

Urban Heat Island Trends of Lagos Communities

Andrew Igila Abe

igiabe.a@gmail.com

University of Lagos

Elijah Akinyele Akindunde

University of Jos

Research Article

Keywords: Urban heat island (UHI), Vegetation, Urban climate, Urban policies, Sustainable development goals (SDGs)

Posted Date: August 4th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10216478/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

URBAN HEAT ISLAND TRENDS OF LAGOS COMMUNITIES

Authors' Biodata

Authors: Andrew Igila Abe (Department of Urban and Regional Planning, University of Lagos, Nigeria)

Email: igiabe@gmail.com <https://orcid.org/0009-0007-2281-0046>

Andrew Igila Abe is a Nigerian researcher and academic affiliated with the University of Lagos (UNILAG), specializing in urban, sustainable urbanism, climate change, and regional spatial development. His research advances inclusive urban development, geospatial analysis, and climate resilience in Nigeria. He contributes to the WITS-TUB-UNILAG Urban Lab, an international collaboration promoting Sustainable Development Goals (SDGs), urban research, and graduate education. Abe has conducted independent studies on sustainability and spatial planning and serves as a peer reviewer for geospatial and environmental science publications.

Elijah Akindele Akintunde, Department of Geography and Planning, University of Jos, Nigeria

Email: akinyelea@unjos.edu.ng Orchid: <https://orcid.org/0000-0003-2353-6628>

Dr. Elijah A. Akintunde (Ph.D.) is an African Union Scholar and environmental management expert with over 10 years of teaching and research experience. He earned a joint Ph.D. from the University of Ibadan and the Pan African University (PAULESI). As CEO of JAYEL Green Consult, he promotes environmental sustainability through research and community engagement. His work focuses on climate action, waste management, environmental education, and land restoration. Dr. Akintunde has led multidisciplinary research projects, mentored students at the University of Jos, and received the 2023 James Kweku Global Mentorship Award.

Authors Consent Letter

I, myself and on behalf of my co-author, hereby give my consent for publishing my manuscript titled “**URBAN HEAT ISLAND TRENDS OF LAGOS COMMUNITIES**” to the ‘**Discover Cities**’, clearly stating that the *study was not a clinical trial*. By submitting my manuscript and signing this letter, I declare my agreement that, after publication, anyone is free:

- to copy, distribute, and display the work properly attached to the author;
- to make derivative works;
- to make commercial use of the work;

Provided the following conditions of Attribution:

- the original author and publisher are clearly and fully given credit (but not in any way that suggests that author and publisher endorse the user or user's use of the work); for any reuse or distribution, it must be made clear to others what the license terms of this work are;

- Any of these conditions can be waived off if the copyright holder gives explicit permission.

Co-authors (in sequence including me)

No.	Author	Affiliation	Email
1	Andrew Igila Abe	University Lagos, Nigeria	Igiabe.a@gmail.com
2	Elijah Akinyele Akintunde	University of Jos, Nigeria	akinyelea@unjos.edu.ng
Note: If your manuscript is authored by more than 3 scholars, please fill out the contribution form available at: Authors' Guidelines page of the journal.			

I hereby transfer the rights as per above statement.

Signed

Authors

Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information

Consent Declaration

Ethics, Consent to Participate, and Consent to Publish declarations: Not applicable.

Funding Declaration

We declare that we receive no funding for this research.

ABSTRACT

Urbanization has intensified the Urban Heat Island (UHI) phenomenon, affecting energy consumption, environmental sustainability, and the thermal comfort of urban residents. This study assessed the Surface Urban Heat Island characteristics of Kosofe, Shomolu, and Ikeja Local Government Areas of Lagos State from 2000 to 2024. It evaluated the effectiveness of climate policies aligned with Sustainable Development Goal (SDG) 13 in mitigating urban heating. Landsat imagery obtained from the United States Geological Survey and administrative boundary data from DIVA-GIS were used to derive the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) in ArcGIS 10.8. Bivariate linear regression was employed to examine the relationship between NDVI and LST across the study period. The results revealed a changing NDVI–LST relationship over time. In 2000, a strong association was observed ($R =$

0.970; $R^2 = 0.942$), indicating that vegetation accounted for a substantial proportion of LST variation. By 2015, the relationship reached its highest level ($R = 0.995$; $R^2 = 0.991$), while maximum LST increased to 48.9°C, suggesting growing anthropogenic influence. In 2024, the relationship weakened considerably ($R = 0.393$; $R^2 = 0.154$) as NDVI declined to 0.13, reflecting increased impervious surfaces and intensified urban heating. The findings indicate that existing climate-related interventions have not sufficiently curbed rising urban temperatures. The study recommends a policy realignment that prioritizes urban greening, ecological restoration, and thermally resilient urban design to mitigate the growing UHI effect and enhance environmental sustainability and urban liveability in Lagos State.

Keywords: *Urban heat island (UHI), Vegetation, Urban climate, Urban policies, Sustainable development goals (SDGs)*

1.0 INTRODUCTION

The global increase in urbanization, with cities occupying approximately 2% of the world's land mass (Dissanayake et al., 2019; Taha & Silvia, 2019; Tang et al., 2017), has transformed the economic, social, and environmental shapes of urban areas and their environments. Cities are the major drivers of economic growth. As a result, there has been continual growth in the number of cities with the prediction that 66% of the world's population being affected (Dissanayake et al., 2019). This growth has not left cities without negative effects, particularly on climate, because the climates of many areas have been reshaped due to the introduction of materials such as concrete, asphalt, and bricks and the high rate of energy (Liu & Liu, 2012). Urban environments face several challenges, such as UHIs, high population density, GHG emissions, air pollution, and high energy demand. The formation of UHI is primarily driven by the alteration of the urban land structure, where naturally vegetated areas are converted into built-up regions (Dissanayake et al., 2019).

Several factors contribute to the formation of heat islands. Human activities and the heat retention of artificial structures, which absorb and store solar radiation, are the primary causes. Human activities, including industrial operations, transportation, CO₂ emissions, and energy consumption, contribute to the increased UHI intensity during the day and night. (Dissanayake et al., 2019; Liu & Liu, 2017). An urban heat island (UHI) refers to the phenomenon where urban areas experience higher temperatures than their surrounding rural regions (Arifwidodo et al., 2018).

Lagos is one of West Africa's largest cities with a fast-growing economy. As a result, the natural environment of traditional earth has eroded the surfaces of the built environment, which includes asphalt, glass, and concrete with different heights and dimensions (Australia Pty Ltd, n.d.; Nuruzzaman, 2015; Tang et al., 2017). An increase in temperature can trigger some diseases

(Australia Pty Ltd, n.d.), increase the cost of energy and water use in cooling houses (Akande et al., 2017a), reduce evapotranspiration, hamper the natural ecosystem, affect human comfort, and decrease human efficiency (Fada et al., 2022). In view of this, the Nigerian and Lagos State governments have introduced policies and programs that align with sustainable development goals (SDGs) (Emah, 2023; Sojobi et al., 2015). Since its implementation, research has focused on the implementation of these agendas. Emah (2023) reviewed progress along the lines of poverty reduction, good water, and quality education. (Fada et al., 2022) assessed the implementation level of these programs. Nothing has been done to quantify the impact of these policies and programs on Nigerian urban areas, particularly heat islands. Notably, this research seeks to assess the UHI of Kosofe, Shomolu, and Ikeja over time and determine the impact of reducing UHI in Lagos through the implementation of policies and programs of SDG 13. The study objectives are to determine the status of UHI in the selected study areas over a period of time; identify the major drivers of UHI change; determine the extent of change in the UHI effect and assess the impacts of Lagos' sustainable development goal policies on the reduction of UHI.

Given the rapid urbanization in Lagos, investigating the UHI trend is essential because of its potential adverse effects on human health, energy usage, and the environment. This research will enable policymakers to assess the effectiveness of current policies, guide the development of mitigation strategies, and support sustainable urban growth.

Hypothesis: Null hypothesis: There are no significant impacts of SDG 13 policies on the UHI effect of Lagos.

2.0. LITERATURE REVIEW

Urbanization expansion is changing the local temperature of the urban setting. Changes in LULC can impact ecosystems at all scales, from local environments to the global system, and play a role in driving climate change (Akande et al., 2017; Akintunde & Abe, 2025; Kasniza Jumari et al., 2023). In 2015, the United Nations made the Sustainable Development Goals to incorporate climate change measures into national policies, strategies, and plans to enhance sustainable urbanization (United Nations, 2022). The observed temperature difference between urban environments and surrounding rural areas is known as the UHI effect. The UHI effect can be defined as the relative warmth of a city relative to the surrounding rural areas, which are cool. The

causes of the UHI effect are numerous, with a primary factor being the alteration of land surfaces due to urban development. This development often replaces natural vegetation with materials that retain heat more efficiently. For example, the construction of buildings and infrastructure removes vegetation, which in turn prevents surface heat from dissipating into the cooler night sky. The types of land cover that contribute to heat retention include pavements, rooftops, sidewalks, roads, and parking lots. The color and composition of these materials also significantly influence the heat retention (Akande et al., 2017).

2.1. Theoretical/Conceptual Framework

The study of the urban heat island (UHI) phenomenon is challenging because of the complex interplay of diverse socioeconomic and biophysical drivers and outcomes. This complexity stems from spatial characteristics, such as the configuration and composition of urban mosaic patches and their temporal changes. Similarly, the arrangement and makeup of urban patches, including green and built-up areas, significantly influence the thermal environment (Mokhtari, 2022). Urban management involves the administration and planning of the urban environment. This process encompasses multiple disciplines, offering essential insights to guide systems, governance, and overall management to promote sustainability and enhance resilience to climate change (Raven et al., 2018). One of its multiple disciplines is urban ecology. Urban ecology is the scientific study of cities, addressing complex social–biophysical challenges and examining the interactions between biological systems, built environments, and human activities (Barot et al., 2019; Mokhtari, 2022). Based on the principle of urban ecology that ecological (biophysical) patterns and processes influence ecosystem services, it becomes clear how urban management can play a vital role in investigating the UHI phenomenon. As a transdisciplinary science, urban management supports the progress of society toward sustainability and resilience (Mokhtari, 2022). Viewing the urban environment in terms of spatial and temporal patterns of urbanization and their impacts on social, ecological, and functional processes, ecosystem services, human well-being, and urban sustainability will be vital for urban managers to effectively manage the urban setting. A robust and holistic approach to studying cities enables decision-makers to better understand the complex relationships among social, ecological, economic, and technological systems. In this context, several factors are considered when examining UHIs, namely, system theory, urban ecology theory, and the concept of spatial heterogeneity.

2.1.1. System Theory

This theory views urban ecosystems as interconnected physical, biological, social, and economic components (Nnah et al., 2024). Urban policies directly and indirectly influence the quantity and quality of energy and materials extracted from the Earth system and those returned to it (Coelho & Ruth, 2006; Mokhtari et al., 2022). Over time, population growth, consumption patterns, and related urban policies governing distribution affect the local environment, climate, and city in complex and often unpredictable ways. Broadly, urban form and economic activity shape temperature patterns (primarily through urban heat islands), influence energy demand, and determine the infrastructure required for their generation and distribution (Coelho & Ruth, 2006; Fink et al., 2018).

Cities, like natural ecosystems, can be described as complex open systems (Coelho & Ruth, 2006) and play a vital role in human health and well-being, liveability, and the quality of urban life. This complexity arises from numerous types of interaction feedback that influence ecosystems, including climate, biogeochemistry, nutrient cycling, hydrology, population growth, urbanization, and development, as well as human perceptions, behaviors, and other factors (Fink et al., 2018).

