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Original Research Article

Spatiotemporal Analysis of Land Surface Temperature Variability across Urban-Rural Gradients in Lagos Mainland, Nigeria Using High Resolution GIS and Remote Sensing

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Abstract: Urbanization in sub-Saharan African cities is altering the land surface and local climate conditions. However, the empirical data on the spatiotemporal patterns of land surface temperature (LST) along the urban–rural gradient at the local administrative level is scarce. Therefore, this study assessed the impact of land use/land cover (LULC) change on the LST dynamics in Lagos Mainland, Nigeria, a rapidly urbanizing area within Africa's most rapidly expanding megacity, between 2015 and 2025 using a combination of GIS and remote-sensing techniques. Multitemporal Landsat 8 OLI/TIRS data (30 m resolution) acquired during the dry season months were employed for this analysis. The data were classified using a supervised classification technique and the maximum likelihood classifier to produce the LULC maps for 2015, 2020, and 2025. LST was obtained in three steps: conversion to spectral radiance, computation of brightness temperature, and emissivity correction using NDVI-based approach. A confusion matrix was used for accuracy assessment and an overall classification accuracy of 87.5% (κ = 0.84) was achieved. A significant LULC change occurred, i.e., 71.1% decline in the vegetation area (from 1065 to 308 ha) and 748.5% rise in the bare area (from 97 to 823 ha) from 2015 to 2025 and built-up area increase (from 867 to 1067 ha). The spatiotemporal variation in LST was found to be prominent as the mean surface temperature was increased from 27.61 °C (2020) to 41.22 °C (2025). Furthermore, the results of the spatial overlay analysis and bivariate correlation analysis show that there are strong positive correlation values between LST and built-up area ($r > 0.80$) and significant negative correlation values between LST and vegetation area ($r < -0.70$), thereby showing that green spaces have potential in mitigating thermal conditions. Thus, the results of this study give an empirical insight into the association between LST and land use and land cover types as evidence of the thermal impacts of urbanization at local administrative level and therefore calls for the need to consider LULC planning strategies to mitigate UHI effects. The study also shows that the use of high resolution remote sensing data is effective in the application of SDGs in tropical developing cities with limited data, and also provides baseline data for policy implications on UHI in rapidly urbanising African cities.

Keywords: Land Surface Temperature, Urban Heat Island, Land Use/Land Cover Change, Remote Sensing and GIS, Lagos Mainland.

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INTRODUCTION

Urbanization is one of the most powerful factors of environmental change occurring in the world today (Alberti, 2008), particularly in the rapidly expanding cities of the Global South. Urbanization results in massive alterations in land use and land cover (LULC), with natural vegetation and permeable surfaces being replaced with built-up impervious surfaces such as asphalt, concrete, and rooftops. Such alterations perturb the surface energy balance, diminish evapotranspiration, and eventually lead to an increase in land surface temperature (LST) in the urban domain (Daramola & Isiofia, 2021). Consequently, most cities in the world are facing the urban heat island (UHI) effect, which is a form of urban microclimate characterized by significantly higher temperatures in the urban domain compared to the surrounding rural areas. LST is a widely used environmental metric for urban climate analysis and temperature change impacts of land cover transformation. Remote sensing and geospatial analysis techniques have made it feasible to track LST changes and the corresponding LULC dynamics at various spatio-temporal scales. For example, Landsat satellite datasets have offered the required long-term thermal infrared records for mapping and analyzing urban thermal characteristics at a reasonably good level of accuracy (Afolabi *et al*., 2025). Such data sources have become indispensable for studying the dynamics of urbanization and surface temperature variation.

Many research works have shown that LST variability is a function of the land cover characteristics. For instance, built-up and bare surface areas have high thermal properties because of their low albedo and low moisture-holding capacity, whereas vegetation and water cover have a cooling effect as a result of their evapotranspiration and shading effects, respectively (Makinde Akiode, 2020). Thus, the transformation of vegetative surfaces into impervious urban surfaces leads to the enhancement of urban heat island (UHI) and thermal hotspots within urban areas. Increases in temperature have significant implications for urban sustainability, including energy use, outdoor thermal comfort, ecological balance, and human health (Daramola Isiofia, 2021).

The relationship between urbanization and LST is a topic of current interest, particularly in the African megacities undergoing rapid urbanization. Among the most rapidly urbanizing cities in Africa, Lagos, Nigeria, is one of the fastest-growing cities experiencing urbanization, with a high rate of population and infrastructure development. This has resulted in the transformation of a large area of land, which in turn has led to increasing urban temperatures within the city, with implications for environmental sustainability and climate change mitigation (Afolabi *et al*., 2025). Several research findings have shown that urbanization and vegetation reduction are responsible for the increased LST in some parts of Lagos, Nigeria, and other cities (Olalekan & Ayodele, 2023; Daramola & Isiofia, 2021).

While studies have been conducted on urban heat in cities of Nigeria, there are limited research studies that have explored the spatiotemporal dynamics of LST across urban and rural continuum at the local government level, where most land use and land cover changes occur. Existing studies have either been conducted at metropolitan city level or considered a few years of data, and consequently may not have captured the local scale thermal environment changes resulting from rapid urbanization. This information is important for the detection of new areas of thermal anomalies and climate-informed urban planning. Besides, the fusion of remote sensing and geographic information systems (GIS) presents a useful platform for analyzing LULC change dynamics and LST pattern. Spatial analysis with the application of GIS technique can be used to identify the location and time of land cover changes, determine their area, and assess their thermal effects. This is especially important for fast-growing cities due to the paucity of ground-truth data (Makinde & Akiode, 2020).

Consequently, this research examines the spatiotemporal variation in land surface temperature (LST) across the urban–rural fringe of Lagos Mainland, Nigeria, through application of high-resolution spatial analytic techniques. In particular, the objective of this research is to (i) analyze multi-temporal land use and land cover (LULC) dynamics in Lagos Mainland, (ii) assess the spatiotemporal variations in LST, and (iii) study the relationship between LULC change and surface temperature. This study is contributing to the research works that are presently documenting the spatiality of urban thermal environment and is an evidence-based resource for urban planning and climate change adaptation in rapidly growing tropical cities.

