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RESEARCH ARTICLE

Spatio-temporal assessment of land use-induced urban heat characteristics on ecosystem services in Ibeju Lekki, Lagos State, Nigeria

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Abstract

Land use and land cover changes increase land surface temperature, resulting in biodiversity loss and urban heat. This study examines the impact of land-use-induced urban heat characteristics on ecosystem services in Ibeju Lekki, Lagos, with the goal of proposing measures to mitigate their effects and improve human well-being. Both primary and secondary sources were utilised for data collection. One hundred and twenty-five questionnaires were administered to households and retrieved. Structured interviews were conducted with industries and stakeholders within the Lekki Free Trade Zone. The study evaluated and analysed the case study's land use and land cover (LULC) using multi-temporal Landsat imagery to determine land surface temperature (LST) and land use/land cover of the study area for 1986, 2002, 2015, and 2022. The findings reveal temperature variations associated with different land uses and land covers in Ibeju Lekki, indicating that the ongoing conversion of natural land cover to other uses contributes significantly to the increase in surface temperature. The study revealed that built-up areas increased considerably from 8.71% in 1986 to 28.12% in 2022, resulting in a substantial loss of vegetation. Variations and increased temperature from the thermal reflection of each land use and land cover in Ibeju Lekki, Lagos, are also evident. The study suggests that converting natural land cover to other uses can significantly raise Ibeju Lekki's surface temperature, necessitating the implementation of green infrastructure. Therefore, this study recommends the provision of green infrastructure, such as urban tree canopies, parks, open spaces, and ecological landscaping, to mitigate surface temperatures in Ibeju Lekki, thereby alleviating health problems and hazards that often accompany rising temperatures.

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1.0 INTRODUCTION

1.1 Background to the Study

Numerous urban centres globally have undergone significant demographic expansion attributable to accelerated urbanisation, a pivotal element precipitating land use change (LUC) on a global scale (Akinbode, 2024). LUC encompasses terrestrial surface alterations that profoundly affect ecosystem services (Ma et al., 2010). The land use transformation represents a consequential anthropogenic alteration that has not only modified the Earth's surface but also influenced the planet's thermal dynamics, thereby impacting its biological processes (Steffen et al., 2007).

The alterations in land use and land cover (LULC), alongside increases in land surface temperature (LST), are among the primary consequences of climate change, which exacerbate biodiversity decline and contribute to the formation of urban heat islands. Ecosystems furnish diverse services essential for human well-being, yet these systems are increasingly jeopardised due to anthropogenic activities. A principal catalyst of land use and land cover change is population growth. Human beings represent the most critical natural resource; with their advancement, they are mutually dependent and interdependent (Fedele et al., 2021). Nonetheless, the significance of land as a vital and limited resource for various human endeavours including forestry, agriculture, industry, energy production, recreation, habitation, and water catchment and storage is manifest in land use.

Land use change (LUC) considerably affects (and is affected by) global climate change, along with the ensuing ecological responses (El-Hattab et al., 2018). Land use and land cover change are fundamental variables that contribute to the increase in land surface temperature. Numerous scholars contend that land-use alterations and the unchecked exploitation of land resources significantly contribute to the escalation of land surface temperatures. The modifications in land use and land cover (LULC) and the concomitant rise in land surface temperature (LST) are prominent outcomes of climate change, which further intensify biodiversity loss and promote urban heat island effects. Ecosystems deliver a comprehensive range of services that underpin human well-being and are currently endangered due to human activities.

In response to humanity's unquenchable demands, significant alterations to the Earth's surface have occurred over recent decades, resulting in anthropogenic phenomena such as deforestation, agricultural practices, and urbanisation. Numerous developing nations are experiencing rapid land use change driven by population growth and shifts in lifestyle resulting from increased income (Wichmann et al., 2009). The transformations in land use and land cover (LULC) and the corresponding increases in land surface temperature (LST) are among the critical repercussions of climate change, which exacerbate biodiversity loss and contribute to the formation of urban heat islands (Singh et al., 2017). The alterations in land use and land cover have emerged as pressing global challenges, serving as a predominant impetus behind environmental transformations worldwide (Choudhury & Jansen, 1998).

Understanding the ramifications of land-use alterations is crucial for mitigating the impacts of anthropogenic environmental interactions. Land use change (LUC) constitutes a fundamental factor influencing the dynamics of human activities and the natural environment; therefore, it necessitates meticulous quantification to elucidate the repercussions of such transformations (Mendosa et al., 2011). Increased land use change will contribute to the urban heat island phenomenon, thus negatively impacting ecosystem services, particularly those related to climate regulation and human health (Meng et al., 2023). In cities, increased temperatures due to UHIs are reducing the effectiveness of the climate to regulate the atmosphere, affecting water quality in streams and rivers, exacerbating heat stress, affecting urban biodiversity, and affecting air quality by increasing pollutants.

Ecosystems are crucial to mitigating the effects of increased surface temperature (Epple et al., 2016). However, they are vulnerable to anthropogenic factors and degradation from excessive heat in urban regions. Valuing ecosystem services is crucial for urban planning and sustainable development. This involves the valuation of ecosystem services, which is the process of assigning monetary or non-monetary values to the benefits that ecosystems provide to humans. This course of action helps in understanding the true worth of nature and informs management decisions and resource allocation to ensure sustainability and social well-being (Popoola et al., 2018).

This research centres on the fluctuations in Land Surface Temperatures (LST) across diverse land-use classifications in Ibeju Lekki, Lagos State, Nigeria, from 1986 to 2022. Furthermore, it assesses the impacts of land use-induced urban thermal characteristics on ecosystem services and proposes potential strategies to mitigate their consequences while enhancing human well-being.

2.0 METHODOLOGY

2.1 Study Area of Observations

Ibeju-Lekki encompasses an approximate area of 445 km², representing approximately 25% of Lagos State's total land area. Geographically, it is situated within the creek zone of tropical southwestern Nigeria, with coordinates of Latitude 6°29'36" N, Longitude 3°43'14" E, and Latitude 6°23'21" N, Longitude 4°21'31" E (See Figure 1). According to the projected demographic data from the 2006 population census, the region is inhabited by approximately 388,226 individuals, exhibiting a growth rate of 3.2%. The demographic composition predominantly consists of rural inhabitants whose livelihoods are predominantly derived from natural resource-based economic endeavours, such as aquaculture, agriculture, and oil palm processing.

The Atlantic Ocean and the Lekki Lagoon represent the principal aquatic bodies within the confines of this study area. The existence of coastal grasses and mangrove wetlands engenders a conducive habitat for many marine fish species, thereby rendering the region economically significant. Additionally, the Lekki Free Trade Zone (LFTZ) is situated within the Ibeju-Lekki Local Government Area (LGA) of Lagos State, Nigeria. The LFTZ, along with the accessible natural resources, plays a pivotal role in fostering ecotourism in Ibeju-Lekki, while the invaluable marine and terrestrial resources further increase the rapid development of the study area (Owolabi, 2010).

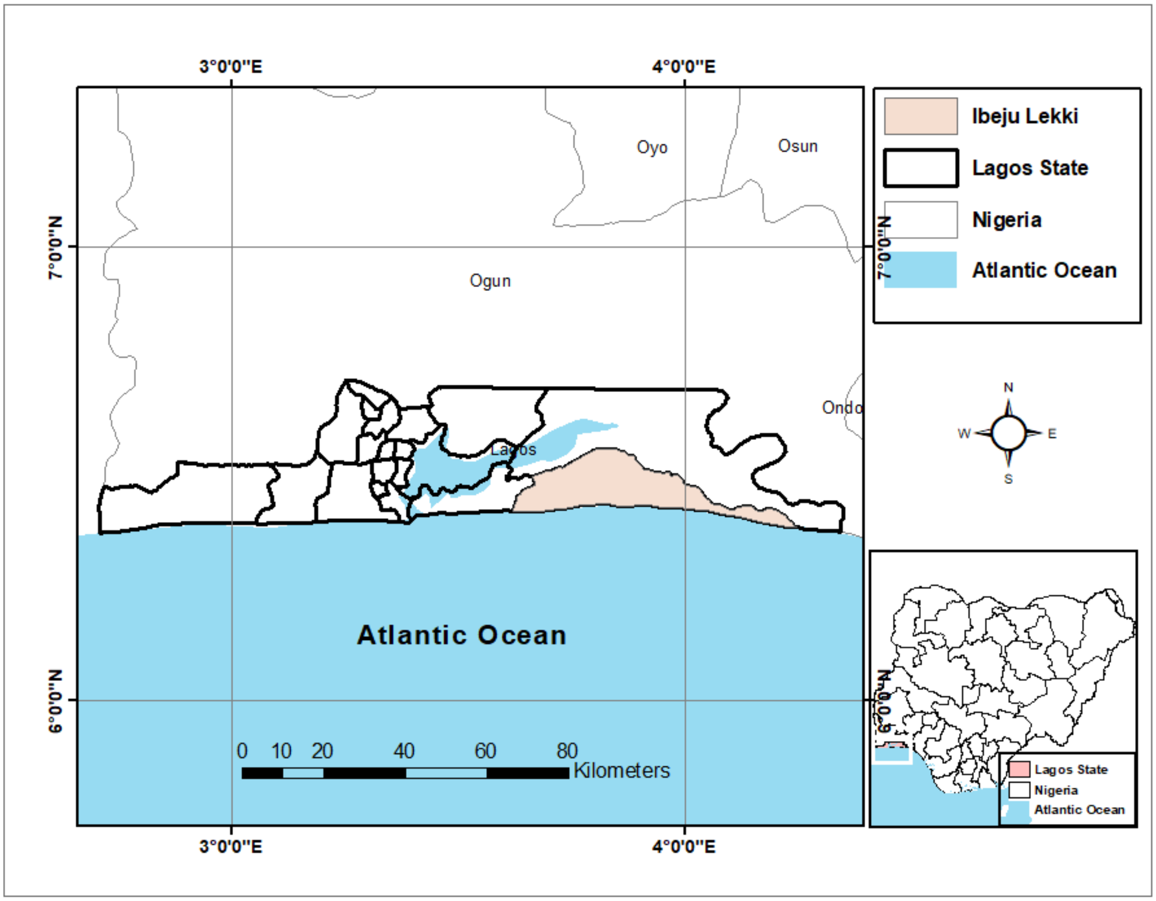

Figure 1: Map of Ibeju Lekki in the Context of Lagos State, Nigeria.

