urban Heat Island of Lagos metropolis for 1984, 2000 and 2013.

Major hotspots were identified in Ikeja, Ikoyi, Surulere, Oshodi, Makoko, Agege, Isolo, and Mushin halt. Table 5 shows LST values are consistently higher in UHI areas compared to non-UHI areas. This indicates increasing thermal discomfort from 1984 to 2013.

Table 5. Spatial extent covered by Urban Heat Island (UHI) and Non-Urban Heat Island (Non-UHI) for Lagos metropolis from 1984 to 2013.

Year	Non-UHI Extent	UHI Extent
1984	866.96	125.01
2000	825.96	166.01
2013	672.59	319.38

Note. Non-UHI Extent/UHI Extent = km²

Transect analysis (Figure 5) revealed a significant inverse relationship between LST and distance from the urban core, with R^2 values of 0.561, 0.556, and 0.669 for 1984, 2000, and 2013, respectively (Table 6). UHI intensity was greatest during the dry season and in areas with minimal vegetation. The spatial growth of UHI corresponds with the expansion of built-up area and the loss of rural open land, confirming that LULC change is the primary driver of UHI intensification in Lagos metropolis. Similar mechanisms have been documented in other rapidly urbanizing regions (Goggins et al., 2012; Smargiassi et al., 2009; Zhou et al., 2017).

5. CONCLUSION

This study applied GIS and remote sensing techniques to analyze UHI dynamics in Lagos metropolis between 1984 and 2013. Landsat imagery was used to derive LST and urban-rural landscape change, providing a consistent basis for assessing daytime thermal patterns. Results show that urbanization-driven LULC change has intensified UHI. Built-up area expanded significantly, while rural open land declined.

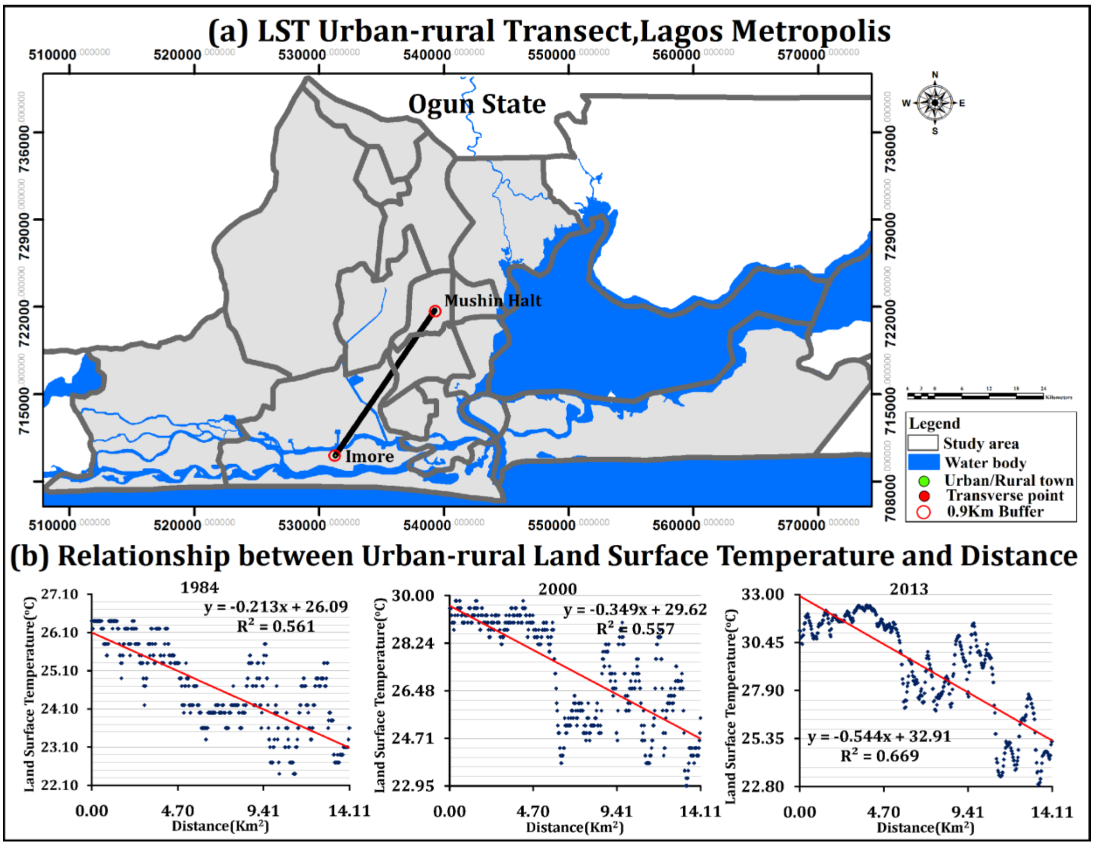

Fig. 5. (a) Urban-rural Land Surface Temperature transect across Lagos metropolis for 1984, 2000 and 2013; and (b) Relationship between urban-rural Land Surface Temperature and distance in 1984, 2000 and 2013.

Table 6. Urban-rural Land Surface Temperature (LST) and distance for 1984, 2000 and 2013.

	1984				2000			
	Distance (km²)		LST (°C)		Distance (km²)		LST (°C)	
Category	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Urban built-up area	0.00	10.12	22.70	26.40	0.00	10.27	24.07	29.80
Suburban built-up area	7.55	11.14	21.10	25.50	6.65	14.05	24.63	27.65
Rural built-up area	6.38	14.11	23.30	24.00	11.59	13.15	25.74	28.46
Urbanized open land	5.57	10.21	23.30	25.30	5.96	10.30	23.80	27.11
Captured open land	8.68	10.96	23.00	25.50	6.68	10.69	25.19	27.65
Rural open land	5.75	13.99	22.40	25.30	7.22	14.11	23.80	28.73

	2013			
	Distance (km²)		LST (°C)	
Category	Minimum	Maximum	Minimum	Maximum
Urban built-up area	0.00	10.90	26.71	32.43
Suburban built-up area	11.47	14.02	24.57	27.46
Rural built-up area	8.93	13.15	25.66	30.79
Urbanized open land	5.84	10.02	24.08	30.07
Captured open land	0.00	0.00	0.00	0.00
Rural open land	11.05	14.11	23.33	27.70

This shift increased urban LST relative to rural areas, reducing the urban-rural temperature distance and expanding the spatial extent of UHI. Using mean LST thresholds, UHI zones were delineated for 1984, 2000, and 2013, revealing progressive spatial growth and higher thermal intensity over time. The observed rise in LST corresponds to reduced thermal comfort across the metropolis. To mitigate UHI effects, three strategies are recommended:

1. Increase surface albedo through cool roofing and reflective building materials to reduce solar heat absorption.

2. Expand urban vegetation in identified hotspots, particularly along the Ifako/Ijaye, Oshodi/Isolo, and Lagos Island axis. Trees, rooftop gardens, and public parks enhance evapotranspiration and shading, lowering ambient temperatures.

3. Improve wind circulation by aligning street canyons with prevailing wind directions to disperse heat from dense urban cores.

Future Research

While this study quantified UHI using LST and LULC change, it did not incorporate surface energy balance components such as net radiation, sensible heat, latent heat, and heat storage. These fluxes are the primary drivers of UHI formation in the urban surface layer. Future work should integrate surface energy balance modeling with satellite-derived LST to better understand the physical mechanisms driving UHI in Lagos and to improve the design of targeted mitigation interventions.

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