METHODOLOGY

Study Area

The study was conducted in Lagos Mainland, Lagos State, Nigeria, located within the rapidly urbanizing Lagos metropolitan region in southwestern Nigeria. Lagos Mainland lies between latitudes approximately 6°29′–6°32′ N and longitudes 3°21′–3°24′ E. The area experiences a tropical wet and dry climate, characterized by high humidity and mean annual temperatures ranging between 25 °C and 32 °C. Annual rainfall ranges between 1500 mm and 2000 mm, with a distinct wet season from April to October and a dry season from November to March. Rapid population growth and infrastructure expansion have resulted in substantial changes in land use and land cover across the metropolis. These transformations often involve the conversion of vegetated landscapes into impervious built-up surfaces, which significantly influence the urban thermal environment and contribute to elevated land surface temperatures (LST) (Abimbola *et al.,* 2025). Monitoring such thermal variations is therefore essential for understanding urban climate dynamics and supporting sustainable urban planning.

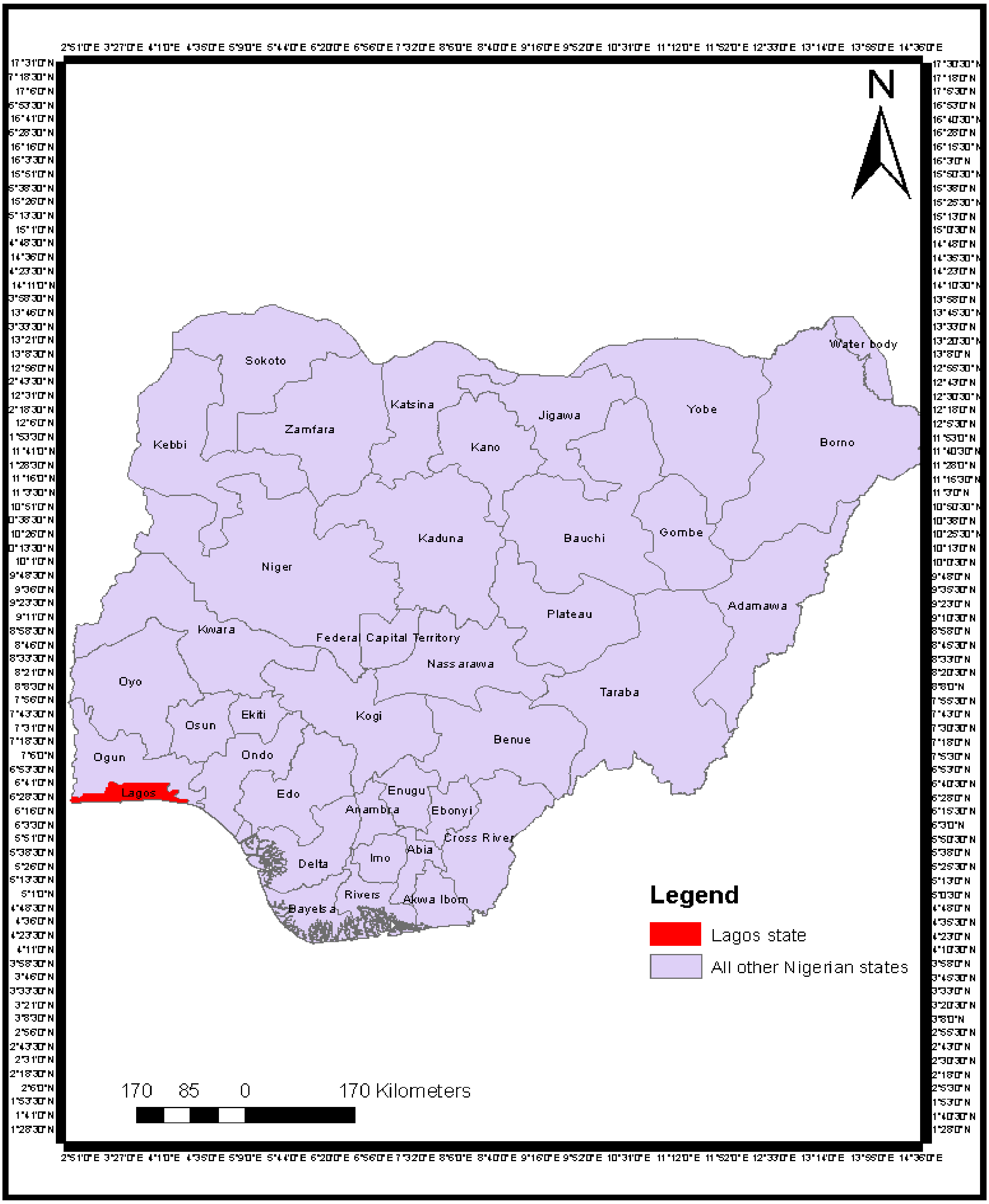

Figure 1: Map of Nigeria Showing Lagos

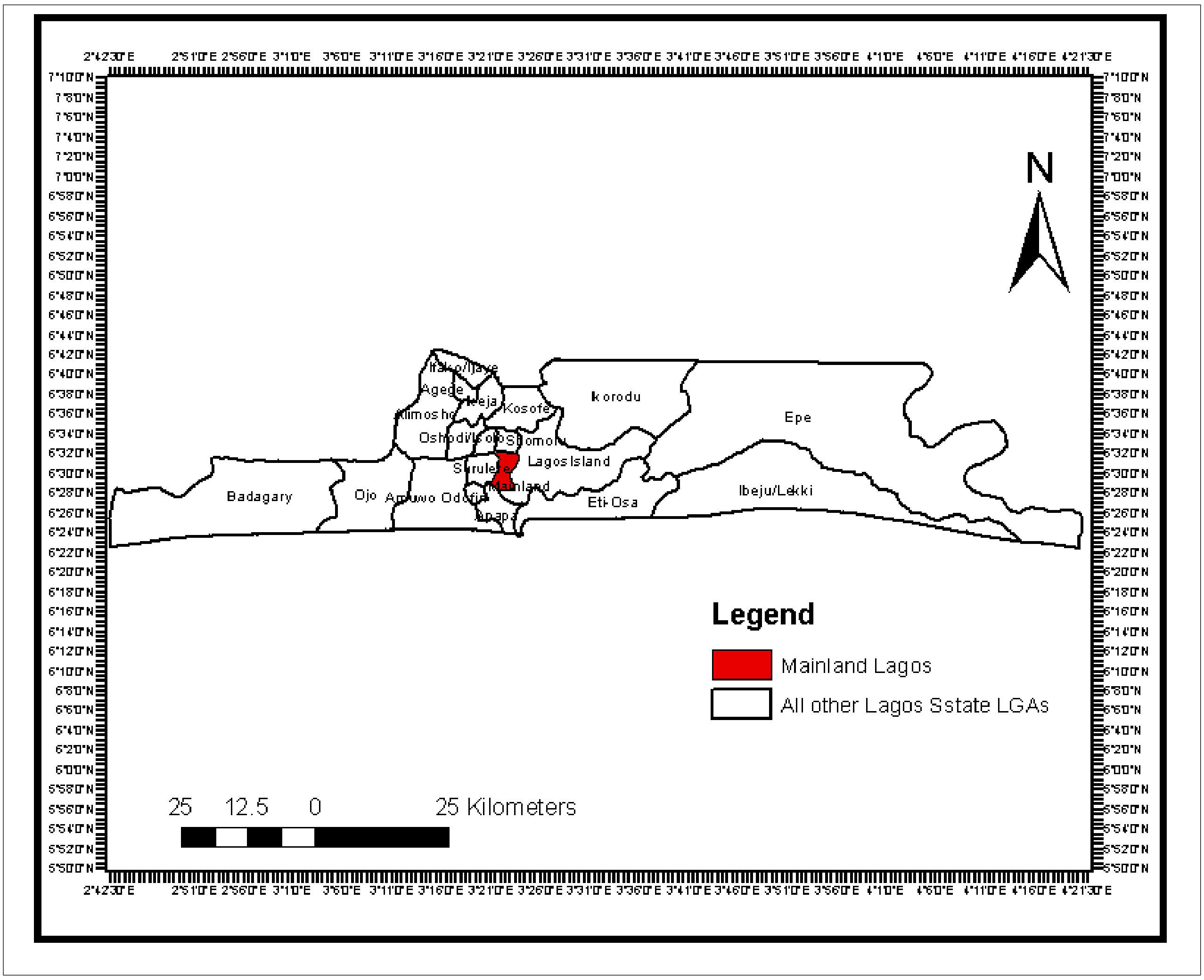

Figure 2: Map of Lagos showing Mainland

Data Sources and Satellite Imagery

To analyze the LULC changes as well as their impact on LST, a bi-temporal (2015 to 2025) data from the Landsat program was employed. Landsat data are popular in urban thermal research as they offer relatively high spatial resolution and possess TIR bands capable of retrieving temperature information. The data include:

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) 2015, 2020 and 2025.

The data from the Landsat Images Are:

- Spatial Resolution: 30 m (multispectral bands)
- 100 m spatial resolution for the thermal bands (resampled to 30 m)

The satellite images used in this study were captured during the dry season to avoid atmospheric disturbance and cloud cover. Moreover, it has been suggested that LST can be estimated from the thermal infrared band of the Landsat series because the thermal infrared sensor has the ability to receive the emitted radiation from the surface of the Earth, and the surface temperature can be estimated with acceptable accuracy (Xie *et al.*, 2025). Other ancillary spatial data employed in this study include the administrative boundary shapefiles of the study area (Lagos Mainland) and base map for georeferencing.

Image Pre-Processing

The satellite images were pre-processed before the analysis to guarantee the data quality and enhance the analysis results. Radiometric correction was done to convert the digital number (DN) values into top-of-atmosphere (TOA) spectral radiance. This step is used to minimize the sensor and atmospheric noise. The output of this process provides the actual radiation measured on the ground instead of the DN (Patna UHI study, 2025). All imagery was projected to the Universal Transverse Mercator (UTM) coordinate system (WGS 84 datum) to ensure spatially referenced compatibility between datasets.