2.2 Research Design

This study integrated qualitative and quantitative research methodologies, employing a case study research framework in conjunction with geospatial analysis. It assessed variations in terrain in terms of surface temperature, vegetation, and ecosystem services. By utilising remote sensing technologies and geographic information systems, it further examined the ramifications of alterations in urban land use on ecosystems and their associated services in Ibeju Lekki, elucidating its implications for human well-being and proposing efficacious strategies to alleviate the adverse effects of land use modifications within the study locale.

2.2.1 Source of Data

The data for this study were derived from both primary and secondary sources. The primary data were collected through questionnaires administered to residents and by using semi-structured interview guides to interrogate officials from various ministries, departments, and agencies within Ibeju Lekki. Historical satellite datasets were procured from the United States Geological Survey (USGS). These datasets comprise unprocessed yet high-quality Landsat imagery for the years 1986, 2002, 2015, and 2022. Detailed descriptions of the datasets are presented in Table 1.

These data facilitated the execution of spatio-temporal analyses of land cover transformations to determine land use and land cover alterations in Ibeju Lekki over the specified study period. Google Earth was employed to gather historical data on Ibeju Lekki, aiding in ground truthing and identifying locations vulnerable to substantial land cover changes.

Table 1: Landsat imagery adopted for the study.

Satellites	Year	Sensor	Spatial Resolution	Band Composite
Landsat 9	2022	Operational Land Imager and Thermal Infra-Red Sensor (OLI & TIRS)	30 metres	Band 5,4,3
Landsat 8	2015	Operational Land Imager and Thermal Infra-Red Sensor (OLI & TIRS)	30 metres	Band 5,4,3
Landsat 7	2002	Enhanced Thematic Mapper Plus (ETM+)	30 metres	Band 4,3,2
Landsat 5	1986	Thematic Mapper (TM)	30 metres	Band 4,3,2

Source: Author's Fieldwork, 2024.

The secondary data sources for this research encompass governmental reports and statistics spanning from 1986 to 2022, which were acquired from the Ministry of Lands in Lagos State. This information proved valuable, as during the study's duration, the land presently recognised as the free trade zone was appropriated by the Lagos State government, resulting in an influx of enterprises into the free zone. Population data were sourced from the National Bureau of Statistics and extrapolated to ascertain the current population of Ibeju Lekki. Additional data concerning historical temperature trends, human well-being, and ecosystem services were extracted from academic journals, technical reports, conference proceedings, newspapers, social media, and blogs.

2.2.2 Research Population

According to the National Population Commission (NPC, 2006), the population of Ibeju Lekki was estimated to be 117,793 in 2006. Utilising the 2006 population as the baseline figure, along with a growth rate of 2.7% and 17 years (2006-2023), the projected population of Ibeju Lekki in 2023 is estimated to be 181,589 individuals. Furthermore, the research population encompasses all enterprises and relevant stakeholders within Ibeju Lekki.

2.2.3 Sampling Frame

The sampling frame for this study includes the companies, stakeholder groups, and communities along the Free Trade Zone Ibeju Lekki. From the pilot study, 24 companies, 12 other stakeholder groups, and 15 communities were found in the free trade zone at Ibeju Lekki. They are shown in Table 3. Interview guides were used to elicit information from companies and other stakeholder groups, while questionnaires were used to gather information from the communities. Twenty per cent of the communities were selected, and a questionnaire was administered. In doing this, the communities were numbered from 1 to 15, and the Random Number Generator of the SPSS Package was used to randomly select 20% of the communities, which suggests that three communities form the sampling frame. The number of buildings in the three communities is 625, which serves as the sampling frame for administering the household questionnaire.

Table 2: List of Companies and Stakeholders Considered for Interviews in Ibeju Lekki

Companies and Organisations		
Dangote Refinery and Petrochemical	China Singye Renewable Energy Technology.	Huayi Furniture Manufacturing Company.
Yulong Steel Pipe Lekki Investment.	Clairgold Oil and Gas Engineering	Harig Oil Supply and Trading.
Huachang Steel Structure Engineering.	Fas Energy and Natural Resources.	Etanzila Petroleum Company.
Sinotruk International	New Energy Service Company.	Nisino Health Investment
Ballore Transport and Logistics.	Imad Oil and Gas	Power Oil Nigeria Ltd
Asia Africa International.	Giorgio Dredging Oil and Gas.	Insignia Print Technology
Crown Nature's Nigeria Plc	Nowas Oil and Allied Products	Green Packaging Enterprise

China Golden Triangle group	China Singye Renewable Energy Technology.	Colgate Tolaram Enterprise
Other Stakeholder Groups		
Lekki LCDA	Community Heads	Fishermen
Youth Leaders	Market Women	Primary Health Care
Farmers	Women Group Associations	Artisans
NGOs	CBOs	Herbalists
Communities along the Lekki Free Zone in Ibeju Lekki		
Magbon-Segun	Idasho	Idotun
Tiye	Ilekuru	Alasia
Imobido	Okeyanta	Okunraye
Ilege	Oke-segun	Olomowewe
Mosa	Itoke	Lekki

Source: Author's Fieldwork, 2024.

2.2.4 Sampling Technique

The qualitative research methodology of case study analysis was employed to develop the interview instruments targeting companies within the Free Zone in Ibeju Lekki. In selecting companies for the interviews, the selection methodology must be characterised by deliberation, transparency, and rationality (Gallagher, 2010; Popoola, 2012). As elucidated by Denscombe (2021), three pertinent criteria are instrumental in selecting specific case studies. These criteria encompass suitability, pragmatism, and the absence of viable alternatives. The suitability criterion considers typical instances, extreme instances, theoretical test sites, and least likely instances.

The pragmatic criterion pertains to inherently compelling case studies, exhibits a willingness to engage, and presents logistical convenience. The absence of viable alternatives criterion pertains to case studies that arise from commissioned research projects. As this criterion is deemed unsuitable for the current investigation, only the suitability and pragmatic criteria will be utilised. All 24 companies within the free trade zone satisfied the suitability criterion as they fulfilled the characteristics of a typical instance and a theoretical test site. Regarding the pragmatic criterion, all 24 case studies were deemed intrinsically interesting for selection, and the researcher found it convenient to conduct interviews with these companies due to their proximity along the same axis within the free zone. However, it is noteworthy that not all enterprises were willing to participate in the study, with only 7 providing their consent, while all other stakeholders indicated their readiness to participate.

Three distinct communities were randomly selected to administer questionnaires, employing the Random Number Generator feature within the SPSS software package. The selected communities are Ilege, Idasho, and Imobido. A systematic random sampling technique with replacement was employed to identify 20% of the buildings within each community for questionnaire distribution. The Random Number Generator within the SPSS Application facilitated the initial sample selection, followed by the selection of every fifth building for questionnaire administration. In instances where the building identified on the map was found to serve commercial, religious, or industrial functions, it was substituted with the nearest residential structure.

Geographic Information Systems and Remote Sensing (GIS & RS) methodologies were implemented to conduct a geospatial analysis concerning land use and land cover change, land surface temperature (LST), Normalised Difference Vegetation Index (NDVI), and ecosystems within Ibeju Lekki. This analysis involved utilising historical Landsat data in spatial assessments to evaluate variations in the aforementioned parameters over time. The Maximum Likelihood (ML) Classification Algorithm was employed for the classification process. Map algebra scripts were utilised to produce spectral indices for LST and NDVI.

2.2.5 Sample Size

The sample size of the companies is 7, as only these companies fulfil the suitability and pragmatic criteria. The identified companies include Dangote Oil Refinery (DPRPFZE), Yulong Steel Pipe Lekki Investment, Huachang Steel Structure Engineering, Sinotruk International, Ballore Transport and Logistics, Asia Africa International, and Crown Nature's Nigeria Plc. All other stakeholders also met the suitability and pragmatic criteria, contributing to the sample size. A questionnaire was administered to 125 households, constituting 20% of the sampling frame, as illustrated in Table 3.