2.2.2. The Urban Ecology Concept

Urban ecology studies humans in cities, nature within cities, and the interconnected relationships between the two. Its multidisciplinary nature and unique focus on human and natural systems within urbanized areas make it distinct (Tiwary, 2018; Wu et al., 2013). Urban ecology is characterized by the use of concepts, principles, laws, models, hypotheses, and theories (Forman, 2016). The science of urban ecology addresses the complex social and biophysical challenges of cities by examining the interactions among biological systems, built environments, and human activities (Forman, 2016; Mokhtari et al., 2022). This study highlights how urban ecology can be valuable in investigating the urban heat island (UHI) phenomenon (Mokhtari, 2022). In urban ecology, urban areas are viewed as spatially heterogeneous, with patterns that significantly influence ecological processes. The UHI, arising from social–biophysical interactions, is also spatially heterogeneous and temporally dynamic (Mokhtari, 2022).

Recently, the integration of landscape and urban ecology has provided a valuable framework for understanding the formation and impacts of spatial and dynamic heterogeneity. It also examines how landscape patterns (land cover and land use composition and configuration) are related to biophysical and socioeconomic processes across multiple spatial and temporal scales (Wu, 2013; Makhtari, 2022). This explains the variations in UHI patterns across spatial dimensions and their dynamics over temporal scales.

2.2.3. The concept of spatial heterogeneity.

The concept of spatial heterogeneity is applicable to urban planning and management, where social and biophysical processes mediate urban functions and sustainability (Mattingly, 1994). Urban management encompasses the management of all city systems, making it complex (Wema, 1995). As a transdisciplinary field, urban management integrates human actions, perceptions, and policymaking with biophysical components (Mokhtari et al., 2022; Özdamar & Önay, 2024; Ramadier, 2004). For example, residents may respond to heat through actions such as planting trees or using air conditioners, illustrating how decision-making and human behavior influence the biophysical processes that shape the UHI. A process-based approach to “dynamic heterogeneity” can help clarify interactions between human and biophysical systems to better understand the mechanisms driving complex urban phenomena (Mokhtari et al., 2022).

2.2. Benchmark for Defining Urban Heat Island Dynamics

There is no globally accepted benchmark established by international organizations such as the UN, WHO, or IPCC to define the presence or strength of the UHI effect. Researchers and planning agencies generally rely on comparative thresholds and methodological conventions. The UHI effect is commonly described as the temperature difference between urban and rural areas ($\Delta T = T_{\text{urban}} - T_{\text{rural}}$) (Oke, 1982). Although not formal benchmarks, studies often classify UHI intensity as weak when $\Delta T < 2^{\circ}\text{C}$, moderate when ΔT ranges from 2°C to 5°C , and strong when ΔT exceeds 5°C , although these ranges may be refined depending on the climate zone (Santamouris, 2015). Major institutions provide different guidelines: the IPCC acknowledges UHI effects but does not prescribe a standard threshold (IPCC, 2021); the WMO recommends consistent urban–rural comparison methods without fixed values (WMO, 2018); the US EPA defines UHI simply as urban areas being hotter than rural areas and evaluating intensity in a local context (US EPA, 2020); and

the European Environment Agency (EEA) emphasizes relative intensity comparisons rather than fixed temperature differences (EEA, 2019).

2.3 Factors affecting heat islands in urban areas

Urban overheating (UO) refers to the environmental conditions in which urban areas experience significantly higher temperatures than their surrounding rural regions. Some studies have reported temperature differences in up to 10°C. Urban features such as buildings, roads, and other infrastructure absorb and subsequently re-emit solar energy, thereby driving this phenomenon. Elevated daytime surface temperatures and sustained higher night-time ambient temperatures typically characterize urban overheating. The severity of this effect can differ depending on factors such as the size of the city, the layout and density of its built environment, and its geographical location (World Bank, 2024).

2.4 Urban heat islands in Lagos, Nigeria

The global climate is changing rapidly, with surface temperatures surpassing historical records. Climate change is most evident in Lagos through three major threats: rising sea levels, extreme heat, and intense rainfall. The sharp increase in climate-related events compared with those in the past decade indicates that this trend will intensify (Ministry of Environment and Water Resources, 2024). Lagos, like many other megacities in the Global South, is grappling with the challenges of the UHI effect. Bassett et al. (2020). Moreover, dry seasons typically have the largest UHIIs and thus pose the greatest heat-based health risk to Lagos. However, tropical environments experience seasonality in UHI (Building Nigeria's Response to Climate Change (BNRCC) Project, 2011). The use of wood as fuel is a major driver of deforestation, land degradation, and biodiversity loss, reducing the forest's capacity to sustain livelihoods and support climate adaptation (Akintunde & Abe, 2025; Building Nigeria's Response to Climate Change (BNRCC) Project, 2011; Sojobi et al., 2015) Ikeja is projected to experience a temperature increase of between 1.4 and 2.3 degrees Celsius by 2046--2065 (Building Nigeria's Response to Climate Change (BNRCC) Project, 2011)

Between 2009 and 2011, the state hosted climate change summits, which engaged global experts to assess climate risks and develop response strategies. In 2011, in collaboration with ICLEI, it organized a congress on *Building Climate Change Resilient African Cities*, where mayors and local leaders endorsed the African Mayors Climate Change Declaration, first drafted at the *Local*

Climate Solutions for Africa 2011 Congress in Cape Town (Building Nigeria's Response to Climate Change (BNRCC) Project, 2011).

The overall strategy aimed to strengthen environmental management and biodiversity conservation in Lagos, Nigeria. It emphasized periodic assessments of land use, vegetation cover, and biodiversity, alongside the integration of biodiversity considerations into regional planning and policy to ensure long-term sustainability. Regular reviews of the state's regional plan were proposed to allow timely conservation adjustments. The key measures included implementing biodiversity conservation programs, enforcing land use zoning to protect sensitive ecosystems, such as wetlands, forests, and floodplains, and designating new forest reserves. To reduce environmental degradation from energy use, the strategy promoted the widespread adoption of energy-efficient fuelwood stoves, encouraged green architectural practices, and introduced a long-term plan to replace fuelwood with renewable energy sources. Collectively, these initiatives were designed to safeguard ecosystems, improve resilience, and support the well-being of Lagos residents (Building Nigeria's Response to Climate Change Project, 2011).

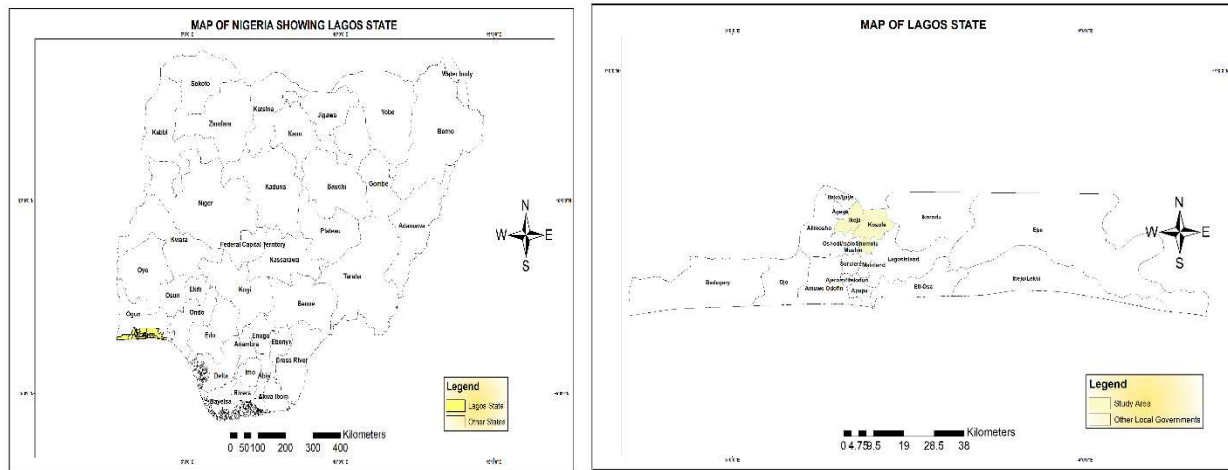
In 2024, under Governor Babajide Sanwo-Olu, Lagos State expanded its eco-friendly policies to combat extreme heat and environmental challenges. The initiatives included rehabilitating waterways to reduce vehicular emissions, maintaining more than 300 urban parks to improve air quality and carbon capture, and redesigning five LGAs to promote heat reduction through shading and street grid improvements, including Badagry, Ikorodu, Ibeju Lekki, Epe, and parts of Eti-Osa. Additionally, 350 manufacturing plants in Kosofe, Apapa, and Eti-Osa were retrofitted with cool surfaces, green envelopes, and cooling systems, whereas 1,800 km of roads in the most heat-impacted LGAs were resurfaced with cool pavements to mitigate health and productivity risks (Ministry of Environment and Water Resources, 2024).

Earlier researchers delved into the study of many urban heat islands with many focuses on AST. Adebamowo et al., 2013; Ishola et al., 2025; Ojeh et al., 2016; Salau, 2016), and recent researchers investigated the socioeconomic impact of LST before many major climate policies were implemented (Bassett et al., 2020). This research delved into the UHI effect considering the Lagos state climate policy implementation since 2012.

3.0. MATERIALS AND METHODS

3.1. Study area and description

The study area covers Kosofe, Ikeja, and Shomolu in Lagos State. The area lies at the equator's longitude and latitude. Shomolu is considered one of the industrial hubs in Lagos, Ikeja is an administrative town, and Kosofe is mainly a residential area. The choice of these cities with representative land uses provides insight into the spatial distribution of UHI across Lagos State. The cities have an aggregate population of 1.38m according to the 2006 census. Based on the Koppen classification, Lagos has a wet and dry climate (Aw) that borders the tropical monsoon climate (Am). It experiences two rainy seasons, from April to July and from September to November, with a brief dry period in August.



(a) (b)

Fig. 1: Nigeria Showing Lagos State, Lagos State showing Kosofe, Ikeja, and Shomolu