The Lagos Mainland administrative boundary was used to clip the satellite imageries to the study area extent. Cloudy and shadow pixels were excluded from the classification and LST calculation to avoid potential biases and uncertainties. Cloud contamination is often a source of significant disturbance to the thermal radiation signal, leading to decreased accuracy in LST retrieval (Liu *et al.,* 2023).

Land Use Land Cover Classification

Supervised classification was performed using the Maximum Likelihood Classifier (MLC) which is one of the commonly used classifiers in remote sensing as it takes into account both the variance and covariance of the spectral signature. The four major land cover categories classified are:

- Built-up areas
- Vegetation
- Bare surfaces
- Water Bodies

Representative training pixels for each class were carefully identified from the high-resolution images and expert interpretation to train the classifier, and LULC maps of 2015, 2020, and 2025 were then generated and used to analyze the spatial dynamics of urban growth.

Accuracy Assessment

Accuracy assessment based on a confusion matrix was performed to validate the accuracy of the classification output. Reference points were sampled from high-resolution images and ground-truth data. The accuracy metrics were computed as follows:

- Average error rate
- Accuracy of the producer
- Accuracy of the user
- Cohen's Kappa

Kappa coefficient is a statistical method for determining the proportion of agreement between classifications, excluding the possibility of chance agreement, and has been widely employed for validating remote sensing-derived classifications.

Change Detection Analysis

The post-classification comparison method was employed to assess the LULC dynamics within the study period. This method calculates changes between classified images of different dates to identify the magnitude, nature and location of land cover changes. Change detection procedure includes:

i. Cross Tabulation of Classified LULC of 2015 and 2020, and 2020 and 2025
ii. Finding class-to-class transitions
iii. Area calculation of each change type

Post-classification comparison is often employed in urban analysis, as this method allows for accurate detection of land cover changes and reduces the possibility of spectral mixing of different land cover categories. The LST was retrieved from the thermal infrared band (Band 10) of the Landsat data using a popular single-channel algorithm.

Step 1: Conversion of Digital Number to Spectral Radiance

The digital number values were converted into units of spectral radiance, by applying the radiometric rescaling equation: $L_\lambda = M_L \times Q_{cal} + A_L$

Where:

The terms in the equation are:

- Lλ = spectral radiance ($W/m_2/sr/\mu m$)
- ML: radiance multiplicative scaling factor
- AL = radiance additive scaling factor
- Q_{cal} = quantized calibrated pixel value (DN)

This step transforms the original satellite data into radiance units $W/m^2/sr/\mu m$(Environmental Earth Sciences study).