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Table 3: Selected settlements and sample size.

Settlements	No of Buildings	Sample Size (20%)
Ilege	171	34
Idasho	250	50
Imobido	204	41
Total	**625**	**125**

Source: Author's Fieldwork, 2024.

2.2.6 Research Instrument

Data collection instruments are interview guides, questionnaires, geographic positioning systems (GPS), remote sensing, geographic information systems (GIS), Google Earth imagery, and Semi-structured interview guides.

2.2.7 Procedure of Data Collection

Geographic Data were obtained from Landsat imagery on the USGS website. These were used to assess changes in land cover and land surface temperature in the study area. The analysis was conducted over 36 years, from 1986 to 2022, with 1986 used as the base year. Geometrically corrected Landsat satellite images were acquired from the United States Geological Survey Portal using appropriate search criteria. The Landsat satellite images (path 191, row 055; path 191, row 056) include Enhanced Thematic Mapper Plus (ETM+), Thematic Mapper (TM), and Operational Land Imager (OLI).

The Landsat dataset bands were stacked together to produce a single true colour composite raster; this is then sampled appropriately to make the various land uses in the study area visible. Training samples were generated from the stacked raster using the image classification tool on ArcMap 10.3.1. The supervised classification method was employed for training the samples using the Maximum Likelihood (ML) classification function. The Maximum Likelihood method performs better than other classification methods, as it incorporates the variance-covariance within each class and the normal distribution. The land use categories used for classification are built-up areas, densely vegetated areas, sparsely vegetated areas, bare ground, rock outcrops, and water bodies.

Similarly, remote sensing techniques were used to estimate the land surface temperature (LST) of the study area from 1986 to 2022. The Landsat thermal Bands 6 (EM & ETM+) and 10 and 11 (TIRS) were used for assessing the LST in the study area, following the single-channel method as applied by Ferrelli et al. (2015). The land surface temperature of the study area was assessed in four main parts which includes; conversion of the digital number (DN) to spectra radiance, estimation of the top of atmosphere (TOA) brightness temperature, calculation of the proportion of vegetation (PV) land surface emissivity (LSE), and finally estimating the land surface temperature (LST). The calibration of processed data images was achieved by converting raw digital numbers (DN) into spectral radiance (Zareie et al., 2016) using Equation 1 as obtained from Zareie et al. (2016).

The procedure is highlighted as follows:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)\ /\ (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN\lambda \quad \ldots\ldots\ldots \text{ Eq 1}$$

Where: QCAL = quantised calibrated pixel value in DN,
LMIN = the spectral radiance scaled to QCALMIN (3.2) watts⁄(m²*ster*μm)
LMAX = the spectral radiance scaled to QCALMAX (12.650) watts⁄(m²*ster*μm)
QCALMIN = the minimum quantised calibrated pixel value in DN (1.0)
QCALMAX = the maximum quantised calibrated pixel value in DN

The top-of-atmosphere (TOA) brightness temperature was calculated in degrees Celsius using Equation 2.

$$TB = K2\ /\ \ln\left(\frac{K1}{L\lambda + 1}\right) \quad \ldots\ldots\ldots \text{ Eq 2}$$

Where:
Lλ = TOA Spectral radiance (Watts/(m2 *srad *μm))
K1 = Thermal conversion constant for the band

K2 = Thermal conversion constant for the band

The Land Surface Emissivity (LSE) model gives the best results for all LST retrieval methods. Moreover, LSE is a necessary factor that influences the accuracy of LST estimation. The effects of vegetation proportion were investigated by estimating the Normalised Difference Vegetation Index (NDVI) using the formula in Equation 3.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{R}) / (\mathrm{NIR} + \mathrm{R}) \quad \text{Eq 3}$$

Where:

NIR = the near-infrared
R = the red reflectance

The proportion of vegetation was computed using the formula in Equation 4 (Sobrino et al., 2012)

$$\mathrm{Pv} = ((\mathrm{NDVI} - \mathrm{NDVIMIN}) / (\mathrm{NDVIMAX} - \mathrm{NDVIMIN}))\ 2 \quad \text{Eq 4}$$

Where:

PV = proportion of vegetation
NDVI = Normalised Difference Vegetation Index
NDVIMAX = Normalised Difference Vegetation Index Maximum value
NDVIMIN = Normalised Difference Vegetation Index Minimum value

Land surface emissivity was determined using the following equations

$$\mathrm{e} = 0.004\mathrm{Pv} + 0.986 \quad \text{Eq 5}$$

The brightness temperature was subsequently converted to LST using Equation 6

$$\mathrm{LST} = (\mathrm{TB} / 1 + (\lambda * \mathrm{TB}/\rho) * \ln(\mathrm{e})) \quad \text{Eq 6}$$

Where:

TB = Top of Atmosphere Brightness Temperature (℃)
λ = wavelength of the emitted radiance (11.45µm)
e = Land Surface Emissivity
ρ = 1.438×10-2Mk

This procedure shows that the land surface temperature is derived from the spectral radiance by first converting the digital numbers (DN) into spectral radiance L. Spectral radiance was further converted to brightness temperature BT in Kelvin. Brightness temperature (BT) in Kelvin was then converted to Celsius using BT (℃) =BT -273.15 to get the LST value for 1986 to 2015 in degrees Celsius. For 2022, Landsat (OLI) was used in conjunction with the NDVI outputs to derive the 2022 Land Surface Temperature, which ranged from a maximum of 40.1 °C to a minimum of 23.3 °C.

The results obtained from the LST value were then applied to the threshold method to examine the urban heat island effect. The requirements for the formulation of the threshold that must be met are as follows (El-Hattab et al., 2018)

$$\mathrm{T} > \mu + 0.5\alpha \quad \text{Eq 7}$$

$$0 < \mathrm{T} \leq \mu + 0.5\alpha \quad \text{Eq 8}$$

The T symbol represents the LST value, while μ and α are the LST average value and LST standard deviation, respectively. This symbolisation also applies to Equation 9, which represents the threshold algorithm (Pratiwi & Jaelani, 2021; Ma et al., 2010) used to mathematically calculate the UHI range. A negative result (-) to 0 represents UHI, while values greater than zero represent non-UHI values (Pratiwi & Jaelani, 2021). The threshold equation is presented in Equation 9.

$$\mathrm{UHI} = \mathrm{LST} - (\mu + 0.5\alpha) \quad \text{Eq 9}$$

Thus, the UHI effect was determined using the Standard deviation of the LST and the average value of the LST, considering the inter-zone regional difference.

2.2.8 Method of Data Analysis

The Maximum Likelihood classification technique was employed to assess the implications of urban heat islands on ecosystem services alongside land use and land cover alterations within Ibeju Lekki. The classification schema for the land use maps comprises urbanised areas, unutilised land, dense vegetation, and sparse vegetation. This classification adheres to an established standard, as articulated by Anderson et al. (1976), and is illustrated in Table 4. Moreover, Popoola (2021) and Popoola et al. (2022) have previously utilised this classification framework. The Maximum Likelihood Classification methodology was employed to detect changes in land use classification across the Landsat imagery from 1986, 2002, 2015, and 2022. Maps were generated to delineate areas of transformation, which were subsequently quantified as percentages for the specified temporal frames. The land surface temperature was derived by obtaining spectral radiance, converting it into brightness temperature, calculating emissivity, and translating it into Land Surface Temperature (LST) for the various images. The Normalised Difference Vegetation Index was utilised to evaluate the health of vegetation in Ibeju Lekki during the years under investigation. The depletion rate was determined and monetarily assessed using the benefit transfer technique, serving as an indicator of residents' well-being to variations in surface temperature.

Table 4: Classification made for the Land Use Land Cover map.

Classifications	Method of data collection
Built-up areas	Residential, commercial, industrial, government facilities, settlements
Bare Land	Areas cleared for physical development are usually open spaces with little or no vegetation.
Dense Vegetation	Areas that are evergreen with a high density of trees.
Sparse Vegetation	Open areas with very light vegetation.

Source: Popoola (2021).

The responses procured from companies and stakeholders were scrutinised utilising the Content Analysis technique. This methodology predominantly applies in qualitative evaluations, particularly in interviews and focus group discussions. The responses were transcribed utilizing Microsoft Excel to facilitate Content Analysis. The Statistical Package for the Social Sciences (SPSS) software was employed to input, code, and transpose the responses derived from the structured questionnaires. The responses underwent descriptive analysis using the Likert scale, along with tables and charts.

3.0: RESULTS AND DISCUSSION

3.1 Socio-Economic Characteristics of Respondents

The demographic distribution of respondents within the study area, stratified by gender, reveals a predominance of male participants (78.4%) in the survey compared to female participants (21.6%). The preponderance of male respondents in Ibeju-Lekki can be attributed to specific companies and industries that predominantly necessitate male labour over female labour. Since fishing constitutes a principal occupation, men are more actively engaged in fishing than women. The educational qualifications of the respondents further indicate that a significant majority, specifically 82.3%, possess secondary education. The relatively elevated proportion of individuals with secondary education indicates that the inquiries regarding the impact of urban heat islands within the study area were comprehensively understood.