Source: Data extracted from Diva-GIS, 2025

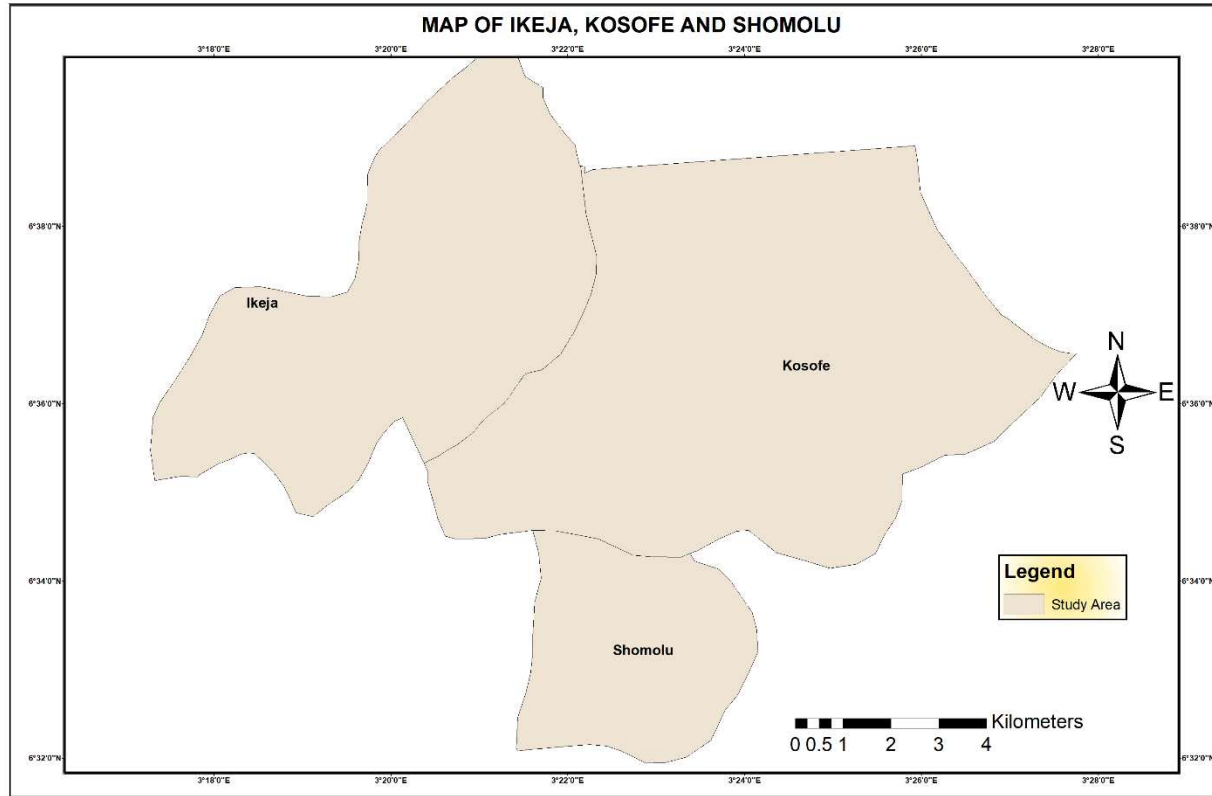


Fig 2: Ikeja, Kosofe, and Shomolu

Source: Diva-GIS, 2025

3.2. Materials

Data were sourced from secondary sources. Landsat images from 2006--2024 were collected at intervals from the United States Geological Survey (USGS) (<http://earthexplorer.usgs.gov>) from 2000--2024. Three images were collected at intervals of 10 years on average, indicating an equal gap before and after the SDGs were implemented in Lagos State. The images included Enhanced Thematic Mapping Plus (ETM+) and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) images. All images were selected during the dry season and during the day for uniformity and when the UHI was considered more intensive. Visual analysis was performed on the image for the selection of images with less cloud cover and other distortions. Details on the spatial, spectral, and metadata attributes of the images are presented in Table 1.

Table 1: Metadata of images

S/N	Data	Sensor	Path/Row	Spatial Resolution	Date	Time	Source	Coordinate System
1	Landsat 7	ETM+	191/055	30 m	07/12/2006	10:55 am	USGS (online)	WGS 1984
2	Landsat 8	OLI/TIRS	191/055	30 m	10/02/2015	11:03 am	USGS (online)	WGS 1984
3	Landsat 8	OLI/TIRS	191/055	30 m	08/02/2024	11:03 am	USGS (online)	WGS 1984
4	Administrative map of Nigeria	—	—	—	—	—	DIVA-GIS	WGS 1984

Source: USGS, 2025

3.3. Methods

The surface reflectance data from the Landsat-8 satellite were used for this investigation: Band 4, Band 5, and Band 10. ArcGIS version 10.8 was used for the analysis. Supervised classification was employed to categorize land uses such as mixed-vegetation and heavily urbanized areas. A pixel-based training approach was applied, with training samples derived from field-collected GPS data for the classification of the NDVI, and LST. The NDVI values extracted from satellite images were reclassified and analysed in ArcGIS 10.8 to calculate the areas and conduct temporal comparisons. Areas with high and low NDVI values were further quantified using the raster calculator tool in ArcGIS. This was performed using the following steps:

i. *Conversion of digital numbers to radians*

$$L\lambda = ML \times Q_{cal} + AL - O_i$$

where ML = the band-specific multiplicative rescaling factor,

Q_{cal} = Band 10 image,

AL = band-specific additive rescaling factor,

O_i denotes the correction applied to Band 10.

ii. *Conversion of the Radiance to the At-Sensor Temperature*

$$BT = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda} + 1\right)} - 273.15$$

where k_1 and k_2 are the band-specific thermal conversion constants obtained from the metadata.

iii. NDVI was calculated.

$$NDVI = (NIR - R) / (NIR + R)$$

where NIR represents Band 5 for Landsat 8 or Band 4 for Landsat 7 and R represents Band 4 for Landsat 8 or Band 3 for Landsat 7.

iv. Calculate the vegetation proportion.

$$P_v = (NDVI - NDVI_s) / (NDVI_v - NDVI_s)$$

v. Calculation of land surface emissivity

$$\epsilon\lambda = \epsilon_v\lambda P_v + \epsilon_s\lambda (1 - P_v) + C\lambda$$

where ϵ_v and ϵ_s = the vegetation and soil emissivity, respectively, and C is the surface roughness, which is a constant value of 0.005. The threshold values for soil pixels (**NDVI_s = 0.2**) and fully vegetated pixels (**NDVI_v = 0.5**) were established by et al. (1990, 2008)..The emissivity (ϵ) values for the soil (ϵ_s) and fully vegetated (ϵ_v) surfaces were assumed to be 0.97 and 0.99, respectively, as reported by Sabrino et al. (2004).

vi. Calculate the land surface temperature.

$$T_s = \frac{BT}{\{1 + \left[\left(\frac{\lambda BT}{\rho} \right) \ln \epsilon \lambda \right] \}}$$

where LST is the land surface temperature (in Kelvin), TB is the radiant surface temperature (in Kelvin), λ is the wavelength of the emitted radiance (11.5 μ m), ρ is $h \times c / \sigma$ (1.438×10^{-2} mK), h is Planck's constant (6.26×10^{-34} J s), c is the velocity of light (2.998×10^8 m/s), σ is Stefan Boltzmann's constant (1.38×10^{-23} JK⁻¹) and ϵ is the emissivity.

vii. Calculate the urban heat island.

$$UHI = \bar{q} + 0.5 \alpha$$

where $\bar{q}$ represents the average LST value and α represents the standard deviation of the LST.

Or

. Calculate the urban heat island.

$$UHI = T_u - T_r$$

where $\bar{q}$ represents the average LST value and α represents the standard deviation of the LST.

Regression analysis of the NDVI and LST was conducted to determine the relationship between the vegetation index and LST. Finally, the UHI intensity was determined using several intentionally accepted benchmarks.

4.0 RESULTS, AND DISCUSSION

4.1 Relationship between the normalized differential index and land surface temperature in Shomolu, Kosofe, and Ikeja.

Numerous sociobiophysical factors, including the spatial representation of the land use–land cover (LULC) of an area, affect urban heat islands (Mokhtari et al., 2022). Previous studies have indicated a strong correlation between UHI and NDVI (Akande et al., 2017).

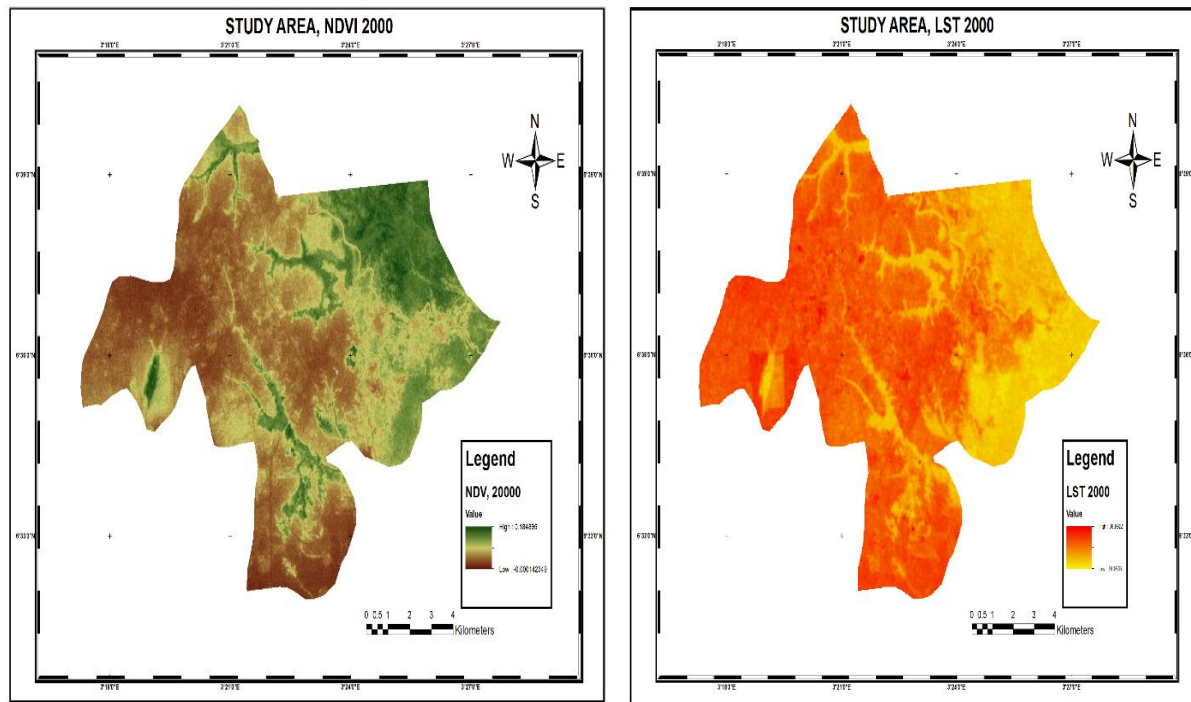


Fig. 5: Relationship between NDVI and LST in 2000

Source: Authors' Analysis, 2025.

The NDVI in 2000 was very weak, with the highest value of 0.18 and the lowest value of less than -0.001, which indicates a very heavily urbanized area with sparse vegetation. The NDVI values ranged from -1 to 1, with values close to 1 indicating high, healthy vegetation and those near -1 indicating low or no vegetation (Ceccato & Dinku, 2010). Sparse vegetation was noted around Kosofe, mostly in areas neighbouring the lagoon, the vast land around the airport and Magodo in Ikeja, and the river-line shores of Shomolu. This indicates that the undeveloped marsh areas are

covered by grass in the neighbouring Lagos Lagoon in Kosofe, the river-line areas of Magodo and Alausa secretariat of Ikeja.

The UHI effect exhibited a reverse trend in areas with high NDVI values. The highest LST of 2000 in the study area was 38.9°C, and the lowest value was 34.9°C, with an LST difference of 40°C. This indicates a moderate temperature range (Jain et al., 2020).