Step 2: Conversion of Spectral Radiance to Brightness Temperature

The at-sensor radiance was then converted into at-sensor brightness temperature using the following formula: Kelvin (K) to Celsius (^oC) Degrees

BT = K2 / In (k1 / Lλ + 1) - 273.15

Where:

- BT: brightness temperature (Kelvin)
- K1 and K2 = calibration constants specific to the sensor
- Lλ: spectral radiance

Brightness temperature is the temperature of an equivalent blackbody that would produce the same radiation as that observed by the sensor.

Step 3: Estimation of Land Surface Emissivity

Surface emissivity (ε) was retrieved through the Normalized Difference Vegetation Index (NDVI) method. Emissivity is a critical variable for LST calculation since most of the natural surfaces are not considered as black bodies (Zhao *et al*., 2020). NDVI was computed as follows: NDVI = NIR - Red NIR + Red NDVI = {NIR - Red} {NIR + Red} NDVI=NIR+RedNIR-Red

Where:

- NIR near-infrared band
- Red = red band

The NDVI data was used to derive fractional vegetation cover and emissivity.

Step 4: Land Surface Temperature Calculation

The last step in determining the final land surface temperature was applying the emissivity corrected equation: LST = BT/ (1 + (λ * BT / c2) * ln(E))

Where:

- LST is land surface temperature (°C)
- BT: brightness temperature (Kelvin)
- λ = wavelength of emitted radiance
- ρ\rhoρ = physical constant (1.438×10^{-2} mK)

This adjustment takes into account land surface emissivity and changes the brightness temperature to surface temperature (Sustainability Journal method).

Spatial Analysis

Spatial analysis of LULC classes with LST was carried out using the Geographic Information System (GIS) technique. In this, an overlay analysis was done to find out the effect of different land cover classes on the surface temperature. The surface temperature values in built-up and bare area usually found high as these areas contain less moisture and have less evapotranspiration processes as compared to vegetation and water body which have a cooling effect.

Data Visualization and Statistical Analysis

The spatio-temporal variation of LULC and LST was examined through maps, graphs, and tables. The minimum, maximum, and mean values of temperatures were examined for the time period to analyze the trend of temperature. The spatio-temporal variation of urban thermal environment could be analyzed at a detailed level with the support of GIS and remote sensing, which could provide useful input for planning and policy-making.

RESULTS AND DISCUSSION

Land Use and Land Cover (LULC) Dynamics (2015–2025)

