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Impact Assessment of Urban Heat Island on Land Use/Land Cover in Owerri Metropolis Using Geospatial Technique

Baywood Cecilian Nkechi[1*], Alabi Babatunde[2*], Baywood Princess Dera[3], Ohamaigo Daniel[4]

[1,2,4]*Department of Surveying and Geo-Informatics, Federal University of Technology, Owerri, Nigeria*
[3]*Abia State University UturuAbia State*

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ABSTRACT
As urban areas like Owerri Metropolitan continue to expand due to changes in government policies, they face significant environmental challenges, including the development of urban heat islands (UHIs). This study explores the relationship between land use/land cover (LULC) dynamics and the emergence of UHIs in Owerri Metropolitan, which includes Owerri West, North, and Municipal areas. Using multi-temporal Landsat imagery from 2003 to 2023 at 10-year intervals, supervised classification in QGIS 3.15 was employed to categorize land cover into water bodies, built-up areas, vegetation, and agricultural land. The Land Surface Temperature (LST) for each year was derived from thermal infrared bands and analyzed in ArcGIS 10.5.The results show significant changes in land use, with built-up areas increasing from 146.7 km² in 2003 to 254.6 km² in 2023, while agricultural land decreased from 244.7 km² to 153.3 km² during the same period. In 2003, agricultural land was dominant, but by 2013 and 2023, built-up areas became the largest land cover type. The most extensive UHIs were observed in the northern part of the study area, expanding significantly by 2023 from the city center towards the North and Northeast. Temperature variations indicated that built-up areas had the highest average temperature of 29.5°C in 2023, with the peak temperature recorded in 2017 at 32.04°C.This study demonstrates the effectiveness of satellite thermal data and geospatial tools in analyzing the impact of LULC dynamics on the intensity of urban heat islands, providing essential insights for urban planning and environmental management in rapidly urbanizing regions.

KEY WORDS: Geospatial, Land Surface Temperature, Urban Heat Island, Regression analyses and Dynamics.

I. INTRODUCTION

Climate change is one of the most significant environmental factors influencing ecosystems and human daily life. A related phenomenon, Urban Heat Island (UHI), significantly affects millions of people worldwide, particularly in rapidly urbanizing areas. UHIs occur when urban areas experience elevated temperatures compared to their rural surroundings due to factors such as increased solar radiation absorption by built surfaces, reduced vegetation, and limited cooling mechanisms (Jabbar et al.,2023). This phenomenon has broad implications, including adverse effects on human health, energy consumption, and the overall quality of urban life(Enete et al., 2013). There is a direct correlation between the intensity of UHIs and the occurrence of heat-related illnesses and fatalities, emphasizing the importance of addressing this issue in urban planning. The process of urbanization, defined as the conversion of land for population and economic growth, is a key driver of UHI formation(Sharma et al., 2021). Urban surfaces, such as buildings and roads, absorb more heat than natural land covers, which