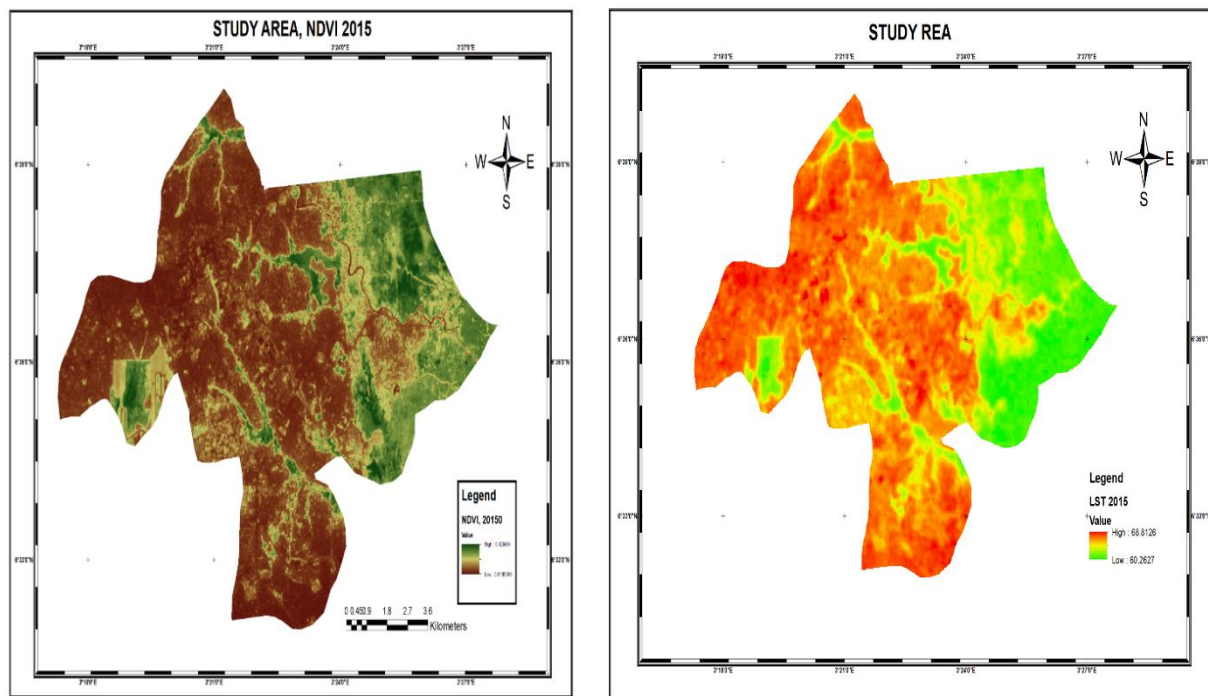


Fig. 6: Relationship between NDVI and LST in 2015

Source: Authors' analysis, 2025.

The NDVI in 2015 was very weak but increased from 0.18 to 0.42, indicating a significant improvement. This implies that the 2012 Lagos urban policy of tree planting and parks impacted the NDVI trend. However, the highest and lowest LSTs increased from 38.9°C and 34.9°C, respectively, to 40.2°C and 48.9°C, respectively, indicating that other factors were also responsible for the increase in UHI in the study area in addition to the vegetation changes.

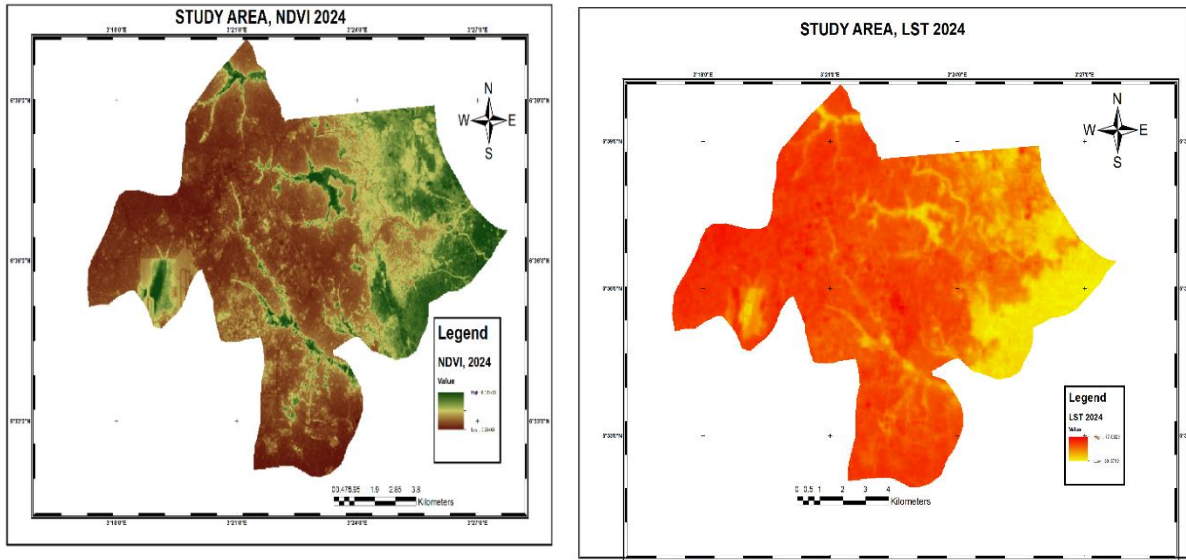


Fig. 7: Relationships between NDVI and LST in 2024

Source: Authors' analysis, 2025.

The NDVI in the year 2024 decreased significantly from 0.42 to 0.13. This decrease may be attributed to the relaxation of the street tree planting policy implemented in 2012 (Building Nigeria's Response to Climate Change Project, 2011). Conversely, the LST continues to increase, reaching a maximum of 57.1⁰C and a minimum value of 49.9⁰C.

4.1.1 Regression analysis of the year 2000 LST and NDVI data

Tables 2, 3, 4, and 5 present the regression model summary for the year 2000, showing the relationship between the NDVI and LST. The correlation coefficient ($R = 0.970$) indicates a strong positive relationship between the two variables. The R^2 value of 0.942 means that NDVI can explain approximately 94.2% of the variation in LST. The adjusted R^2 (0.922) confirms the model's strong explanatory power, even after adjusting for sample size. The estimate's standard error (0.4411) indicates that the model's predictions are fairly precise.

Table 2: Model summary of the year 2000 regression analysis

Model	R	Adjusted R Square	Std. Error in the Estimate	Change Statistics			Sig. Change	F	Durbin-Watson
				R-square	F Change	df1			
1	.970 ^a	.942	.4411	.942	48.402	1	.006	1.859	

a. Predictors: (Constant), NDVI

b. Dependent variable: LST

Source: Authors' analysis, 2025.

The F statistic (48.402), with a significance value of 0.006, indicates that the model is statistically significant (Table 3), implying that the NDVI has a meaningful influence on the LST in year 2000. This assumption is aligned with that of Akande et al. (2017), who used MODIS in the Ibadan metropolis.

Table 3: ANOVA results for year 2000

Model		Sum of the Squares	df	Mean Square	F	Sig.
1	Regression	9.416	1	9.416	48.402	.006 ^b
	Residual	.584	3	.195		
	Total	10.000	4			

Source: Authors' analysis, 2025.

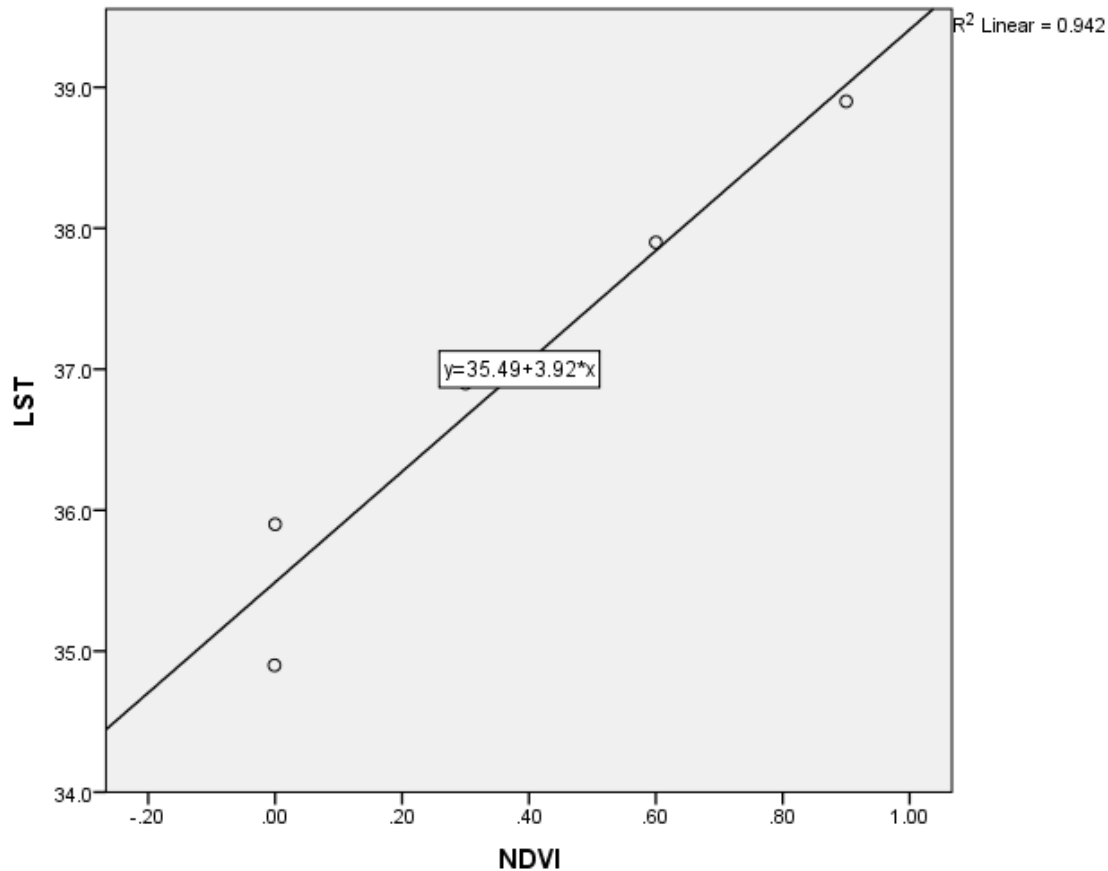


Fig. 8: Regression of the LST and NDVI for year 2000

Source: Authors' analysis, 2025.

A scatter plot revealed a negative and linear relationship between the LST and NDVI and did not reveal bivariate outliers. The correlation between the LST and integrated NDVI was statistically significant, with $b = -0.97$, $t(0.5)$, and $P = 0.441$. The regression equation is $Y = 35.49 - 3.92X$. The scatterplot of the regression line reinforces this strong linear association, indicating that areas with lower NDVI values tended to exhibit elevated surface temperatures during 2000. Overall, the model underscores a clear and statistically significant positive relationship between the vegetation index and LST in the study area for the period under review.

Table 4: Coefficient summary of the regression analysis for year 2000

Model	Unstandardized Coefficients		Standardized Coefficients		Sig.
	B	Std. Error	Beta	t	
1 (Constant)	35.490	.283		125.465	.000
NDVI	3.920	.563	.970	6.957	.006

Source: Authors' analysis, 2025.

Table 5: Summary of Residual Statistics for year 2000

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	35.486	39.018	36.900	1.5343	5
Residual	-.5856	.4105	.0000	.3820	5
Std. Predicted Value	-.922	1.380	.000	1.000	5
Std. Residual	-1.328	.931	.000	.866	5

a. Dependent variable: LST

Source: Authors' analysis, 2025.

4.1.2 Regression analysis of the 2015 LST and NDVI data

Table 6: Descriptive statistics of the LST and NDVI for 2000

Mean	Std. Deviation	N
------	----------------	---

LST	44.580	3.4470	5
NDVI	.1100	.17393	5

Source: Authors' analysis, 2025.

Table 7: Model summary of the regression analysis of LST and NDVI for 2015

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.995 ^a	.991	.989	.31268	2.429

a. Predictors: (Constant), NDVI

b. Dependent Variable: LST

Source: Authors' analysis, 2025.

Tables 8–10 and Figure 7 present the regression analysis between the LST and NDVI for 2015. The analysis of variance in Table 8 shows a highly significant model with an F value of 375.568 ($p < 0.001$), indicating that the NDVI strongly predicts LST variations.

Table 8: ANOVA of LST and NDVI for 2015

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	71.916	1	71.916	735.568	.000 ^b
	Residual	.684	7	.098		
	Total	72.600	8			

a. Dependent variable: LST

b. Predictors: (Constant), NDVI

Source: Authors' analysis, 2025.

The coefficient summary (Table 9) reveals that the NDVI has a substantial positive effect on the LST, with an unstandardized coefficient (B) = 19.818 and a standardized coefficient (Beta) = 1.000, confirming a significant linear relationship between the two variables. The constant term (42.400) represents the baseline LST when the NDVI is zero. The regression is expressed as follows: **$Y = 42.4 - 19.818X$** .