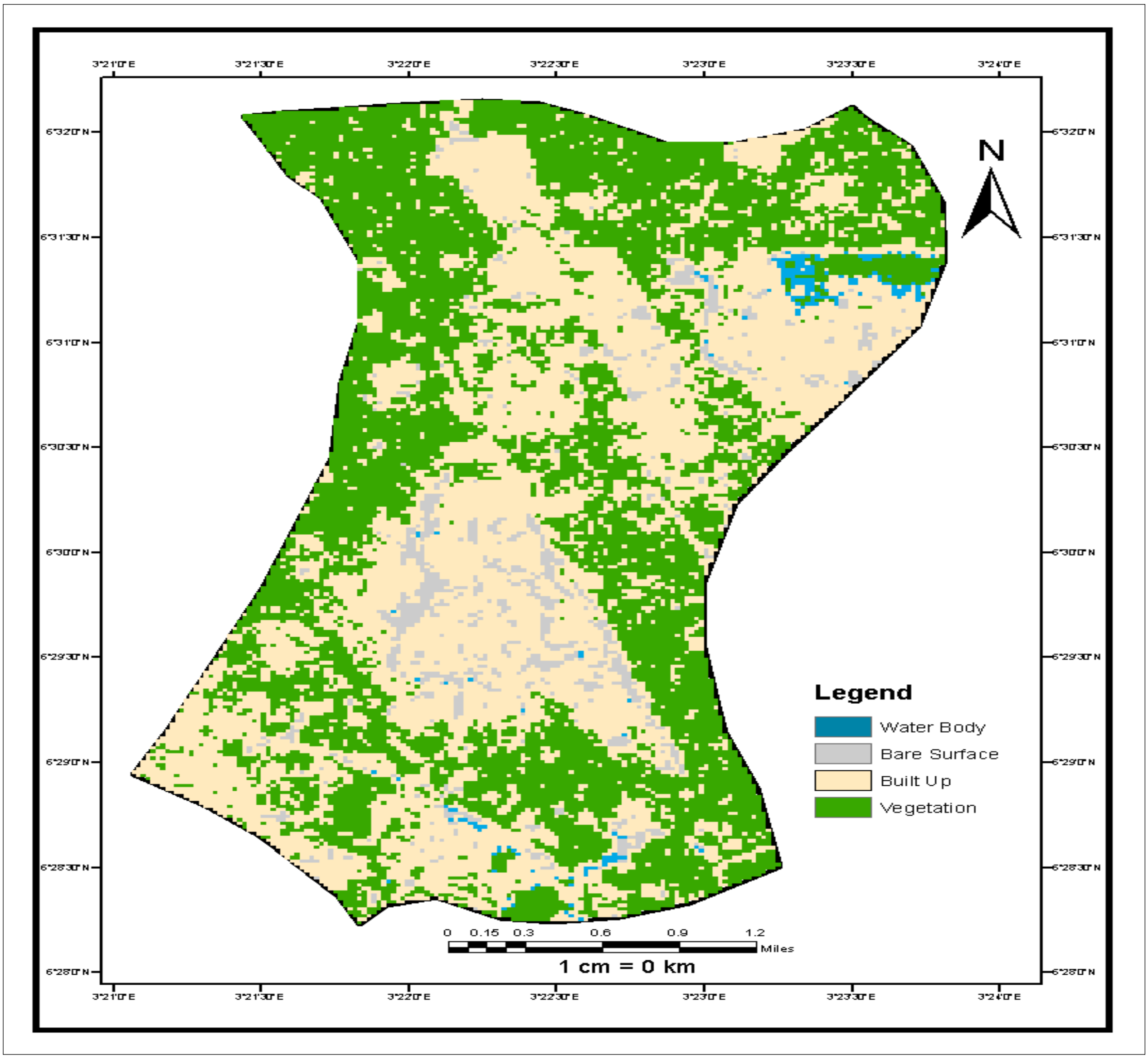

Figure 3: LULC Map of Lagos Mainland 2015

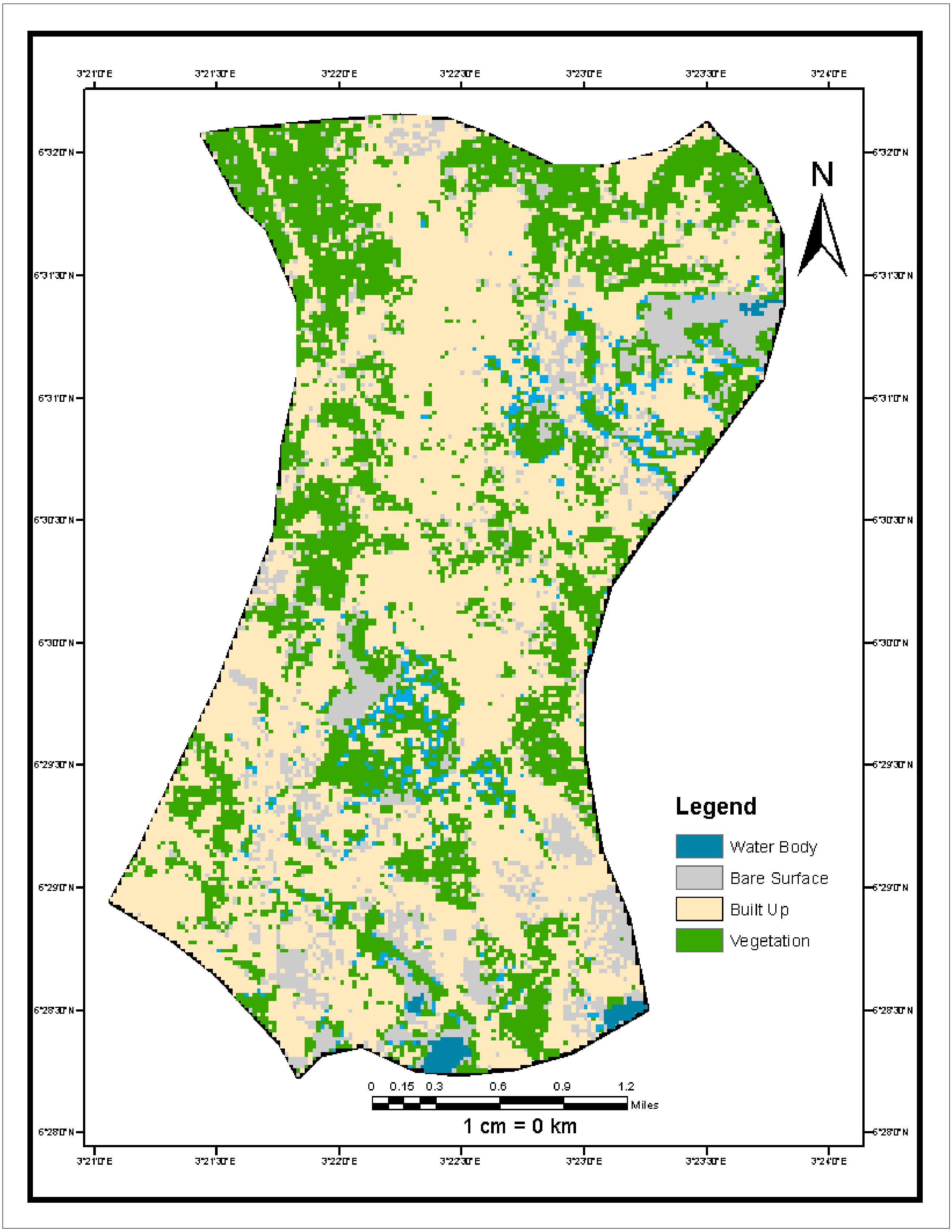

Figure 4: LULC Map of Lagos Mainland 2020

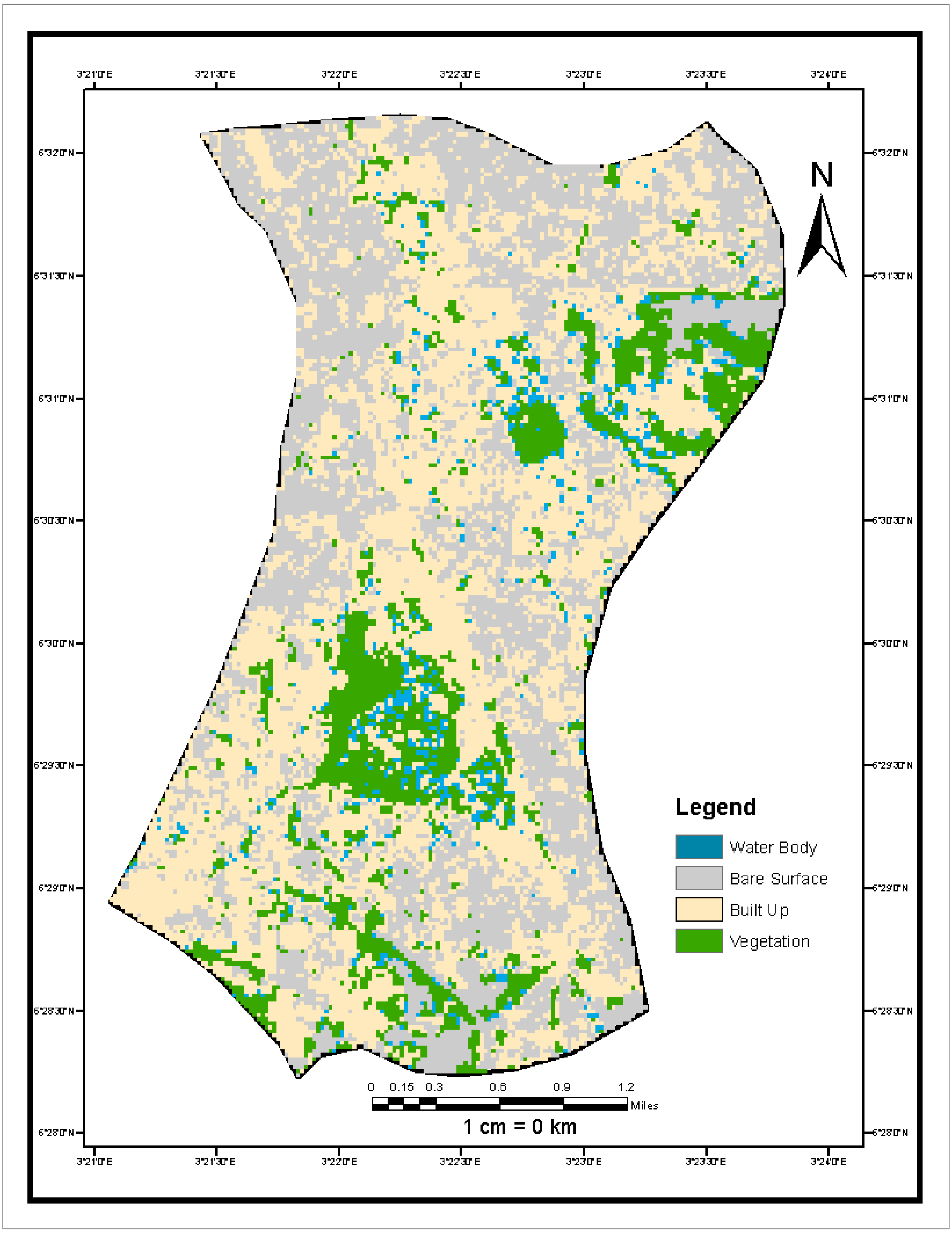

Figure 5: LULC Map of Lagos Mainland 2025

Table 1: LULC of Mainland Lagos 2015 - 2025

LULC_2025	AREA_2025	Area_2015	Area_2020
Water bodies	69	18	14
Built Up	1067	1086	889
Vegetation	308	1065	1311