The marital status of the respondents indicates that over 60% of them were married, which enhances the reliability of the study's findings. The duration of stay in Ibeju Lekki shows that 56% of the respondents have resided in the area for more than 10 years, while others stayed between 6 and 10 years. This suggests that the respondents are well-informed about the course of study. Unfortunately, only 40% of the respondents earned above the minimum wage, which implies that the residents of the area may not be willing to pay for the green measure.

3.2 Presence and intensity of urban heat characteristics in Ibeju Lekki between 1986 and 2022

The presence and intensity of urban heat characteristics were determined in Ibeju Lekki between 1986 and 2022. Results from the land surface temperature of the study area show the minimum and maximum temperatures from the satellite imagery, along with surface temperature maps. The land surface temperature, as recorded in 1986, reached a maximum of 35.5℃, while the lowest temperature was 23.5℃.

The minimum temperature between 1986 and 2002 was 23.6℃. The highest temperature in 1986 increased significantly from 35.5 °C to 37.3 °C by 2002. This indicates that there is no annual increase in the minimum temperature, but the maximum temperature increases by 1.8 °C. By 2015, the minimum and maximum temperatures reached 23.5 °C and 37.4 °C. The minimum temperature dropped in 2022 (23.3℃). The maximum temperature also increases to 40.1℃. Average temperatures indicate a 4.6℃ increase between 1986 and 2022 in Ibeju-Lekki. Table 5 and Figures 2 and 3 highlight the trends in LST's spatial characteristics, showing that the temperature increased steadily from 1986 to 2022.

Table 5: The Intensity of Urban Heat Island in Ibeju Lekki

Year	Minimum temperature (℃)	Maximum temperature (℃)	Standard Deviation
1986	23.5	35.5	2.48
2002	23.6	37.3	2.57
2015	23.5	37.4	2.57
2022	23.3	40.1	2.60

Source: Author's Fieldwork, 2024

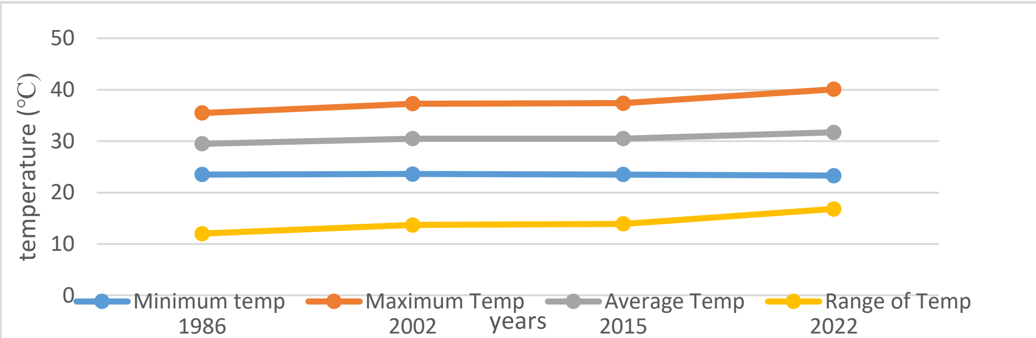

Figure 2: Land Surface Temperature trend between 1986 and 2022

Source: Author's Fieldwork, 2024

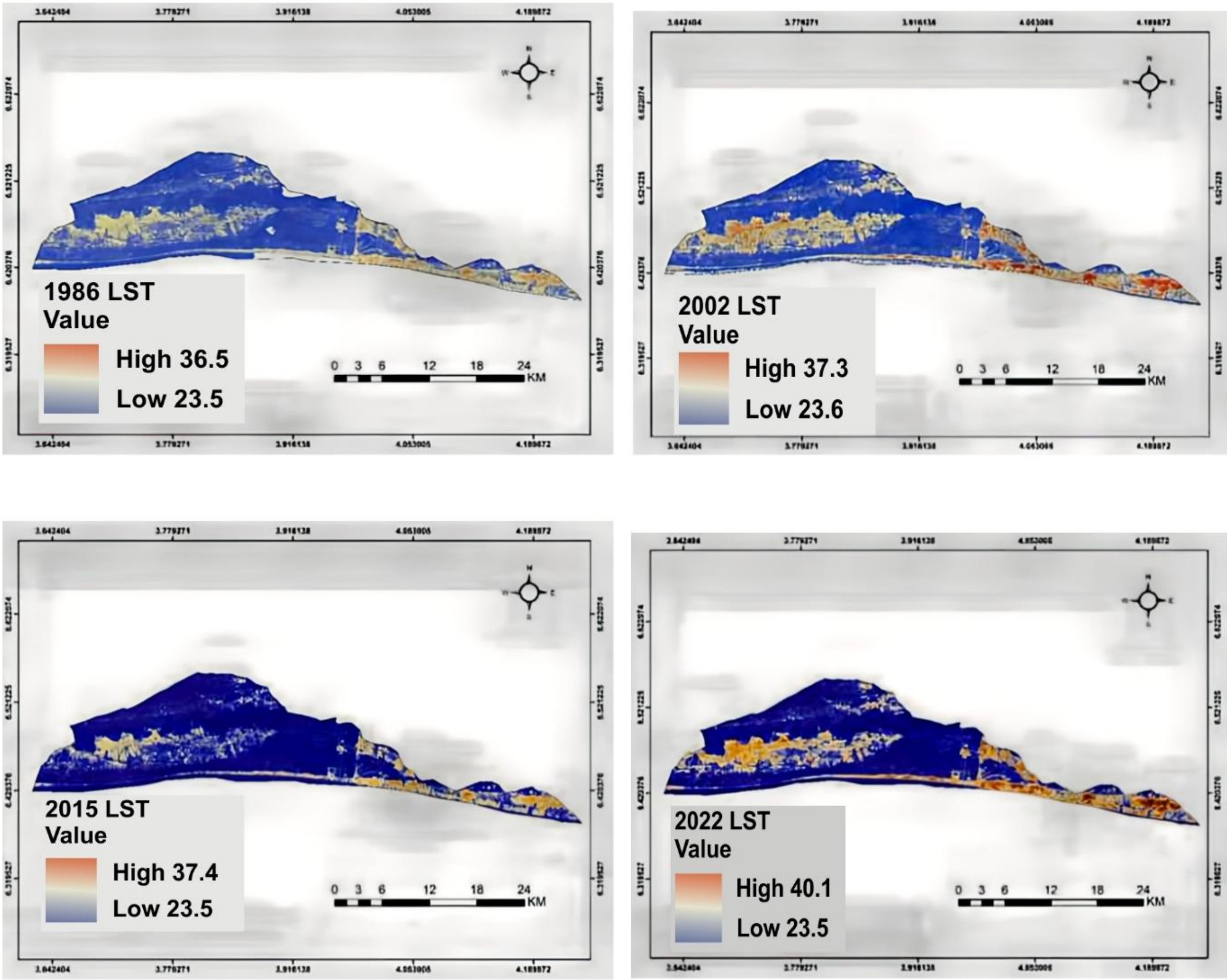

Figure 3: Land Surface Temperature for Ibeju Lekki between 1986 and 2022.
Source: Author's Fieldwork, 2024

3.3 Spatio-temporal Assessment of Vegetation Health between 1986 and 2022

The study utilised the Normalised Difference Vegetation Index (NDVI) to quantify vegetation greenness and examine changes in vegetation health over the study period. This was necessary to correlate vegetation indices with the potential for urban heat characteristics in the study area. The findings, as shown in Figure 4, reveal that a significant amount of vegetation cover was converted to other land uses between 1986 and 2022 within the study area. This resulted from converting surface water bodies through sand filling and land reclamation, as well as removing vegetation covers through land clearing, to establish infrastructure and support urban land use in Ibeju-Lekki. The primary cause, apart from residential projects, is industrialisation, particularly the construction of the Dangote refinery, an integrated refinery, and a petrochemical project. The Dangote refinery is being developed on 2,635 hectares in the Lekki Free-Trade Zone. Other human activities have contributed to the degradation of vegetation and wetlands on a large scale within the study area, resulting in an increase in bare ground and rock outcrops, which in turn contribute to a temperature increase in Ibeju Lekki. The study area's surface thermal properties exhibit a general trend of increasing surface temperature as vegetation cover decreases over time.