exacerbates local climate conditions. The rapid growth of cities, especially in developing countries like Nigeria, has led to widespread land use and land cover (LULC) changes. In Owerri metropolis, these changes, driven by industrialization and economic development, have contributed to increasing urbanization and the intensification of UHI effects. Understanding the relationship between land cover and UHI formation is essential for reducing these impacts and promoting sustainable urban growth. Geospatial techniques, particularly satellite remote sensing (e.g., Landsat and MODIS), are crucial for analyzing land cover changes and their thermal effects (Lu et al.,2014 and Weng 2012). Poor adherence to urban planning regulations has further compounded the problem. Anyaegbu et al. (2015) examined the impact of Urban Heat Islands (UHIs) and land cover in Owerri Municipal, Nigeria, using geospatial techniques. With urbanization on the rise, Owerri faces increasing UHI challenges, which present environmental and health risks. The study emphasizes the importance of understanding the relationship between land cover changes and UHI formation to address these issues. Owerri's rapid urban expansion, replacing natural and agricultural areas with built-up spaces, has led to significant thermal effects. Geospatial technologies, such as remote sensing and Geographic Information Systems (GIS), have emerged as effective tools for analyzing LULC changes and assessing UHI impacts. Satellite data, such as Landsat imagery, combined with GIS, can provide valuable insights into the spatial and temporal dynamics of UHI and LULC. Adegoke et al. (2019) explored Urban Heat Island (UHI) and land cover dynamics in tropical urban areas, including Nigeria, using remote sensing data to analyze UHI patterns across major cities. Their comparative study enhances the understanding of UHI behavior in tropical climates. Okoro et al. (2019) and Osuji and Okoro (2021) utilized Land Surface Temperature (LST) data to map the spatial distribution of Urban Heat Island (UHI) intensity in Owerri. Their research revealed significant UHI effects, with temperatures ranging from 2°C to 5°C on average and hotspots exceeding 7°C in densely built-up areas. The research highlighted the thermal stress residents face, particularly in urban cores, and emphasized the value of geospatial techniques in modeling and predicting UHI dynamics to address urban heat challenges. Opara et al. (2018) also used remote sensing and GIS techniques to assess land cover changes in Owerri, focusing on the expansion of impervious surfaces and its impact on temperature variations. The study provides valuable insights into how urbanization affects the local climate.This study seeks to utilize these technologies to analyze the impact of UHI on the LULC of Owerri metropolis, highlighting the importance of the relationship between UHI, LULC changes, and urban temperature variations for effective urban planning and climate adaptation strategies. Given the ongoing trends of rapid urbanization and the associated environmental challenges, it is crucial to explore the impacts of UHIs, particularly in growing cities like Owerri. This research will provide insights into the extent of UHI effects and offer data that can inform policies to mitigate their adverse consequences.