Table 9: Coefficient summary of the regression analysis of LST and NDVI for 2015

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	42.128	.138		304.273	.000
	NDVI	15.134	.558	.995	27.121	.000

Source: Authors' analysis, 2025.

This implies that a unit increase in the NDVI increases the LST of approximately 19.82°C, highlighting a strong positive association. The residual statistics of the model in Table 10 show minimal deviation (residual = ± 0.04 , sad. deviation = 0.0316), confirming the predictions' accuracy and stability. The scatterplot in Figure 7 further illustrates this strong linear relationship, showing that the observed and predicted LST values closely align along the regression line. The 2015 analysis demonstrated that the NDVI was an excellent predictor of LST, explaining nearly all the observed variation in ST across the study area.

Table 10: Residual Statistics Summary of the LST and NDVI for the year 2015

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	40.4634	48.9383	44.6000	2.99824	9
Residual	-.26344	.72586	.00000	.29249	9
Std. Predicted Value	-1.380	1.447	.000	1.000	9
Std. Residual	-.843	2.321	.000	.935	9

Source: Authors' analysis, 2025.

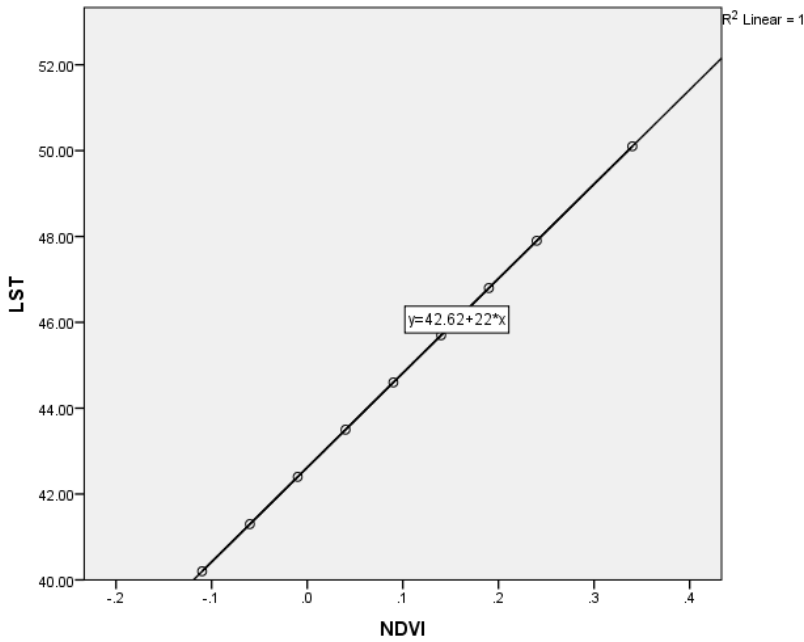


Fig. 9: Regression of the LST and NDVI data for 2015
Source: Authors' analysis, 2025.

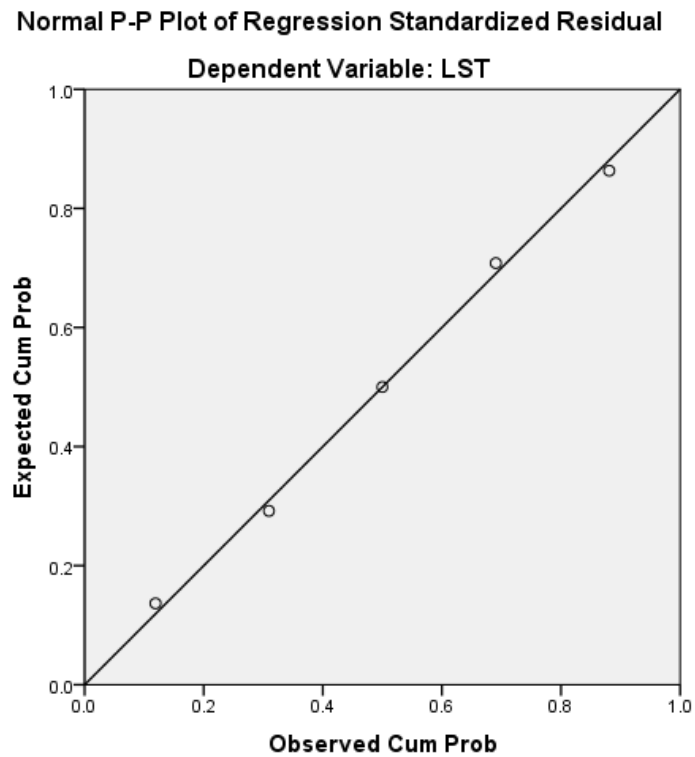


Fig. 10: Regression standardized residuals of the LST and NDVI for year 2015
Source: Authors' analysis, 2025.

4.1.3 Regression analysis of the LST and NDVI for year 2024

Tables 11–14 and Figure 8 present the regression results illustrating the relationship between the LST and NDVI for 2024. The model summary (Table 11) reveals a weak positive correlation ($R = 0.393$) between the NDVI and LST, with a low coefficient of determination ($R^2 = 0.154$), indicating that the NDVI explains only approximately 15.4% of the LST variation. The adjusted R^2 (0.013) further confirms the model's weak explanatory power.

Table 11: Model summary of the LST and NDVI regression analysis for year 2024

Change Statistics										
Model	R	Adjusted R Square	Std. Error of the Estimate	R-square change	F Change	df1	df2	Sig. F Change	Durbin-Watson	
1	.393 ^a	.154	.013	16.9238	.154	1.093	1	6	.336	2.476

a. Predictors: (Constant), NDVI

b. Dependent variable: LST

Source: Authors' analysis, 2025.

The ANOVA results (Table 12) indicate that the regression model is not statistically significant ($F = 1.093$, $p = 0.336$), the NDVI did not significantly influence LST in the year 2024. The regression equation is expressed as follows: $y = 50.24 + 46.11X$

Although the slope coefficient is positive, the large standard error (± 44.11) and wide confidence interval (-61.83 – 154.05) indicate high uncertainty in the estimate. The NDVI variations were not reliable predictors of the LST in 2024. As illustrated in Figure 8, the regression plot reveals a weak linear trend between the NDVI and LST, with widely scattered points around the regression line. The fitted line ($y = 50.24 + 46.11x$) confirms the NDVI's minimal predictive strength, which is consistent with the low R^2 value (0.154) displayed on the graph.

The 2024 model reveals a weak and statistically insignificant relationship between vegetation cover and surface temperature, which contrasts sharply with the strong positive correlations observed in 2000 and 2015. This resulted in a decoupling of the NDVI–LST relationship, potentially resulting from intensified urbanization, reduced vegetation sensitivity, or altered land surface dynamics in the study area.

Table 12: ANOVA results for the year 2024

Model		Sum of the Squares	df	Mean Square	F	Sig.
1	Regression	313.003	1	313.003	1.093	.336 ^b
	Residual	1718.497	6	286.416		

Total	2031.500	7
-------	----------	---

a. Dependent variable: LST

b. Predictors: (Constant), NDVI

Source: Authors' analysis, 2025.

Table 13: Coefficient summary of the regression analysis for the year 2024

Model	Unstandardized Coefficients		Standardized Coefficients		t	Sig.	95.0% confidence interval for B	
	B	Std. Error	Beta				Lower Bound	Upper Bound
1	(Constant)	50.244	6.478		7.757	.000	34.394	66.094
	NDVI	46.115	44.113	.393	1.045	.336	-61.825	154.054

a. Dependent variable: LST

Source: Authors' analysis, 2025.

Table 14: Summary of Residual Statistics, year 2024

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	38.715	57.161	47.650	6.6869	8
Residual	-37.4268	11.1847	.0000	15.6684	8
Std. Predicted Value	-1.336	1.422	.000	1.000	8
Std. Residual	-2.211	.661	.000	.926	8

a. Dependent variable: LST

Source: Authors' analysis, 2025.

The residual statistics in Table 14 show several residuals (−37.43--11.18) with a standard deviation of 15.67, implying substantial variability and a challenge in the model's predictions. However, the Durbin–Watson value (2.476) indicates that the residuals were independent and not serially correlated.

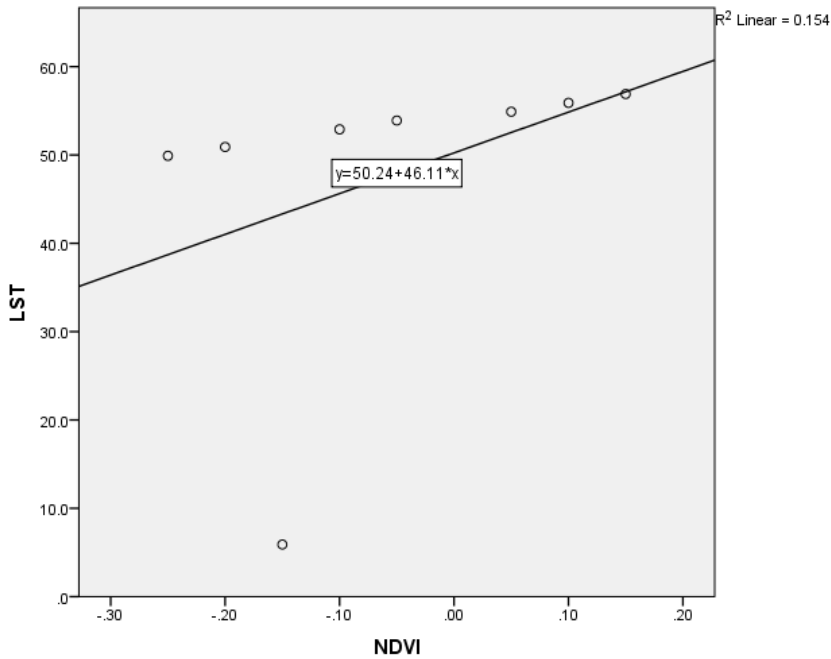


Fig. 11: LST and NDVI regression for 2024

Source: Authors' analysis, 2025.

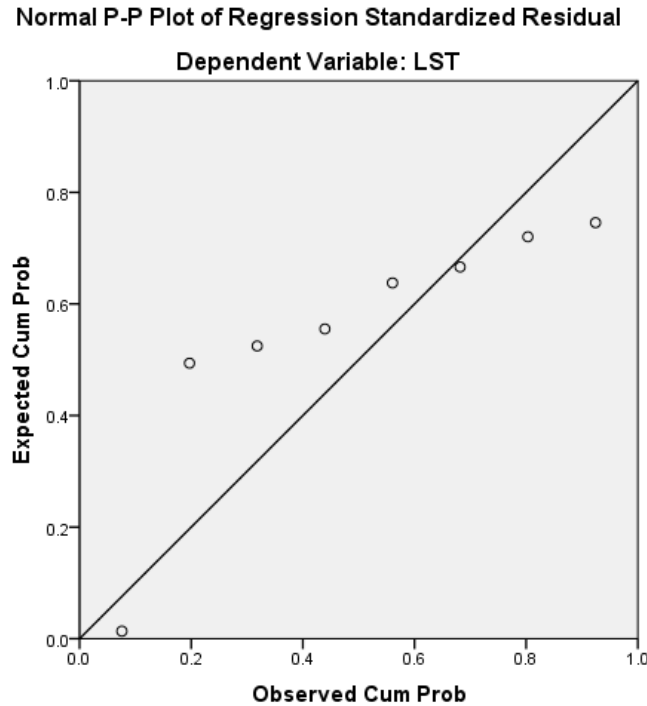


Fig. 12: Regression standardized residuals of the LST and NDVI for 2024

Source: Authors' analysis, 2025.