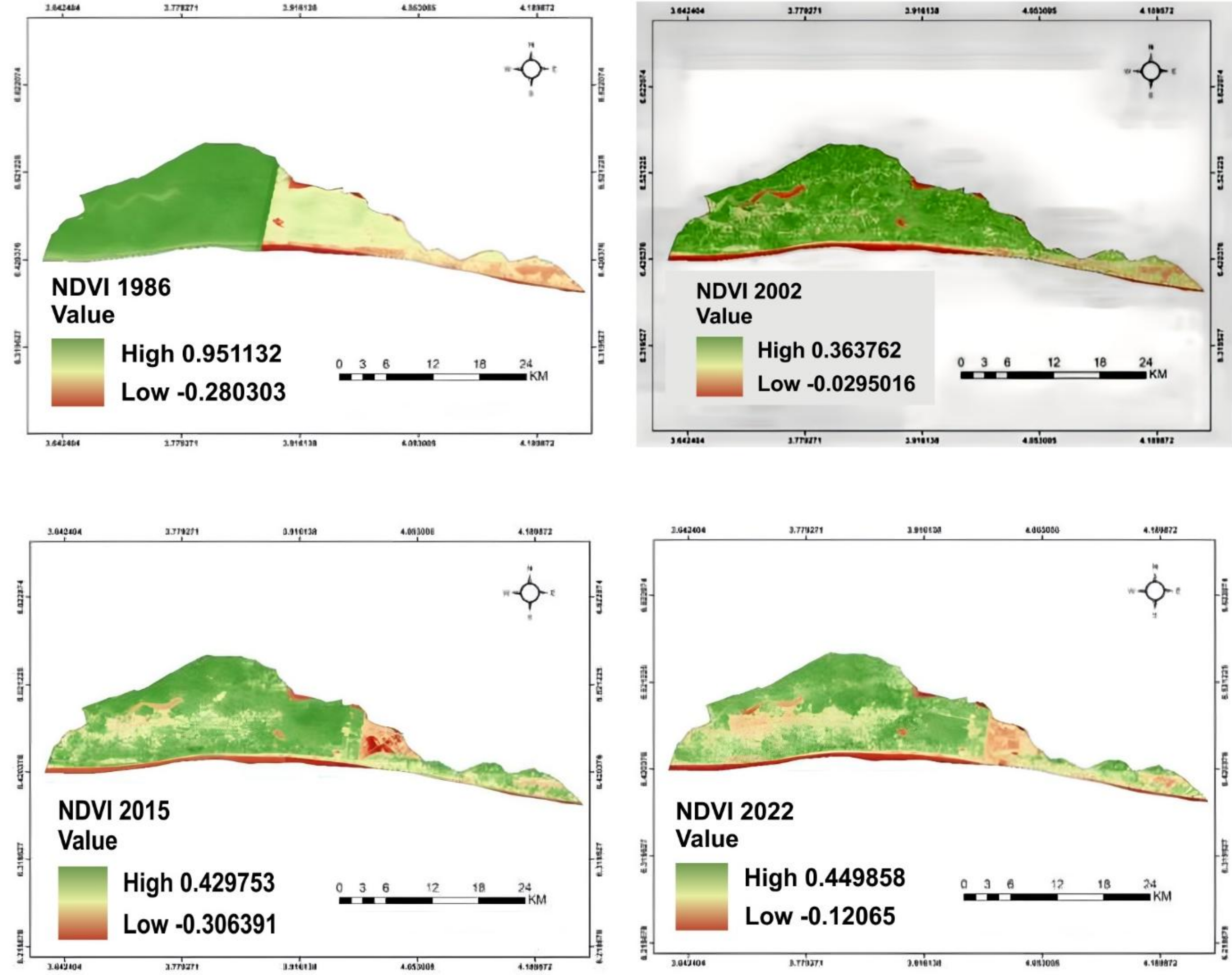

Figure 4: Normalised difference vegetation index analysis for Ibeju Lekki between 1986 and 2022
Source: Author's Fieldwork, 2024

3.4 Urban Heat Island Presence and Intensity Threshold

The UHI presence in Ibeju-Lekki was minimal in 1986, covering an area of only 0.01 sq. km (0.002% of the total land area). This can be attributed to the predominance of vegetation coverage before 1986, which allowed for the absorption of solar energy and radiation, thereby ensuring a cooler environment in the study area. This is reflected in Figure 5, which visually suggests that the study area was a non-Urban Heat Island (UHI) area at that time. In 2002, a significant increase in urban heat characteristics was observed, with the affected area expanding to 96.58 sq. km (19.886% of the total land area) and the non-UHI areas reduced to 389.07 sq. km, occupying 80.114% of the study areas.

In 2015, the UHI area slightly decreased to 96.06 sq. km (19.779% of the total land area), indicating a potential stabilisation or minor reduction in urban heat. The area exhibited a minor reduction of 0.52 sq. km between the UHI and non-UHI areas, representing an approximately 0.11% difference. The total percentage of the area with UHI is 19.779%, while areas without UHI occupied 80.221% of the total land area. By 2022, results indicate a rise in UHI areas from 96.02 sq. km to 111.33 sq. km, accompanied by a reduction in non-UHI areas to 374.32 sq. km, down from 389.59 sq. km recorded in 2015. Analysis showed a resumption in the agglomeration of UHI areas in the southeast, while they appear to be increasingly fewer in the north and western regions of the area.

The general conclusion from this analysis is that there was an overall increase in UHI during and at the end of the 36 years encompassed by the analysed years. This is attributed to industrialisation and other human activities such as deforestation for construction purposes, encroachment of forested areas and vegetation cover on waterways and drainage systems, and land reclamation of potential wetlands within the study area. According to a study by Mohan et al. (2012), the results of UHI obtained show that dense urban and highly commercial areas exhibited the highest UHI, with an hourly maximum of 10.7°C and a mean daily maximum of 8.3°C. This result agrees with the outcome obtained within the Ibeju Lekki metropolis.

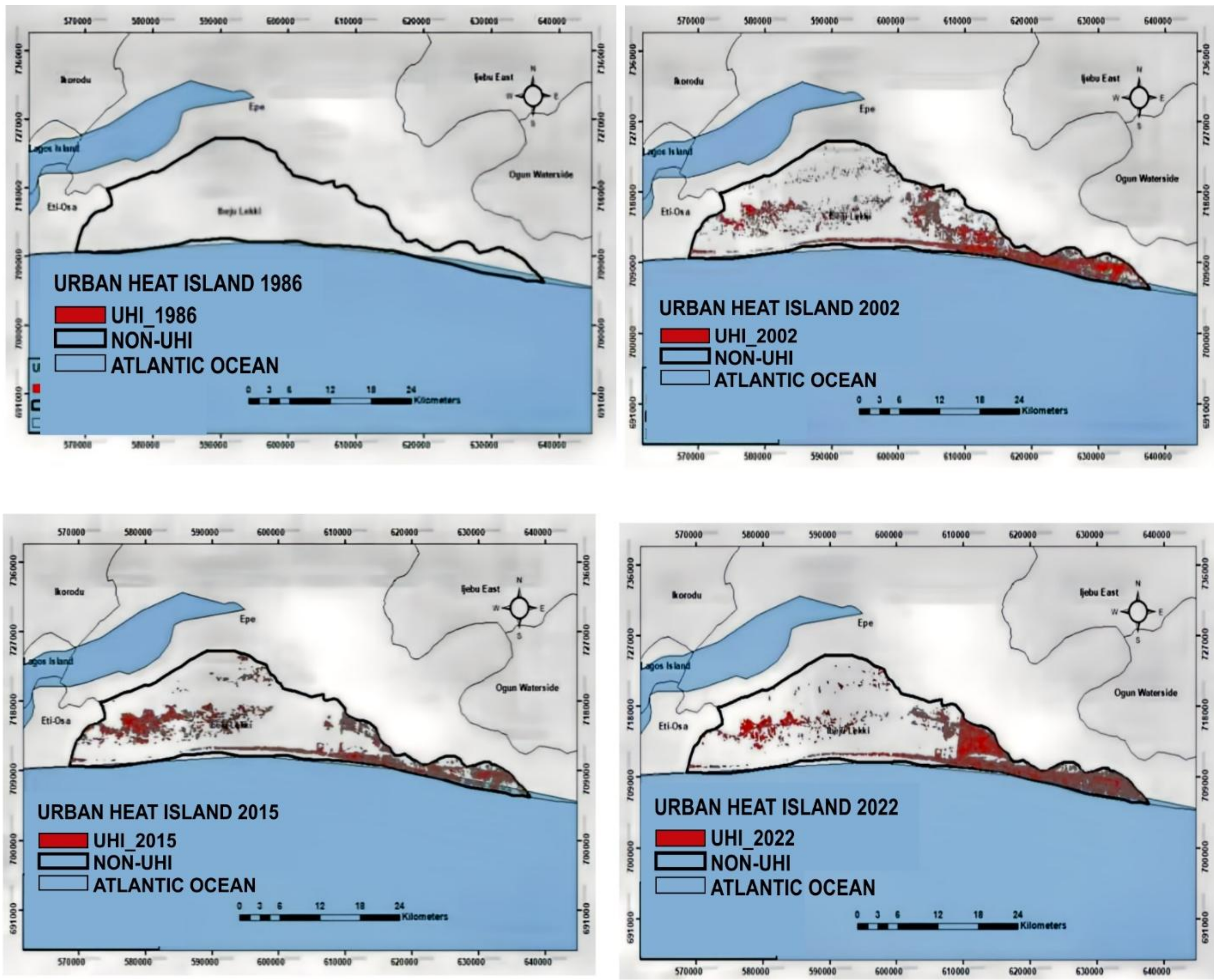

Figure 5. Spatial Distribution of UHI Between 1986 and 2022,
Source: Author's Fieldwork, 2024

3.5 Land cover dynamics to surface temperature of Ibeju Lekki, Lagos, from 1986 to 2022

Five major land covers were identified in the study area: built-up areas, water bodies, sparse vegetation, dense vegetation, bare surfaces, and rock outcrops (Figure 6). As shown in Table 6, prior to 1986, the study area was characterised by dense vegetation, bare surfaces, and water bodies. In 1986, the dominant land cover was dense vegetation (55.5%), followed by bare surfaces (35.1%), water bodies (5.2%), and built-up areas, which made up the least, accounting for approximately 4.1% of the total study area. The built-up area and forest/vegetation increased slightly to 5.5% and 57.8%, respectively, in 2000, while bare surfaces and water bodies decreased slightly during the same period. By 2015, the built-up area was the only land covered, and the percentage coverage had increased considerably to approximately 14%; others had dropped substantially during this period. Following previous trends, built-up areas witnessed a significant increase, reaching 20.9%, and forest/vegetation and bare surfaces decreased to 48.6% and 26.5%, respectively, in 2022. Water bodies increased slightly during this period, which could be attributed to the rise in artificial ponds and lakes in the area.