II MATERIALS ANDMETHODS

2.1 Study Area

The area of study is Owerri metropolis of Imo State which is geographically located in the South East region of Nigeria, in the rainforest belt of West Africa. Owerri, the capital of Imo State, is precisely located between latitudes $5^0$24’N and $5^0$33’N and longitudes $6^0$58’E and $7^0$06’E as shown in figure 1. Owerri is basically drained by River Nworie and River Otamiri. The geology of Owerri shows that it lies within the coastal plain sands of the Benin Formation. More than fifty percent of the Imo River Basin is covered by the Benin Formation which is made up of sands of clay and sandy clay. The vegetation of the area is dominantly tropical rainforest with herbaceous plants forming the forest floor while trees form the canopies and the climate of the area is a tropical wet climate or monsoon climate according to the Koppen-Geiger weather classification (Beck et al., 2018) characterized by high temperature and humidity.

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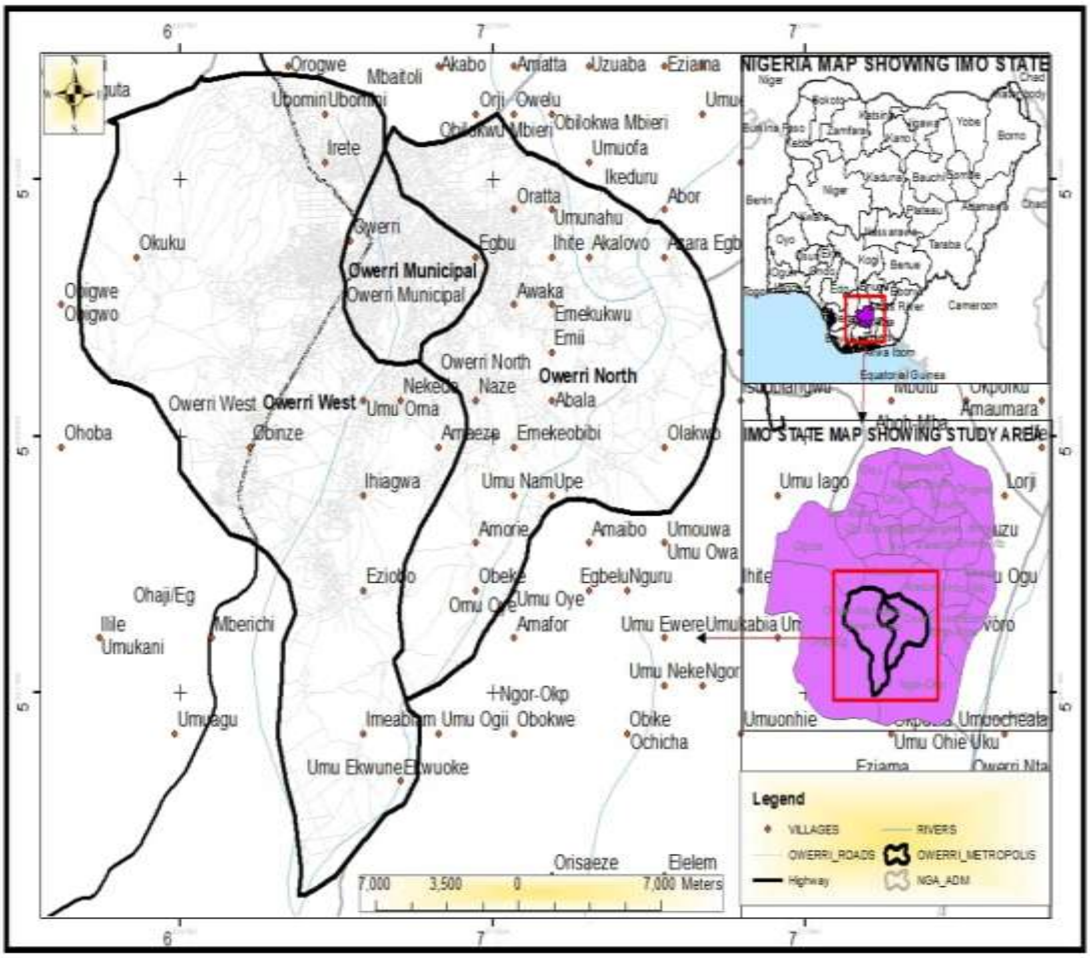

Figure 1: Study area map of the area

2.2 Materials

Table 1showsthedifferentdatasetsusedforthis studyandtheirsources

S/N	DATA	Acquisition Date	Spatial Resolution(m)	Source
1	Landsat 7 ETM+	**2003**	**30**	U.S.GeologicalSurvey(USGS)
2	Landsat 7 ETM+	**2013**	**30**	U.S.GeologicalSurvey(USGS)
3	Landsat 9 OLI	**2023**	**30**	U.S.GeologicalSurvey(USGS)
4	Administrative Map of Nigeria			OSGOF