4.1.4 Temporal variation in the relationship between NDVI and LST (2000–2024)

The comparative trend from 2000 to 2024 indicates a progressive weakening of the NDVI–LST relationship (Table 15). The initially strong positive correlations in 2000 and 2015 showed that vegetation played a critical role in regulating surface temperature. However, by 2024, this relationship had substantially deteriorated, likely due to intense urban expansion, vegetation degradation, and land surface modification.

Table 15: Summary of the trend Relationship between the UHI and NDVI

Year	R-Square
2000	0.942
2015	0.991
2024	0.154

Source: Authors' analysis, 2025.

These findings indicate that anthropogenic activities have increasingly disrupted the natural vegetation–temperature balance in the study area, resulting in a decoupling effect between the NDVI and LST.

4.2 Intensity of urban heat island

Air temperatures in urban areas are generally higher than those in their surrounding rural regions because natural vegetation is replaced by nonporous, non-evaporative, and highly heat-conductive materials such as concrete and asphalt. Additionally, the *urban canyon effect* contributes to this phenomenon, as the walls of multistorey buildings release stored daytime heat more slowly at night than nonurban surfaces (Akande et al., 2017). The UHI effect is typically quantified via the UHI intensity ($\Delta T_{(u-r)}$), which is defined as the temperature difference between an urban area (u) and its surrounding rural area (r). This measurement is usually taken within the urban canopy layer (UCL), which is the air layer extending from the ground level to the average height of buildings or tree canopies

Table 16: LST analysis from 2000--2024

(SCALE: Weak UHI: $\Delta T < 2^{\circ}\text{C}$; Moderate UHI: $\Delta T = 2\text{--}5^{\circ}\text{C}$; Strong UHI: $\Delta T > 5^{\circ}\text{C}$ derived from (Jain et al., 2020))

Temperature Range	2000	2015	2024	Difference between 2000 and 2015	Difference between 2015 and 2024
Highest	38.9 $^{\circ}\text{C}$	48.9 $^{\circ}\text{C}$	57.1 $^{\circ}\text{C}$	10 $^{\circ}\text{C}$	2.2 $^{\circ}\text{C}$
Lowest	34.9 $^{\circ}\text{C}$	40.2	49.9 $^{\circ}\text{C}$	5.7 $^{\circ}\text{C}$	9.7 $^{\circ}\text{C}$
Tu-Tr	4 $^{\circ}\text{C}$	8.7 $^{\circ}\text{C}$	7.2 $^{\circ}\text{C}$		
UHI Intensity	Moderate	Extreme	Extreme		

Source: Authors' analysis, 2025.

Table 16 summarizes the land surface temperature dynamics of the study area between 2000 and 2024. This figure reveals a consistent temperature increase, with the highest LST increasing from 38.9°C in 2000 to 57.1°C in 2024 and the lowest from 34.9°C to 49.9°C. The temperature range varied slightly, while the intensity of the urban heat island (UHI) shifted from moderate in 2000 to extreme in both 2015 and 2024, indicating an increase in urban heat stress over time.

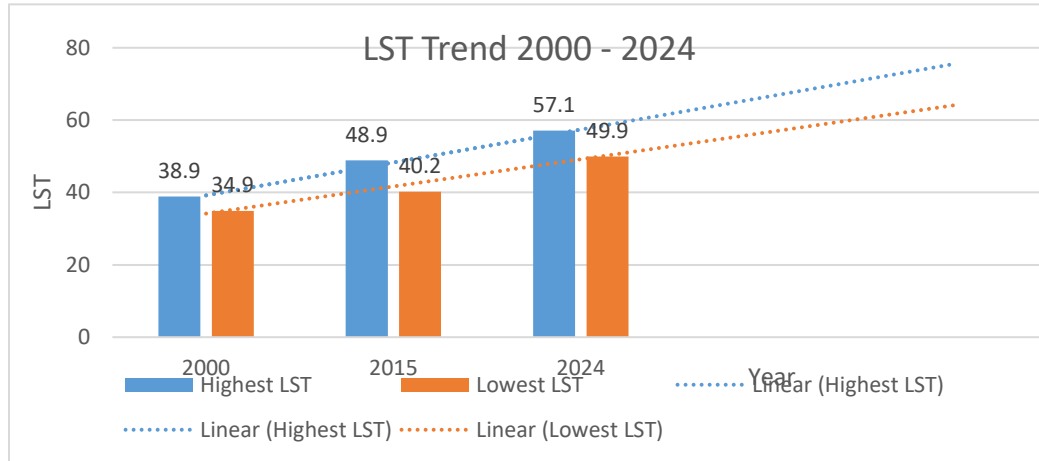


Fig. 13: LST trend in Ikeja Shomolu and Kosofe (2000–2024)

Source: Authors' analysis, 2025.

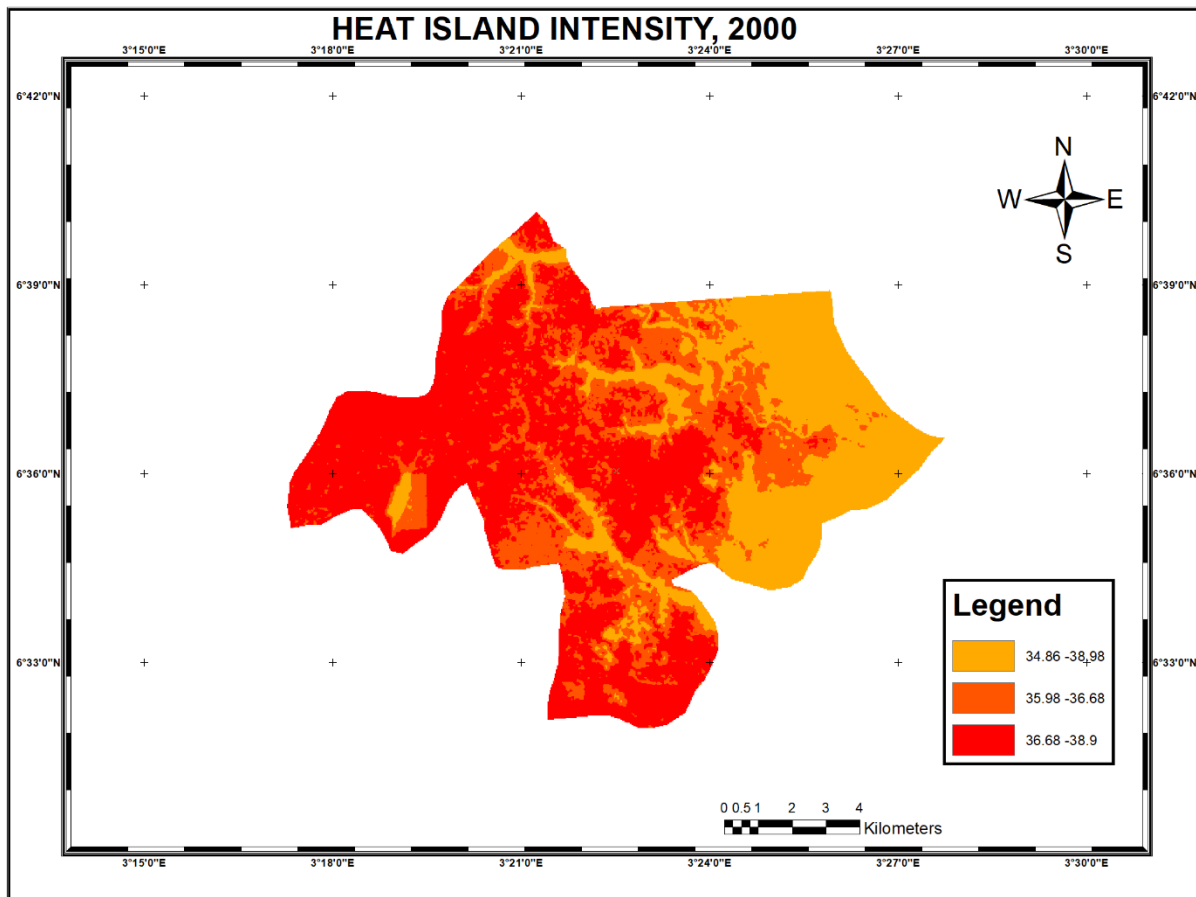


Fig. 14: UHI intensity in Ikeja, Kosofe, and Shomolu (2000).

Source: Authors' analysis, 2025.

Fig. 14 shows the urban heat island intensity of the study area in 2000, with Ikeja and Shomolu being predominantly hotter than 35°C and Kosofe having predominantly less than 34°C.

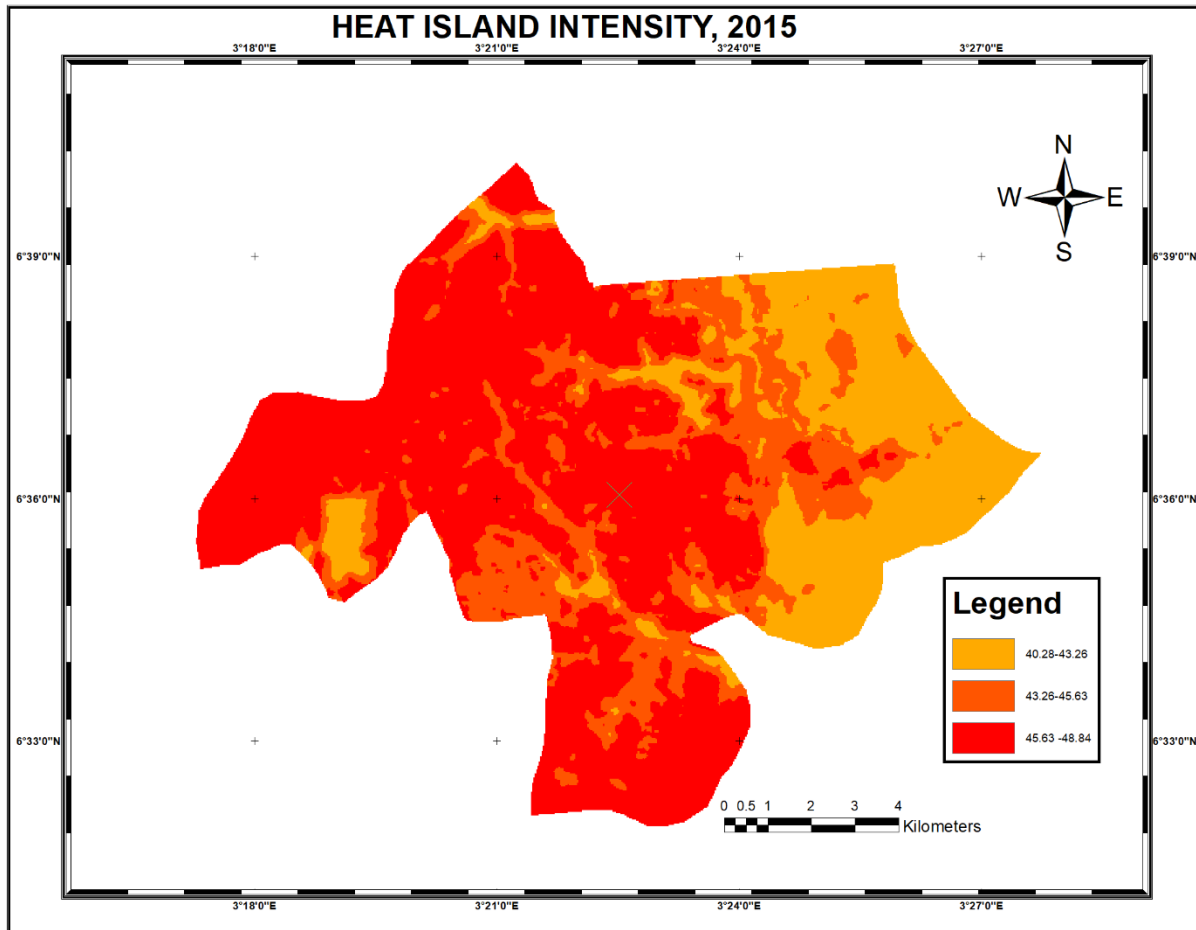


Fig. 15: UHI intensity in Ikeja, Kosofe, and Shomolu (2015)

Source: Authors' analysis, 2025.