Bare surface	823	97	52
Total	**2267**	**2266**	**2266**

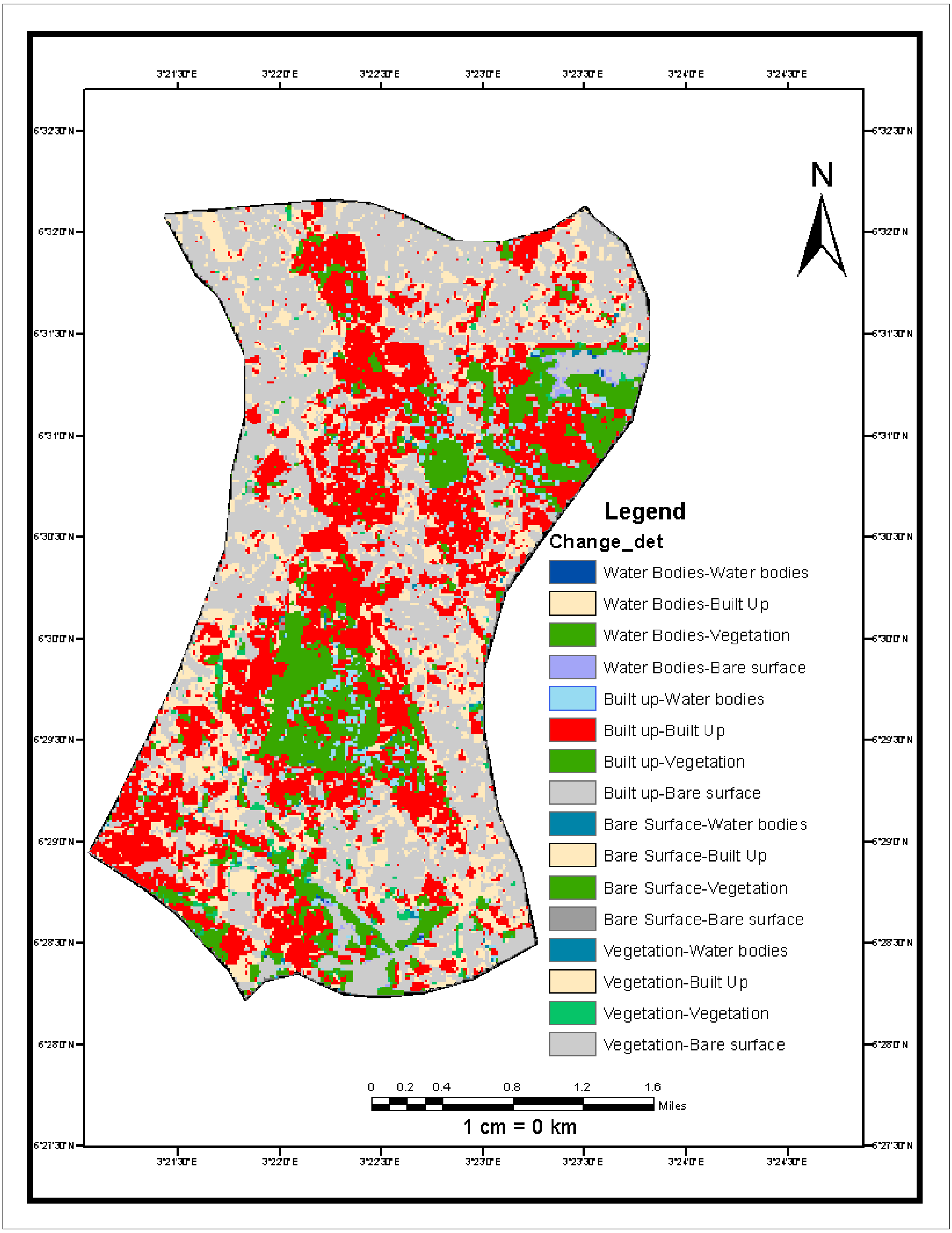

Figure 6: Change Detection Analysis of Mainland 2015 -2025

Table 2: Mainland Detected Changes 2015-2020

Change Detection	Area (ha)
Bare Surface-Bare surface	2.646811
Bare Surface-Built Up	27.978108
Bare Surface-Vegetation	62.072473
Bare Surface-Water bodies	4.111997
Built up-Bare surface	136.218247