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2.3 Methods

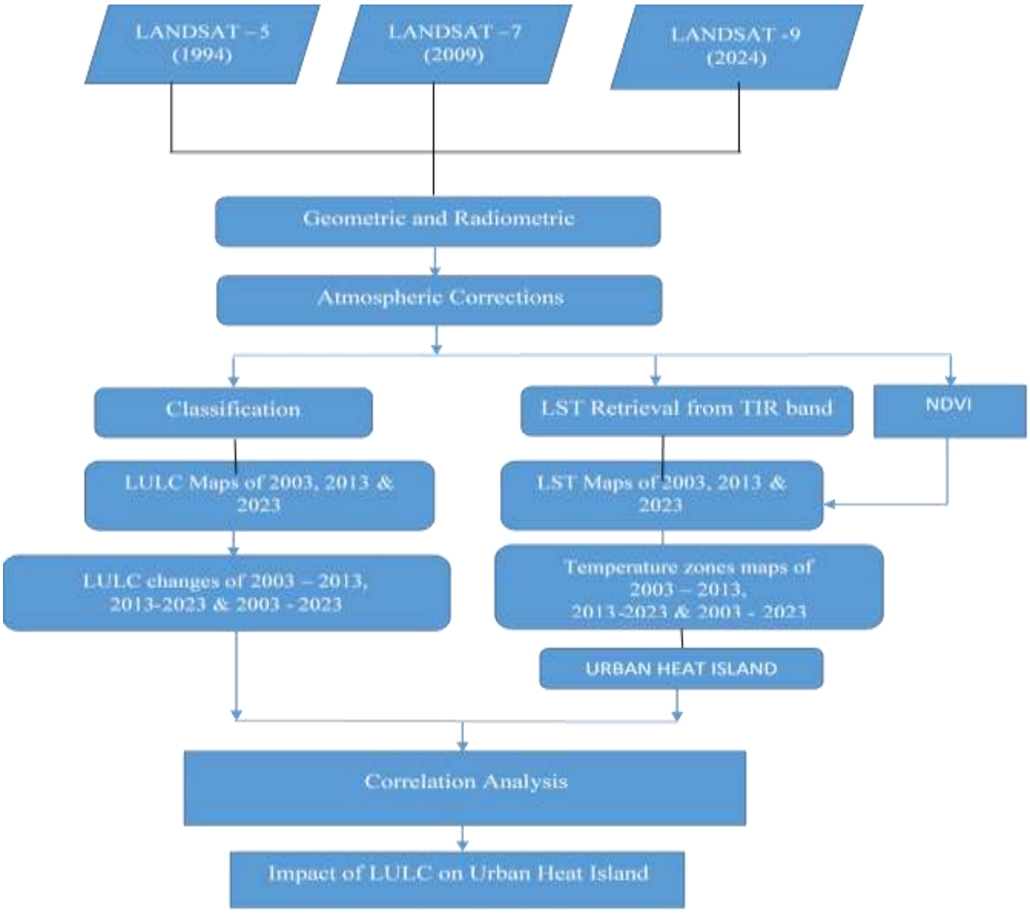

Figure 2: Methodology flow chart

Source: The Author

2.3.1 Calculation of Normalized Difference Vegetation Index (NDVI)

Landsat 7 and sentinel data was used to calculate the normalized different vegetation index (NDVI) for 2003, 2013 and 2023 respectively. This is because vegetation affects the thermal state and increases thermal fluctuations. The near infrared and red bands of each data are used to calculate the NDVI of the using sentinel data. The formula was used to determine NDVI. Otherwise, the equation (1).

$NDVI=\frac{Red\_band - NIR\_band}{Red\_band + NIR\_band}$...[1]

Where SWIR denotes Band 5 (Landsat 7) and Band 6 (Sentinel) and NIR denotes Band 4 (Landsat 7) and Band 5 (Sentinel).

2.3.2. Land Surface Temperature (LST) Retrieval.

One of the key parameter in study global climate change and biophysical is through estimation of LST (Thomas .U. Omali, 2020). To analysis and identify the LST distribution pattern of Owerri Municipal, thermal band (band 6_2) of Landsat 5, band 10 and 11 of Landsat 7 and 9 satellite image was used through digital image processing techniques. Landsat 9 Science Data Users Handbook describes the retrieval method of LST from the thermal band of an image. The process are describe below;

First, spectral radiance was calculated (for Landsat 7 and sentinel 2A) using the following equation [2]:

L=Lmin + (Lmax-Lmin) *DN/255… [2]

Where L is Spectral Radiance, DN is Digital Number, and the values of Lmin and Lmax are documented in the metadata. Conversion of **TOA** to at-satellite brightness temperature in Kelvin T (K), by using the following equation [3]:

$BT=\frac{K2}{[\frac{LnK1}{L}+1]}$…. [3]

Where, K1 and K2 are calibration constants documented in the metadata, BT = Brightness

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Temperature. Then, Kelvin-Celsius conversion was done as follows:

T (ºC) = TB - 273.15.. [4]

The NDVI generated in equation (1) above was used to calculate the proportion of vegetation (PV) using equation (5).

$$PV=square(\frac{[NDVI - NDVI\ min}{NDVImax\ - NDVImin}))..[5]$$

Where PV is portion of vegetation, NDVI is the Normalized Difference Vegetation Index, NDVIMIN is minimum NDVI, and NDVIMAX is maximum NDVI.