Table 6: Land cover analysis between 1986 and 2022.

Classification	1986 Area (sq. km)	%	2002 Area (sq. km)	%	2015 Area (sq. km)	%	2022 Area (sq. km)	%
Bare Ground	34.35	7.07	20.95	4.31	8.81	1.81	10.35	2.13
Built-Up	42.60	8.77	80.41	16.56	147.29	30.33	136.57	28.12
Dense Vegetation	163.19	33.60	119.92	24.69	125.50	25.84	61.01	12.56
Rock Outcrop	33.44	6.89	69.05	14.22	31.49	6.48	62.74	12.92
Sparse Vegetation	176.30	36.30	160.73	33.09	128.03	26.36	177.15	36.48
Water	35.78	7.37	34.60	7.12	44.53	9.17	37.83	7.79
Grand Total	**485.66**	**100**	**485.66**	**100**	**485.66**	**100**	**485.66**	**100**

Source: Author's fieldwork, 2024.

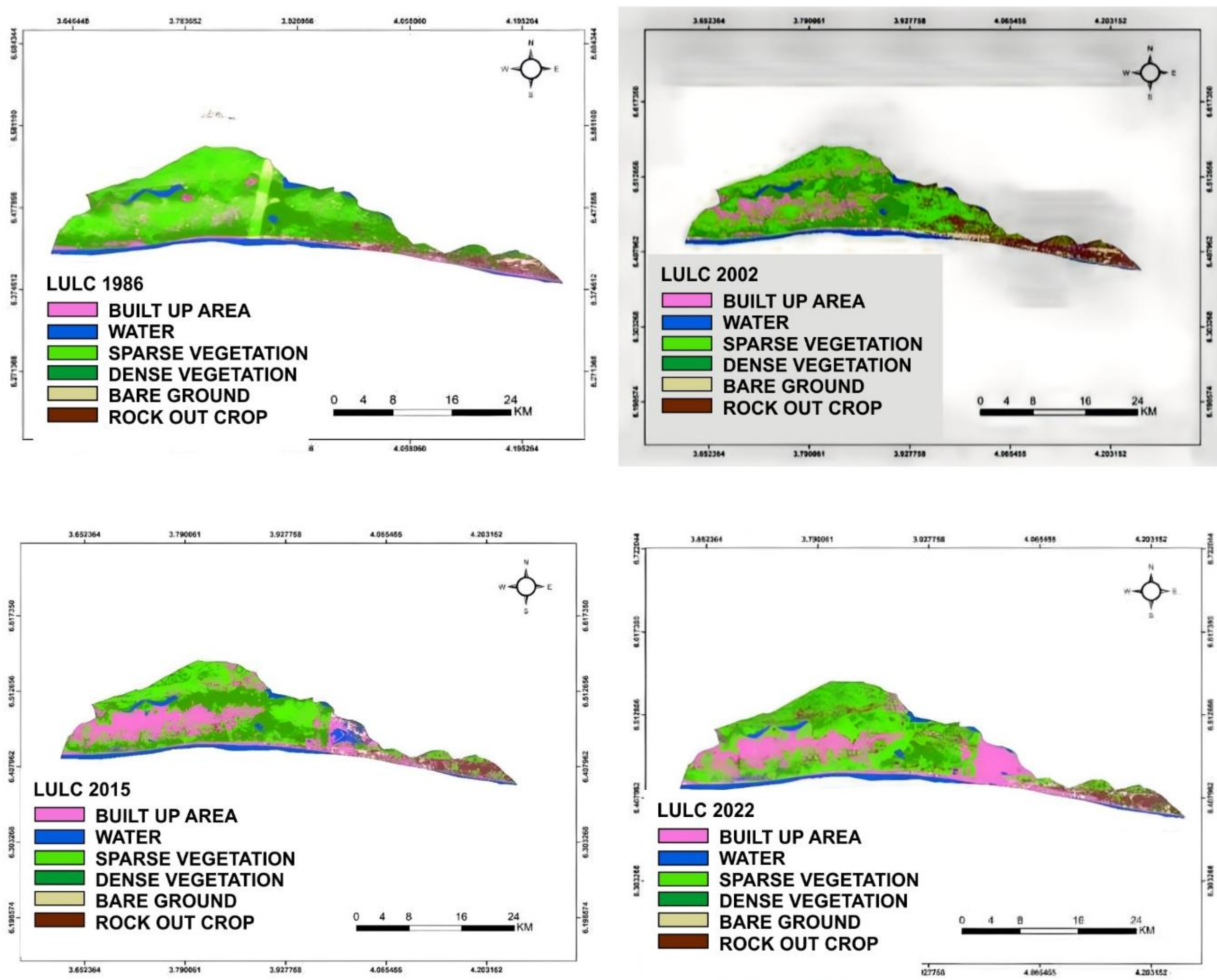

Figure 6: Land use land cover changes in Ibeju-Lekki between 1986 and 2022
Source: Author's Fieldwork, 2024

3.5.1 Correlation of Urban Heat Characteristics and Land Cover Change between 1986 and 2022

The 1986 analysis showed a negligible occurrence of UHI in the area (Figure 7). This is not surprising as sparse and dense vegetation combined made up 69.9% of the study area, water covered 35.78 sq. km (7.37%), bringing the total percentage coverage of non-UHI generating land cover to 77.27%, while UHI-generating land uses, which are bare grounds, built up areas and rock outcrops occupied the remaining 22.73%. At 8.7% built-up areas, it shows the minimal presence of urbanisation, allowing for minimal waste heat generation, which could have contributed to UHI.

Analysis revealed that in 2002, more built-up areas appeared at different locations in the study area in response to the rapid urbanisation and development needs. The extent occupied by built-up areas increased by 7.79% (from 42.60 square kilometres to 80.41 square kilometres). This increase in built-up areas to cater to residential, industrial, recreational, and other human needs is not without its negative consequences on other land covers and the entire study area. As space cannot be created out of nowhere, reductions of 0.25%, 3.21%, and 8.91% were observed in areas previously occupied by water, sparse vegetation, and dense vegetation, respectively. The only other land use that increased in tandem with built-up areas, with a percentage increase of 7.33%, is rock outcrops. As vegetation was cleared for construction and other purposes, more rocks were exposed during the process, which explains the increase in UHI levels in 2002.