Fig. 15 shows the urban heat island intensity of the study area in 2015, with Ikeja and Shomolu being predominantly hotter than 43°C and Kosofe having temperatures predominantly less than 43 °C. The spatial pattern of HII across the study area in 2015 demonstrated a varying pattern. The heat intensity values varied between 40.28°C and 48.84°C, with the highest intensities (45.63–48.84°C) concentrated in the central and southwestern parts of the study area. These zones, represented by deep red tones, correspond to areas with dense built-up surfaces and minimal vegetation cover. Conversely, the eastern and peripheral regions, depicted in yellow (40.28°C–43.26°C), experienced lower surface temperatures, reflecting the cooling influence of vegetation and open spaces.

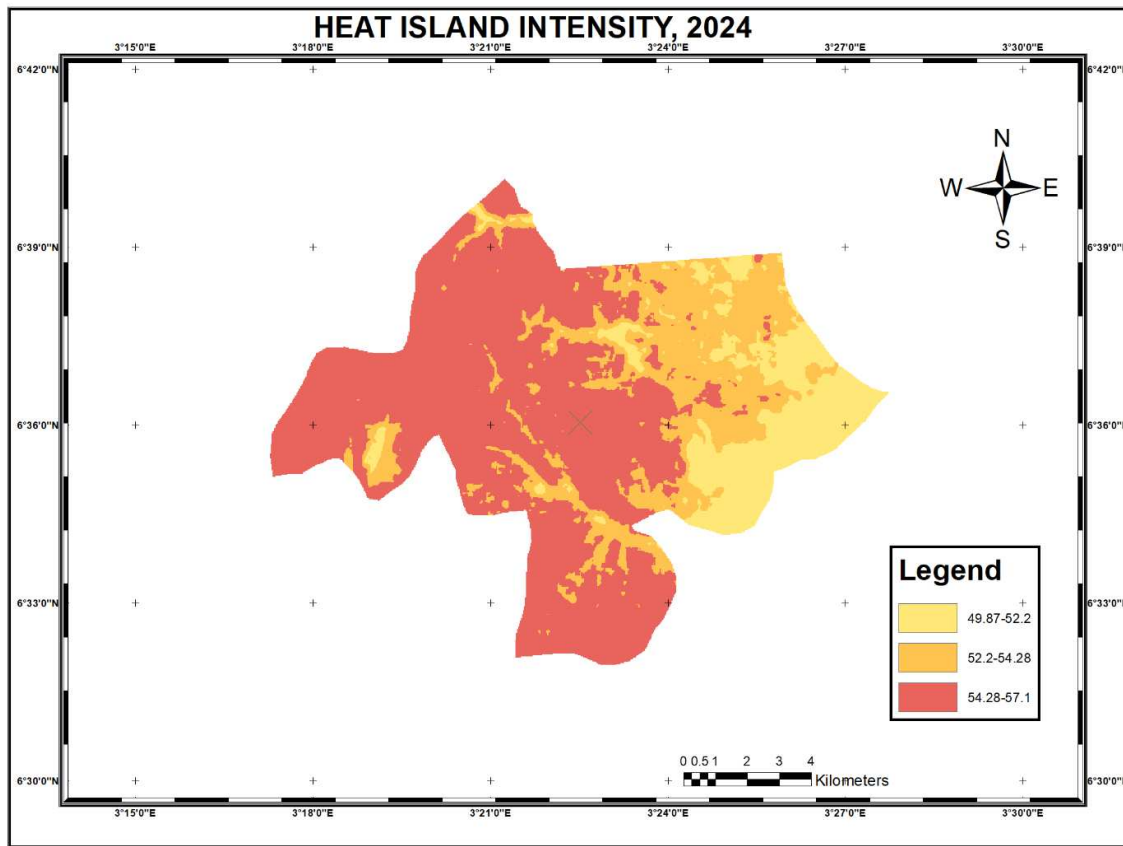


Fig. 16: UHI intensity in Ikeja, Kosofe, and Shomolu in 2024

Source: Authors' analysis, 2025.

In 2024, there was a sharp increase in the intensity of urban heat islands from 2015. The heat intensity values varied between 49.8°C and 57.1°C, with the highest intensities (54.3–57.1°C) concentrated in the central and southwestern parts of the study area. These zones, represented by deep red tones, correspond to areas with dense built-up surfaces and minimal vegetation cover. The observed increase in UHII signifies increased surface thermal emissions from impervious and built-up structures during peak solar radiation because all the satellite images were acquired at approximately 12:00 noon local time. (Anniballe et al., 2014; Lai et al., 2021). The spatial area coverage of the high heat island increased significantly, covering a greater percentage of land than did the 2015 heat intensity map.

4.3 Lagos SDG 13 Policies and Urban Heat Island Dynamics

The primary policies in Lagos to address the issue of urban heat islands have focused on tree planting, the creation of open spaces, and the introduction of sustainable transport (Akinola et al., 2020; Building Nigeria's Response to Climate Change (BNRCC) Project, 2011; Ministry of Environment and Water Resources, 2024). A cursory review of existing urban development policies reveals limited consideration of the thermal properties of construction materials, which many scholars identify as a major contributing factor to the increase in UHI intensity (Liu et al., 2025; Muhammad & Wonorahardjo, 2020; Ren et al., 2025). Although there is a significant correlation between vegetation and urban heat islands in this study, such a correlation is insufficient to address the issue of the increasing urban heat islands in the study area and Lagos. This is because the urban heat island effect continued to increase in 2015, even when the NDVI reached its peak. Studies have shown that the thermal properties of the materials used for construction should be deliberately controlled for urban heat islands to be reduced (Muhammad & Wonorahardjo, 2020). Hence, the Lagos 13 climate policies did not control the urban heat island effect in the Lagos metropolis, and the null hypothesis was accepted.

5.0 MAJOR FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of the major findings

This study revealed significant spatial and temporal variations in vegetation cover, surface temperature, and UHI intensity across Ikeja, Kosofe, and Shomolu between 2000 and 2024. The results revealed that vegetation (NDVI) had a strong cooling influence on surface temperature (LST) in 2000, with a high correlation ($R^2 = 0.942$), indicating that areas with relatively high vegetation experienced relatively low temperatures. By 2015, despite a temporary increase in vegetation due to state greening programs, surface temperatures rose sharply, and the UHI intensity reached an extreme level of 8.7°C , suggesting that built-up density and anthropogenic heat emissions had become dominant factors. In 2024, vegetation cover declined drastically (NDVI = 0.13), the NDVI–LST relationship weakened significantly ($R^2 = 0.154$), and surface temperatures peaked at 57.1°C , reflecting severe surface heating and a loss of vegetation's moderating effect. Spatially, Ikeja and Shomolu consistently presented high thermal concentrations due to dense development and impervious surfaces, whereas Kosofe remained cool due to its proximity to Lagos Lagoon and vegetative buffers. The findings highlight the progressive weakening of vegetation's ecological buffering capacity and the increasing dominance of human-induced factors in shaping the thermal environment of Lagos. Although vegetation changes initially influence

temperature patterns, the UHI phenomenon has been dramatically amplified by continued infrastructure expansion, high-rise development, and widespread replacement of permeable surfaces with concrete and asphalt. The satellite imagery captured around noon local time, further supports this observation — peak-hour solar radiation intensified surface heat emissions from impervious materials, especially in densely built districts.

The evaluation of Lagos State’s climate-related policies under SDG 13 revealed partial effectiveness in mitigating the UHI problem. Policies introduced between 2010 and 2024, such as the tree planting initiative, the development of recreational parks, and the promotion of sustainable transport, produced short-term gains in the NDVI (e.g., the improvement noted in 2015). However, these measures were neither sustained nor adequately integrated into urban development frameworks.

A critical weakness identified was the lack of policy emphasis on the thermal properties of the construction materials used in urban development. Current building codes and planning regulations do not explicitly address albedo control, heat reflectivity, or surface permeability, which are key determinants of STR. As several studies (Muhammad & Wonorahardjo, 2020; Liu et al., 2025; Ren et al., 2025) emphasize, managing the thermal characteristics of urban materials is as crucial as vegetation restoration for effective UHI mitigation.

The Lagos case illustrates that vegetation-based interventions alone are insufficient to counteract escalating urban heat. The persistence of high LST values even during periods of improved NDVI (as in 2015) shows that the material composition and spatial configuration of urban infrastructure are now the dominant factors driving heat accumulation. Thus, despite commendable policy intentions, the SDG13 framework in Lagos has not fully addressed the structural contributors to UHI formation.

5.2 Conclusion

The findings of this study underscore the complex and evolving relationships among vegetation, land surface temperature, and urbanization in Lagos, Nigeria. Between 2000 and 2024, vegetation cover declined substantially, whereas surface temperatures rose sharply, culminating in severe urban heat island effects across Ikeja, Kosofe, and Shomolu. Initially, the NDVI was a strong predictor of surface temperature, but by 2024, its influence had weakened dramatically, suggesting

that rapid urban expansion and material-induced heat retention now dominate the city's thermal dynamics.

The results revealed that the Lagos urban environment has transitioned from a vegetation-controlled thermal regime to a built-surface-controlled system, where temperature elevation is driven by impervious materials, compact building forms, and anthropogenic heat sources. The extreme surface temperatures (up to 57.1°C) recorded in 2024 highlight the need for integrated urban climate management strategies.

To mitigate future UHI effects, Lagos must adopt a dual approach that combines green infrastructure expansion with a thermal-smart urban design. This includes the adoption of reflective and permeable building materials, the enforcement of green roofing and façade greening, the preservation of urban wetlands, and the expansion of vegetated corridors. Furthermore, climate adaptation policies should be embedded in urban development plans, emphasizing not only vegetation restoration but also material-based heat mitigation.

In conclusion, the Lagos experience demonstrates that sustainable heat management in rapidly urbanizing cities requires comprehensive policy realignment that integrates ecological restoration with thermal-resilient urban design, while vegetation remains vital for moderating microclimates. Without such measures, the urban heat island phenomenon will continue to intensify, posing serious challenges to environmental sustainability, urban liveability, and public health in the coming decades.

5.3 Recommendations

To address the challenge of increasing urban heat intensity, we recommend the following:

- i. Lagos must adopt a thermal-smart urban design that integrates the use of reflective and permeable building materials that absorb less heat and encourage the use of green roofing. The Lagos State Building Control Agency should be mandated to enforce the use of materials with lower thermal properties to reduce the amount of surface emissivity.
- ii. There is an urgent need to preserve existing parks while new parks are being built to act as natural thermal regulators of Lagos's land surface temperature.

- iii. Lagos should be modelled as a smart city that uses smart green infrastructure with higher concentrations in Ikeja and Shomolu, urban sensors, and AI-based thermal mapping to monitor and mitigate urban heat islands.
- iv. Higher-resolution imagery will be vital for subsequent research to enable precise urban feature mapping.
- v. Future research should investigate the change in the structural thermal properties and their contribution to the increase in UHI in the study area.