Change Detection	Area (ha)
Built up-Built Up	678.738866
Built up-Vegetation	211.056148
Built up-Water bodies	58.05144
Vegetation-Bare surface	677.263925
Vegetation-Built Up	357.965335
Vegetation-Vegetation	22.792435
Vegetation-Water bodies	4.983875
Water Bodies-Bare surface	5.003163
Water Bodies-Built Up	0.271799
Water Bodies-Vegetation	11.373587
Water Bodies-Water bodies	1.218021
Grand Total	**2261.74623**

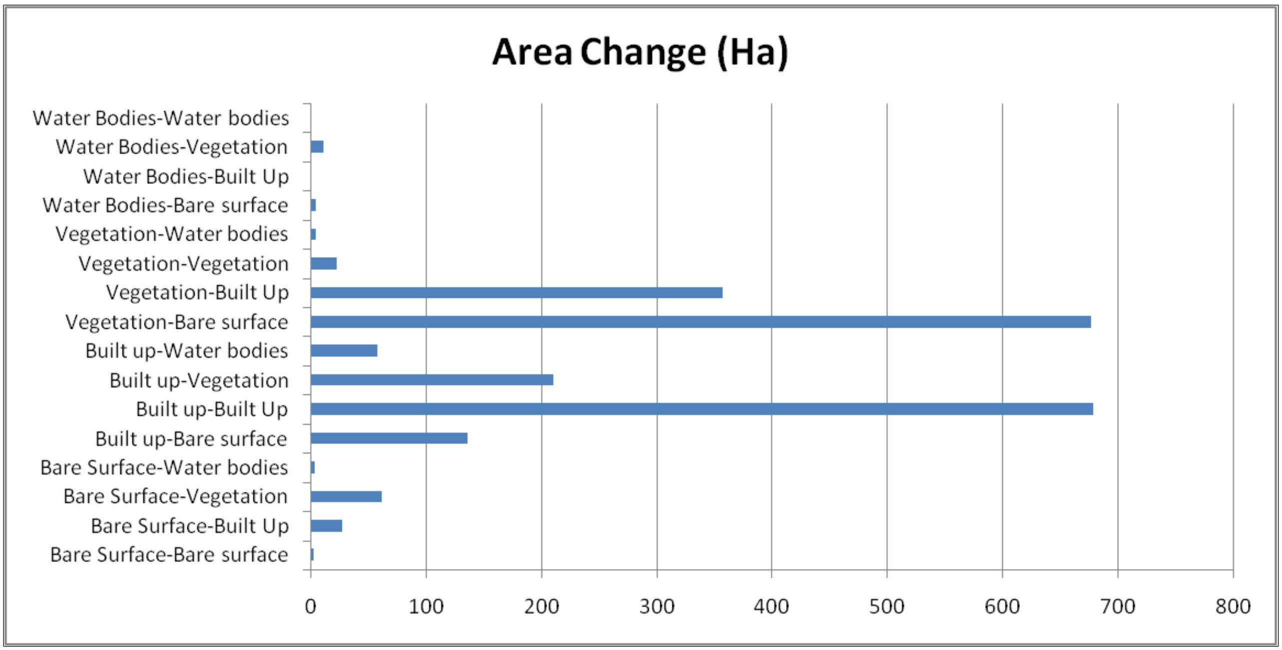

Figure 7: Chart Representation of Mainland 2015 -2025 Change Detection

Spatial analysis showed that there is significant land use and land cover change in the study area (Lagos Mainland) within the time frame of this research. The LULC result shows that there is an increasing trend of built-up and bare areas with a relative decrease in vegetation from 2015 to 2025. The vegetation decreased sharply from 1065 ha in 2015 to 308 ha in 2025. Built-up areas dominate the study area for the entire duration of the research. However, bare area increase rapidly from 97 ha in 2015 to 823 ha in 2025. The increase in the area of built-up and bare surfaces suggest that the region is undergoing intensive infrastructure and road constructions and residential and commercial developments. The similar trend was also observed in other fast growing cities, where natural land was gradually converted into impervious areas (Liu *et al*., 2024).

Moreover, the results of the change detection analysis show that significant conversions took place from vegetation to built-up and bare areas, indicating considerable alterations to the urban environment that were primarily caused by urbanization. These conversions are known to be one of the most significant factors in the environmental changes occurring in urban areas (Dahy *et al*., 2025).

Spatiotemporal Variability of Land Surface Temperature

The LST results showed significant changes in the temporal patterns within Lagos Mainland from 2015 to 2025. It was evident from the minimum, maximum and mean temperature values that thermal heterogeneity is increasing in the study area.

Table 3: LST of Mainland Lagos between 2015 to 225

LST 2015			LST 2020			LST 2025		
Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
30.3299	44.2539	39.235	17.9535	31.8754	27.605	30.4676	47.2774	41.22

The mean LST values were:

- 2015: 39.24 °C
- In 2020, it was 27.61 °C.
- 2025: 106.2 °F

The results revealed that there is a significant rise in the surface temperature from 2020 to 2025. This implies that the thermal regime of the region due to urban growth has become more severe. The spatio-temporal analysis of the temperature pattern revealed that the higher temperature classes were mostly located on the built-up and bare lands, whereas the lower temperature classes were mostly found on the vegetation and water body. This is as expected as several research outcomes have already revealed that LST is higher on the built-up area compared to the vegetated area as the impervious surfaces of the urban environment trap the incoming solar radiation (Ahmad *et al.,* 2024). Moreover, the long-term urban heat research has shown a positive association of built-up with the urban temperature and UHI intensification (Akhter *et al*., 2025).

Relationship between LULC and LST

The results of the overlay analysis of LULC and LST maps depict that there is a clear spatial relationship between LULC classes and surface temperatures. Built-up land is seen to be the warmest class with a higher surface temperature, whereas bare land and vegetation have a relatively low temperature. The variations in surface temperature of the LULC classes are due to the physical characteristics of LULC classes. Built-up surfaces such as pavement, buildings, and roofs have low albedo and low evapotranspiration (i.e., are impervious), which results in high temperature. In contrast, the surfaces with green cover have low temperature due to evapotranspiration and shading effects. Previous studies have reported a negative relationship between NDVI and LST (Vegetation index and Surface temperature), whereas the NDBI (Built-up index) is positively correlated with LST (Singh *et al*., 2025).