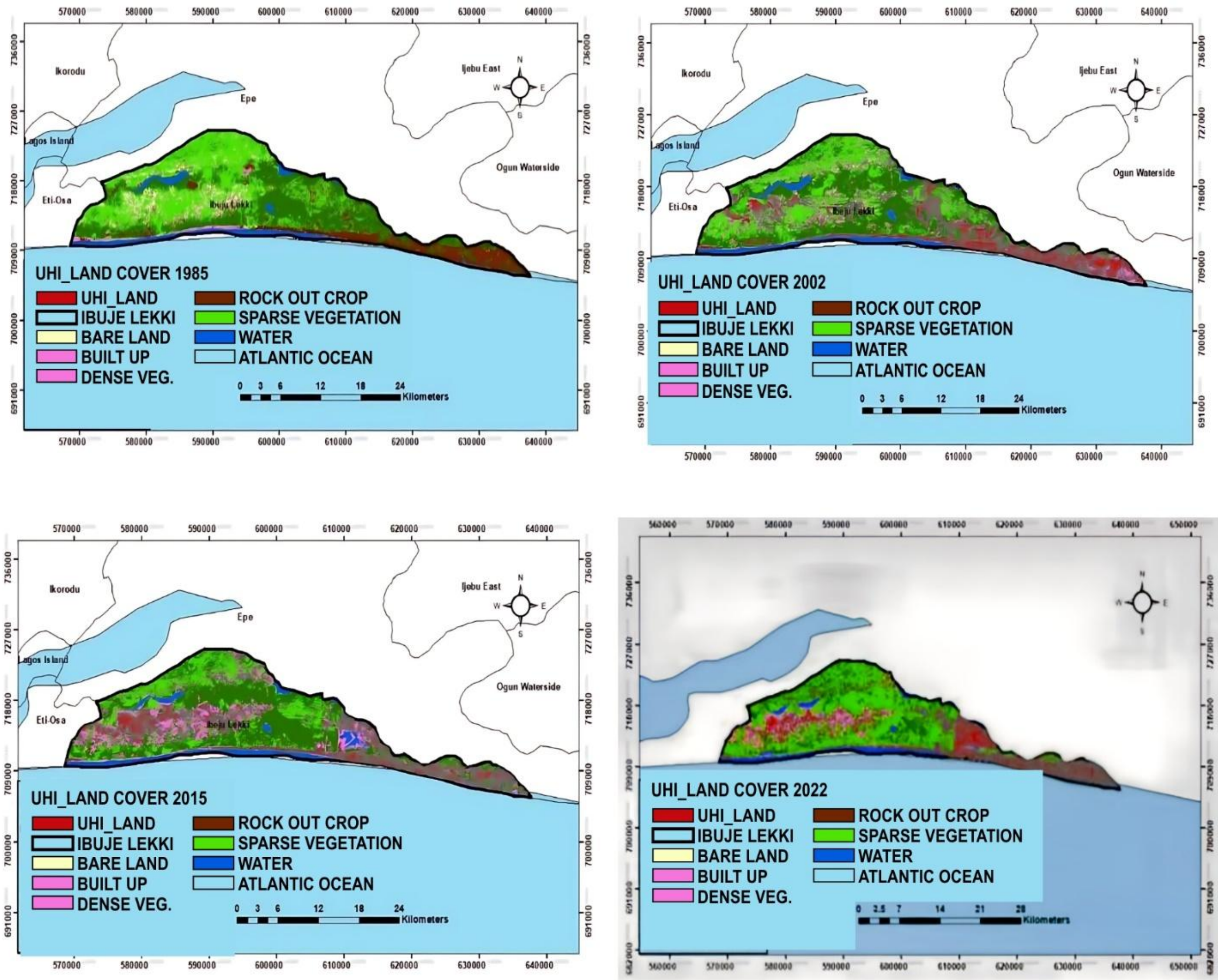

Figure 7: LULC and UHI overlay between 1986 and 2022
Source: Author's Fieldwork, 2024

In 2015, analysis shows that built-up areas increased to cover 30.33% of the total study area, a corresponding increase to 9.17% and 25.84% was also noticed in water bodies and densely vegetated areas, respectively, while sparse vegetation, bare grounds and rock outcrops reduced to cover 26.36%, 1.81% and 6.48% of the land area, respectively. This explains the decrease in recorded UHI between 2002 and 2015, as more efforts were geared toward revitalising natural elements in the study area within this study timeframe.

By 2022, the area coverage of built-up areas had decreased by 2.21% from that observed in 2015; however, the overall UHI level of the study area was found to have increased by 3.145%. This is attributed to the recorded increase in land area of bare lands and rock outcrops, which cover 10.35 square kilometres and 62.74 square kilometres, respectively. Combined with built-up areas, these still account for 43.17% of the study area. This is because the densely forested central regions, as noticed in 2015, are all but gone, leaving shadowy, sparse vegetation in their wake. Water reserves in the southeastern parts, where development is at its densest (as indicated by the proliferation of built-up areas), are depleted. The western region continues to be visibly ravaged by UHI, ranking second only to the southeastern regions, where developments have been identified as the source. Generally, UHI areas by this time have increased to cover 111.33 sq. km, accounting for 22.924% of the total land coverage, and this rise is attributed to the continuous increase of built-up areas.

Ibeju-Lekki has undergone substantial urbanisation and demographic expansion, transforming previously vegetated landscapes into constructed environments. This transition has led to an increase in impervious surfaces, which absorb and retain greater quantities of thermal energy, thereby enhancing the urban heat island (UHI) effect. The removal of vegetation to facilitate urban development and infrastructural projects has significantly diminished the region's inherent capacity for thermal regulation. Trees and vegetation are essential in alleviating UHI effects through providing shade, evapotranspiration, and the absorption of solar radiation. The proliferation of industrial facilities, commercial centres, and various economic activities within Ibeju-Lekki has engendered heightened energy consumption, waste heat generation, and extensive land clearing, exacerbating the UHI phenomenon. As a coastal locality, the UHI in Ibeju-Lekki may also be modulated by the temperate influences of the Atlantic Ocean, particularly in regions adjacent to the shoreline. Nevertheless, as urbanisation progresses inland, the mitigating effects of the ocean appear to wane.

3.6 Analysis of the changes in ecosystem services in Ibeju Lekki due to urban heat characteristics between 1986 and 2022

In 1986, the urbanisation process in Ibeju-Lekki was in its early phase, characterised by a negligible urban heat island effect, with the UHI occupying only 0.002% of the total land area. Consequently, the ramifications of UHI on the local ecosystems were deemed minimal. However, by 2002, a marked temperature increase occurred due to land use modifications and urban expansion, resulting in the expansion of urban heat islands from 0.002% to 19.89% within the study area. This substantial alteration precipitated significant transformations in the ecosystem biomes, adversely affecting the services they provide. The UHI rate experienced a slight reduction from 19.89% to 19.78% in 2015, a change attributed not to a deceleration in urbanisation but instead to broader land use changes that had become more prevalent in Ibeju-Lekki when compared to 2002, where changes were more localised. Nevertheless, in 2022, the pace of urbanisation escalated further, accompanied by profound alterations in land-use patterns within the study area, as illustrated in Figure 7, with an astonishing increase from 19.78% to 22.92% over the seven years.

3.7 Ecosystem Service Valuation of the Ibeju Lekki Area

In Table 8, the analysis delineates four principal ecosystem types in Ibeju Lekki: aquatic bodies, rainforests, swamp forests, and mangroves. The expanse of each ecosystem type is quantified in hectares (ha). Swamp forests represent the most extensive ecosystem type, encompassing over 42,530 hectares, followed by aquatic bodies (over 3,185 hectares), mangroves (over 2,243 hectares), and rainforests (606 hectares). The findings elucidate the economic valuation of each ecosystem service per hectare annually, expressed as dollars per hectare per year ($/ha/year). Mangroves exhibit the highest economic value per hectare at $193,806/ha/year, followed by swamp forests at $25,669/ha/year, rainforests at $5,383/ha/year, and aquatic bodies at $12,512/ha/year. Furthermore, swamp forests manifest the most significant total value at $1,091,718,998.16 (₦1.63 quadrillion) per annum, followed by mangroves at $434,848,336.38 (₦650 billion) per annum, aquatic bodies at $39,853,097.28 (₦59.6 billion) per annum, and rainforests at $3,262,851.62 (₦4.9 billion) per annum.

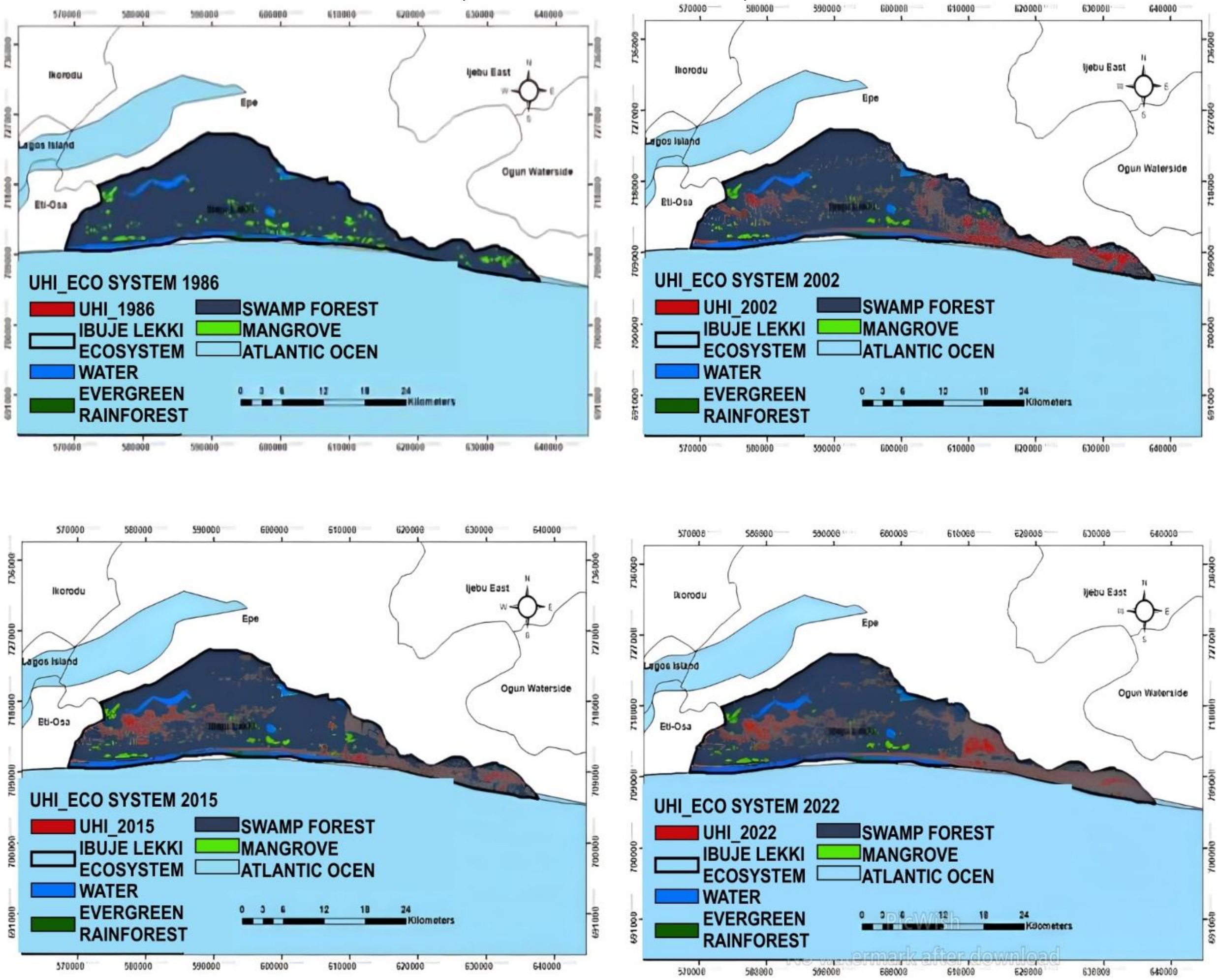

Figure 7: Urban Heat Characteristics Influence on Ecosystem Services between 1986 and 2022
Source: Author's Fieldwork, 2024