REFERENCES

- Adebamowo, M. A., Sangowawa, T. B., & Godwin, J. (2013). *Low energy design of buildings in the tropics; the case of Lagos, Nigeria*. www.theijes.com
- Akande, S., Felix Folorunsho, A., Balogun, I., Adediji, A., & Olumide, A. (2017a). Assessment of urban heat island over Ibadan Metropolis using. *International Journal of Environment and Bioenergy*, 12(1), 62–87. <https://www.researchgate.net/publication/318535171>
- Akande, S., Felix Folorunsho, A., Balogun, I., Adediji, A., & Olumide, A. (2017b). Assessment of urban heat island over Ibadan Metropolis using. *International Journal of Environment and Bioenergy*, 12(1), 62–87. <https://www.researchgate.net/publication/318535171>
- Akinola, A. O., Opoko, A. P., Ibem, E. O., Okagbue, H. I., & Afolabi, A. O. (2020). Climate change adaptation and mitigation strategies in Lagos, Nigeria: built environment professionals' perspective. *International Journal of Engineering and Advanced Technology*, 9(3), 1273–1282. <https://doi.org/10.35940/ijeat.B2630.029320>
- Akintunde, E., & Abe, A. (2025). Geospatial assessment of vegetation dynamics and climate impact on sustainable urbanism: A case study of Adi Town, Benue, Nigeria. *Modern Geogra'fia*, 21(1), 95–120. <https://doi.org/10.15170/MG.2026.21.01.06>
- Anniballe, R., Bonafoni, S., & Pichierri, M. (2014). Spatial and temporal trends of the surface and air heat island over Milan using MODIS data. *Remote Sensing of Environment*, 150, 163–171. <https://doi.org/10.1016/j.rse.2014.05.005>
- Arifwidodo, S., Bangkok, T., Rizqi, A., & Tetsu, K. (2018). *Understanding Urban Heat Island Effect and Its Implications to Climate Change Adaptation Strategies in Major Southeast Asian Cities*. APN-GCR. Retrieved from www.apn-gcr.org/resources/
- Australia Pty Ltd, A. (n.d.). *Economic Assessment of the Urban Heat Island Effect* www.aecom.com
- Bassett, R., Young, P. J., Blair, G. S., Samreen, F., & Simm, A. W. (2020). The megacity Lagos and three decades of urban heat island growth. *American Meteorological Society*. <https://doi.org/10.1175/JAMC-D-20>

- Building Nigeria's Response to Climate Change Project (2011). *Toward a Lagos State Climate Change Adaptation Strategy* (pp. 330). Building Nigeria's Response to Climate Change
- Ceccato and Dinku. (2010). *IRI Technical Report 10-04 Remote Sensing for Monitoring Rainfall, Temperature, Vegetation, and Water Bodies*
- Coelho, D., & Ruth, M. (2006). Seeking a unified urban systems theory. *WIT Transactions on Ecology and the Environment*, 93, 179–188. <https://doi.org/10.2495/SC060171>
- Dissanayake, D., Morimoto, T., Murayama, Y., Ranagalage, M., & Handayani, H. H. (2019). Impact of urban surface characteristics and socio-economic variables on the spatial variation of land surface temperature in Lagos City, Nigeria. *Sustainability (Switzerland)*, 11(1). <https://doi.org/10.3390/su11010025>
- Emah, E. M. (2023). A mid-term review of Nigeria's progress toward achieving the sustainable development goals. *AKSU Journal of Administration and Corporate Governance*, 3(3), 35–47. <https://doi.org/10.61090/aksujacog.2023.018>
- Fada, S. J., Akintunde, E. A., Goyol, S. S., Binbol, N. L., Bombom, L., Dabi, D. D., Baklit, G., & Oche, C. Y. (2022). An appraisal of Nigeria's progress in achieving the SDG-13 climate action goal. *Journal of Sustainable Development*, 15(2), 66. <https://doi.org/10.5539/jsd.v15n2p66>
- Fink, S., McPhearson, T., Karki, M., Herzog, C., Santiago Fink, H., & Dubbeling, M. (2018). *Urban ecosystems and biodiversity*. Cambridge University Press.
- Forman, R. T. T. (2016). Urban ecology principles: Are urban ecology and natural area ecology really different? *Landscape Ecology*, 31(8), 1653–1662. <https://doi.org/10.1007/s10980-016-0424-4>
- Ishola, I. S., Adeyemi, K. O., Ozigis, I. I., & Zarmai, M. T. (2025). Rising heat, rising challenges: Cooling and heating dynamics in Lagos amid global warming. *Next Research*, 2(3), 100671. <https://doi.org/10.1016/J.NEXRES.2025.100671>
- Jain, S., Sannigrahi, S., Sen, S., Bhatt, S., Chakraborti, S., & Rahmat, S. (2020). Urban heat island intensity and its mitigation strategies in the fast-growing urban area. *Journal of Urban Management*, 9(1), 54–66. <https://doi.org/10.1016/j.jum.2019.09.004>
- Kasniza Jumari, N. A. S., Ahmed, A. N., Huang, Y. F., Ng, J. L., Koo, C. H., Chong, K. L., Sherif, M., & Elshafie, A. (2023). Analysis of urban heat islands with landsat satellite images and GIS in Kuala Lumpur Metropolitan City. *Heliyon*, 9(8). <https://doi.org/10.1016/j.heliyon.2023.e18424>
- Lai, J., Zhan, W., Voogt, J., Quan, J., Huang, F., Zhou, J., Bechtel, B., Hu, L., Wang, K., Cao, C., & Lee, X. (2021). Meteorological controls on daily variations of nighttime surface urban heat islands. *Remote Sensing of Environment*, 253, 112198. <https://doi.org/10.1016/J.RSE.2020.112198>
- Liu, H., & Liu, Q. (2012). *The Urban Heat Islands Analysis Factors of Building Surface, Green Area and Lighting*. *Journal of Environmental Studies*, 59, 69–79.

- Liu, H., & Liu, Q. (2017). *Urban planning characteristics to mitigate climate change in context of urban heat island effect*. www.teriin.org
- Liu, L., Zhou, Y., Tan, L., & Jiang, R. (2025). Nonlinear heat effects of building material stock in Chinese megacities. *Smart Cities*, 8(4). <https://doi.org/10.3390/SMARTCITIES8040119>
- Mattingly, M. (1994). Reply meaning of urban management. *Cities: The International Journal of Urban Policy and Planning*, 11(3), 201–205. <https://doi.org/10.1016/j.urbanpol.1994.1994>.
- Ministry of the Environment and Water Resources. (2024). *Lagos State Climate Adaptation and Resilience Plan (LCARP)*.
- Mokhtari, Z., Barghjelveh, S., Sayahnia, R., Qureshi, S., & Russo, A. (2022). Dynamic and heterogeneity of urban heat island: A theoretical framework in the context of urban ecology. In *Land*, 11(8). MDPI. <https://doi.org/10.3390/land11081155>
- Muhammad, F., & Wonorahardjo, S. (2020). Building material in the perspective of energy efficiency and thermal environment in TOD area. *IOP Conference Series: Earth and Environmental Science*, 532(1). <https://doi.org/10.1088/1755-1315/532/1/012021><https://doi.org/10.1088/1755-1315/532/1/012021>
- Nnah, S. I., Esechie, S., & Ikwueze, U. H. (2024). Impact of urbanization on gully erosion in Benin City, Edo State using remote sensing and GIS. *International Journal of Innovative Environmental Studies Research*, 12(2), 33–44.
- Nuruzzaman, Md. (2015). Urban heat island: causes, effects and mitigation measures-a review. *International Journal of Environmental Monitoring and Analysis*, 3(2), 67. <https://doi.org/10.11648/j.ijema.20150302.15><https://doi.org/10.11648/j.ijema.20150302.15>
- Ojeh, V. N., Balogun, A. A., & Okhimamhe, A. A. (2016). Urban rural temperature differences in Lagos. *Climate*, 4(2). <https://doi.org/10.3390/cli4020029>
- Oke, T. R. (1982). The energetic basis of the urban heat island. In *J. R. Met. Soc.*, 108, 455.
- Özdamar, E., & Önay, E. (2024). An overview of transdisciplinary and bottom-up approach for urban resilience: The case of Turkey. *Environmental Science and Sustainable Development*, 9(3), 01–16. <https://doi.org/10.21625/essd.v9i3.1093><https://doi.org/10.21625/essd.v9i3.1093>
- Ramadier, T. (2004). Transdisciplinary and its challenges: The case of urban studies. *Futures*, 36(4), 423–439. <https://doi.org/10.1016/j.futures.2003.10.009><https://doi.org/10.1016/j.futures.2003.10.009>
- Ren, S., Huang, Z., Yan, X., Yin, G., Zheng, J., Qi, J., Zhang, H., Li, X., & Bao, Y. (2025). Background environment mitigate heat islands from inadequate urban green coverage while amplifying socioeconomic thermal inequities. *Sustainable Cities and Society*, 132. <https://doi.org/10.1016/j.scs.2025.106815>
- Salau, O. R. (2016). *The changes in temperature and relative humidity in Lagos State, Nigeria*. www.worldscientificnews.com

- Santamouris, M. (2015). Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. *Science of the Total Environment*, 512–513, 582–598. <https://doi.org/10.1016/j.scitotenv.2015.01.060><https://doi.org/10.1016/j.scitotenv.2015.01.060>
- Sobrino, J. A., Caselles, V., & Becker, F. (1990). Significance of the remotely sensed thermal infrared measurements obtained over a citrus orchard. In *ISPRS Journal of Photogrammetry and Remote Sensing*. pp. 57–76.
- Sobrino, J. A., Jiménez-Munoz, J. C., El-Kharraz, J., Gómez, M., Romaguera, M., & Sòria, G. (2004). Single-channel and two-channel methods for land surface temperature retrieval from DAIS data and its application to the Barrax site. *International Journal of Remote Sensing*, 25(1), 215–230. <https://doi.org/10.1080/0143116031000115210>
- Sobrino, J. A., Jiménez-Muñoz, J. C., Sòria, G., Romaguera, M., Guanter, L., Moreno, J., Plaza, A., & Martínez, P. (2008). Land surface emissivity retrieval from different VNIR and TIR sensors. *IEEE Transactions on Geoscience and Remote Sensing*, 46(2), 316–327. <https://doi.org/10.1109/TGRS.2007.904834>
- Sojobi, A. O., Balogun, I. I., & Salami, A. W. (2015). Climate change in Lagos state, Nigeria: what really changed? *Environmental Monitoring and Assessment*, 188(10). <https://doi.org/10.1007/s10661-016-5549-z><https://doi.org/10.1007/s10661-016-5549-z>
- Taha, C., & Silvia, T. (2019). *Urban growth, heat islands, humidity, climate change: the costs multiply in tropical cities*.
- Tang, J., Di, L., Xiao, J., Lu, D., & Zhou, Y. (2017). Impacts of land use and socioeconomic patterns on urban heat island. *International Journal of Remote Sensing*, 38(11), 3445–3465. <https://doi.org/10.1080/01431161.2017.1295485>
- Tiwary, A. (2018). *An Elementary Introduction to Urban Ecology and its Concepts* (Vol. 5). www.jetir.org
- United Nations. (2022). *Transforming Our World: The 2030 Agenda for Sustainable Development* United Nations *United Nations Transforming Our World: The 2030 Agenda for Sustainable Development*
- World Bank. (2024). *Urban overheating and adaptation measures: An analysis at the EU, national, and local levels*
- Wu, J., He, C., Huang, G., & Yu, D. (2013). Urban landscape ecology: Past, present, and future. In *Landscape Ecology for Sustainable Environment and Culture*. Springer Netherlands, pp. 37–53. https://doi.org/10.1007/978-94-007-6530-6_3