It has been also found recently that the fast growth rate of impervious areas plays an important role in rising the thermal stress in the cities (Rahman *et al*., 2026).

Accuracy Assessment

To validate the LULC classification, a confusion matrix was constructed, which cross-tabulates the classified data against reference data. Accuracy assessment is a critical component in remote sensing analysis because it provides a measure of how well the classified data matches the reality on the ground (Cheng *et al*., 2019).

Confusion Matrix

Reference Data	Built-up	Vegetation	Bare Surface	Water Body	Row Total
Built-up	48	3	2	1	54
Vegetation	4	46	3	2	55
Bare Surface	2	3	44	1	50
Water Body	1	1	2	37	41
Column Total	55	53	51	41	200

Accuracy Metrics

- The total accuracy is 87.5%
- Kappa Coefficient: 0.84

Although no common agreement exist, the overall accuracy of greater than 85 % and Kappa statistic greater than 0.80 are considered satisfactory for LULC classification, showing excellent agreement between classified and reference data.

LST–LULC Statistical Correlation Analysis

For the numerical evaluation of the relationship between land cover classes and thermal data, a correlation analysis was applied.

Correlation Results

The results indicate that there is a strong positive correlation between built-up areas and LST. This suggests that urban surface has the greatest influence on the relatively high surface temperatures. Bare surfaces also had a positive correlation with LST, which is relatively lower compared to that of the built-up areas. On the other hand, a strong negative correlation was detected between vegetation cover and LST, suggesting that the surfaces covered with greenery significantly lowered the LST. Water bodies also appeared to have a cooling effect. These results are consistent with the existing body of urban climate literature, which indicates that urban surface features such as vegetation are cooling while impervious surfaces are warming (Liu *et al*., 2024; Singh *et al*., 2025).

Environmental Implications

The finding of this study which indicates the expansion of built-up area with simultaneous increase in LST shows that the thermal condition of Lagos Mainland is worsening. Future expansion of the urban area without environmental considerations will further exacerbate the UHI effect with its attendant consequences on health, energy consumption, and environmental sustainability. Therefore, planning scenarios such as investment in green infrastructure, urban tree planting, and maintaining linear vegetation forms are highly essential for mitigating UHI and improving urban climate.

CONCLUSION

This study investigated the spatio-temporal changes of land use/land cover (LULC) and its impact on land surface temperature (LST) in Lagos Mainland, Nigeria from 2015 to 2025 using high-resolution GIS and remote sensing data. The results indicate that the area has witnessed massive land cover change, mainly as a result of extensive urbanization and infrastructure growth. The LULC dynamic analysis revealed that the vegetation has decreased sharply during the study period whereas the built-up and bare land have increased significantly. The vegetation has decreased from 1065 ha in 2015 to 308 ha in 2025, whereas the bare land has increased sharply from 97 ha to 823 ha between 2015 and 2025. This is a common signature of fast expanding metropolitan cities in developing countries (Seto *et al.,* 2012). The results of LST show that there is a considerable spatial and temporal variation throughout the study region. The higher temperature values were found in the built-up and bare land use classes, whereas the lower temperature values were found in the vegetation and water classes. A significant rise in the thermal signatures has been observed from the mean LST values especially from 2020 to 2025 which suggests an enhancement in the degree of urbanization to the thermal environment.

Statistical correlation analysis showed that land cover characteristics were more statistically correlated with the LST. A very strong positive relationship was found between built-up and LST, while a significant negative association was seen between vegetation and LST, suggesting the impact of cooling the urban thermal environment. These findings are in line with previous studies suggesting that changes in urban areas and the reduction of green spaces are the major driving factors for the urban heat island (UHI) effect (Zhou *et al*., 2019; Santamouris, 2015).

Generally, the study shows that the swift urbanization of Lagos Mainland has caused significant environmental consequences through the reduction of the vegetal cover and the increase of the surface temperature. The results of this study are expected to contribute to the understanding of the spatio-temporal aspect of the urban thermal environments and to the implementation of the sustainable land use planning strategies in order to reduce the negative impacts of the urban heat island.

Recommendations

As a result of this research, recommendations are made to ensure sustainable urban planning and to minimize the thermal effects of rapid urban growth in Lagos Mainland.

i. Urban Green Infrastructure Development

Accordingly, urban and environmental authorities should consider incorporating green infrastructure (e.g., urban forest, parks, green roofs, vegetated corridors) into urban planning. Green infrastructure can effectively decrease the land surface temperature by means of evapotranspiration and shading, and thus can be used to alleviate UHI intensity (Gunawardena *et al*., 2017).

ii. Protection and Restoration of Urban Vegetation

There is a need to conserve the existing green spaces and revegetate the denuded areas in Lagos Mainland. Urban vegetation conservation policies can go a long way to ensure ecological balance and enhance the microclimatic condition of the urban area.

iii. Climate-Sensitive Urban Planning

Policies for urban planning should include climate-sensitive design techniques such as cool materials, permeable pavements, and other sustainable urban planning practices to minimize the urban heat island effect and reduce the amount of heat that is absorbed (Santamouris, 2015).

iv. Integration of Remote Sensing in Urban Monitoring

Finally, remote sensing and GIS technologies are recommended to be adopted in the urban environmental monitoring systems in order to enable the regular monitoring of land use changes and thermal conditions. It has been confirmed that remote sensing data are a cost-effective and reliable means for urban environmental planning and management (Weng, 2012).

v. Future Research Directions

The future research should use the higher spatial resolution data, time series climate data and advanced modeling methods to simulate the UHI effect, and add socioeconomic and demographic data to analyze the underlying causes and effects of urban land use changes.

DECLARATION

Consent to Publish: All authors reviewed and approved the final manuscript to be published.

Consent to Participate: Not applicable.

Ethics approval and consent to participate: Not applicable.

Funding: No funding was received for conducting this.

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

Availability of Data and Materials

The data were collected as primary data through a six-month field survey (household waste collection, sorting, and weighing) in Aba Urban, Abia State, Nigeria, between 2024 and 2025. The raw data are available from the corresponding author (Onuegbu, F.E. onuegbu.francis@abiastateuniversity.edu.ng) upon reasonable request.

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