The total value of ecosystem services at Ibeju Lekki before the UHI Effect is $1,569,345,459.44 (₦2.4 quadrillion). The percentage value shows the contribution of each ecosystem service to the total value. Swamp forests contribute the most (69.6%), followed by mangroves (27.65%), water bodies (2.54%), and rainforests (0.21%). The results highlight the economic value of ecosystem services in Ibeju Lekki, with swamp forests and mangroves providing the most value. It emphasises the importance of conserving these ecosystems to maintain their ecological and economic benefits. Removing the ecosystem will result in a loss of ₦1.63 quadrillion, ₦650 billion, ₦59.6 billion, and ₦4.9 billion for swamps, mangroves, water bodies, and rainforests, respectively. In total, ₦2.4 quadrillion represents the potential value of the services provided by these ecosystems.

Table 7: Value of Ecosystem Services in Ibeju Lekki at the Pristine State

Ecosystem	Ecosystem Land Area (ha)	Value of Ecosystem ($/ha/year)	Total Flow Value ($/year)	Percentage Value
Water	3185.19	12,512	39,853,097.28	2.54
Rain Forest	606.14	5,383	3,262,851.62	0.21
Swamp Forest	42530.64	25,669	1,091,718,998.16	69.6
Mangrove	2243.73	193,806	434,848,336.38	27.65
Total	48565.7		1,569,345,459.44	100

Source: Adapted from (Costanza et al., 2014; de Groot et al., 2012)

There is an ever-increasing threat to land cover and the components (ecosystems) that make it up due to UHI. From the results, it can be deduced that the higher the rate of UHI, the higher the rate of loss in the environment due to the negative impacts of UHI. Table 9 shows the loss due to the area experiencing UHI in Ibeju Lekki. In 1986, a total of 1 hectare of land was affected by UHI, resulting in a yearly loss of $313,396 (₦468,683,718). The value increased from the stated amount in the first baseline year to **$**312,142,812 (₦466,809,575,346) due to the increasing rate of UHI. There was a slight reduction from 2002 to 2015, to **$**310,416,532 (₦464,227,923,606), which was followed by a 2.8% increase in UHI, resulting in an additional **$**8,772,477 (₦13,000,000,000). In total, the loss in 2022 is **$**359,693,979 (₦537,922,345,594.5).

The findings show that UHI is increasing and is in tandem with urbanisation. This implies further loss of ecosystems and their services to humanity due to drastic changes caused by UHI over the years.

Table 9: Value of ecosystem services lost in Ibeju Lekki due to urban heat characteristics

Year	Ecosystem Land Area (ha)	% of UHI Effect/Ha	Total Flow Value ($/year)	$ loss due to UHI (LUC)
1986	3185.19	0.02(1)	39,853,097.28	313,869
2002	606.14	19.89(9658)	3,262,851.62	312,142,812
2015	42530.64	19.78(9606)	1,091,718,998.16	310,416,532
2022	2243.73	22.92(11133)	434,848,336.38	359,693,979
Total	48565.7		1,569,345,459.44	

Source: Adapted from (Costanza et al., 2014; de Groot et al., 2012)

3.8 SUMMARY OF FINDINGS

This investigation has scrutinised the magnitude of urban heat and the dynamics of land use on the surface temperature of Ibeju Lekki over 36 years. This analysis has demonstrated the presence of urban heat island (UHI) characteristics within Ibeju-Lekki, utilising the Normalised Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) assessments to indicate that regions with a pronounced incidence of deforestation and infrastructural expansion exhibit elevated land surface temperatures, thereby experiencing a greater degree of urban heat. The escalation of infrastructural development and urbanisation has significantly influenced the city's thermal architecture, resulting in Ibeju Lekki's urban zones being consistently warmer than the adjacent rural regions, thereby confirming the existence of an urban heat island (UHI) within the study area. The UHI intensity derived from this research indicates an average temperature differential of 10.2°C warmer than that of the rural areas over the preceding decade. The temperature discrepancies observed between urban and rural locales, as well as seasonal fluctuations, throughout the 36 years of analysis in Ibeju Lekki, have elucidated that the predominant UHI intensity reaches its zenith.

The land cover of Ibeju Lekki has undergone significant alterations due to rapid urbanisation and socio-economic advancements. The proportion of built-up areas has surged to 28.3%, resulting in the depletion of water bodies, dense vegetation, sparse vegetation, rock outcrops, and barren surfaces throughout the study area. This transformation has altered the surface radiative attributes, resulting in an upward trajectory of the LST, which has in turn generated a heat island phenomenon in Ibeju Lekki.

Lastly, the investigation explored the correlation between the evolving ecosystem and human well-being. Anthropogenic activities pose substantial threats to the provision of ecosystem services in Ibeju Lekki, affecting residents, government entities, and multinational corporations alike. Findings from the research indicate that in the quest to fulfill daily necessities essential for human well-being, various anthropogenic activities such as land conversion, urbanisation, deforestation, mining, oil exploration, pollution, and agricultural practices have profoundly contributed to the precarious condition of the ecosystems and the decline in biodiversity within the study region.

4.0 RECOMMENDATIONS AND CONCLUSION

4.1 RECOMMENDATIONS

One of the primary contributors to the urban heat island phenomenon is the loss of natural ground cover, often accompanied by deforestation. The alteration of land cover has emerged as a pivotal element in contemporary strategies aimed at resource management and environmental monitoring. Consequently, both governmental and non-governmental organisations should prioritise effective land-use management and evaluate the ecological impacts of each land-use and land-cover change. It is recommended that governmental bodies implement afforestation initiatives, while individuals, residents, technocrats, and stakeholders should be motivated to engage in these programs. The models could be designed to ensure that an equivalent number of trees is replaced for every N number of trees removed. Implementing passive cooling solutions in structures through green roofs mitigates heating and cooling demands. Moreover, beyond their aesthetic appeal, green roofs can filter airborne pollutants, particularly in the remediation of greenhouse gases that contribute to global warming within the atmosphere.

Policymakers and practitioners within the Ibeju Lekki region and the broader context of Lagos must prioritise the implications of prospective horizontal urban expansion while contemplating strategies for vertical development. The diverse stakeholders, commencing with the Local Government Area and extending to various Ministries, Departments, and Agencies engaged in the urban formation ecosystem, must devise a comprehensive plan for sustainable green infrastructures, including environmentally conscious construction practices, green building initiatives, and the implementation of green or cool roof technologies to mitigate the urban microclimate warming effect and, consequently, alleviate the impacts of Urban Heat Islands (UHI). A structured framework and master plan must be established to cultivate ecologically and compactly urban environments, essential for sustaining ecosystem services and biodiversity. To avert further occurrences of UHI within Ibeju Lekki, the Urban Planning Department must integrate Green Infrastructure (GI) into the planning processes pertinent to the study area.

4.2 CONCLUSION

The intensity of the UHI phenomenon poses significant threats to human and environmental health. It is anticipated to escalate in response to ongoing Land Use and Land Cover (LULC) changes, necessitating immediate action. Beyond the implications of global warming, physical characteristics inherent to urban environments, such as surface mineralisation, diminished vegetation cover, and the generation of anthropogenic heat, exacerbate the UHI phenomenon. Data regarding land surface temperature serves as a robust methodological approach to elucidate the development and proliferation of UHI, which invariably influences the climatic conditions of any given locality. Satellite imagery offers a cost-effective and efficient means of assessing land surface temperature on both spatial and temporal scales, as demonstrated in this investigation. The emergence of urban heat islands is virtually unavoidable, particularly given the persistent concentration of populations, which is poised to continue expanding. This trend will invariably lead to the ongoing removal of natural landscapes, supplanted by artificial constructions. Consequently, proactive measures must be undertaken to mitigate these adverse effects. The land cover in Ibeju Lekki has undergone marked transformation due to rapid urban growth and socio-economic advancement. The dynamic shifts within ecosystems carry significant implications for human well-being. The conservation and restoration of ecosystems can bolster the provision of essential services, foster economic resilience, enhance health outcomes, and safeguard cultural heritage. Conversely, ongoing ecosystem degradation can yield considerable adverse consequences for human communities, underscoring the critical necessity for sustainable management and conservation strategies.

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