2.3.4 Land surface emissivity

Emissivity is the ratio of the radiant energy emitted from a real-world body to that emitted by a black body at the same temperature (Jensen, 2000). The emissivity values are critical parameters for modeling LST from satellite images. Emissivity (ε) is a proportionality factor, which is used to scale blackbody radiance to predict emitted radiance (Planck's law). It is the efficiency of transmitting thermal energy across the surface into the atmosphere. The land surface emissivity was calculated using the equation [6].

ε = 0.004*PV*0.986 … [6]

Where ε is emissivity and PV is represent the proportion of vegetation.

2.3.5 LAND SURFACE TEMPERATURE

Land surface temperatures were derived from geometrically corrected Landsat thermal infrared (TIR) bands as shown in Table 2. The raw digital numbers (DNs) were converted to radiances by applying the calibration coefficients (gains and offsets) specified in the Landsat handbook (Berkowitz et al., 2012). Equation 7 will be used for LST estimation and derivation of the temperature map.

$$LST=\frac{[BT]}{[1+0.00115*\frac{BT}{1.4388}]}*\mathrm{Ln}(\mathcal{E})\ \ ..[7]$$

Where LST is Land Surface Temperature, BT is the Brightness Temperature, and ε is emissivity.

2.3.6 Urban Heat Island (UHI)

Urban heat island is one of the critical factor in the assessment of climate change(Jabbar et al.,2023), its most effective study is for monitoring the thermal variation and heat stress in the urban area (Bijay Halder and Jatisankar Bandyopadhyay,2021).To determine the UHI in urban area the equation Eq. (8) was used;

$$UHI = \frac{Ts - Tmean}{SD} \ldots [8]$$

Impact of urbanisation on UHIs

A linear model in Microsoft Excel 2016 between urban cover-age, LST, and UHI from 2001 to 2021

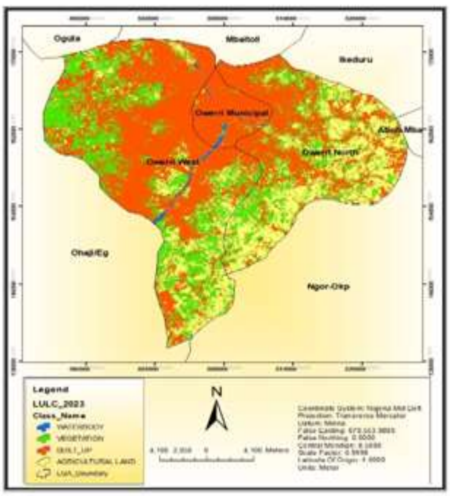
2.3.7 Regression analysis

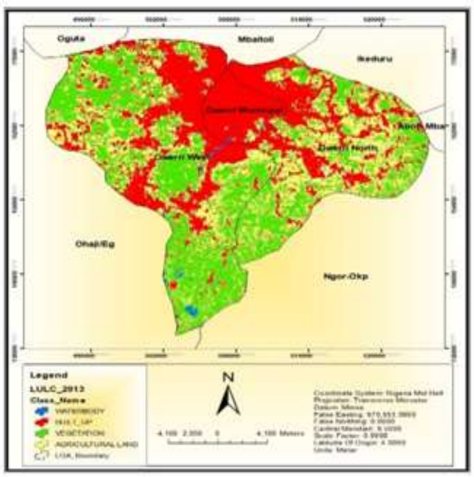
The relationship between the dependent variable (LST) and LULC was determined using Microsoft Excel 2016. Both, the variable wasinform of raster layers. A boundary shapefile of Owerri was used to calculate the percentage of urban and vegetated areas for each year. These LULC percentages was used to determine the relationship between LST and UHIs, the result will be display in form of a graph.

III. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Land use/Land cover(2003 -2023)

TheLand Use/CovermapsofOwerri metropolisarea of Imo statefortheyears 2003,2013, and 2023 are showninfigure 3.





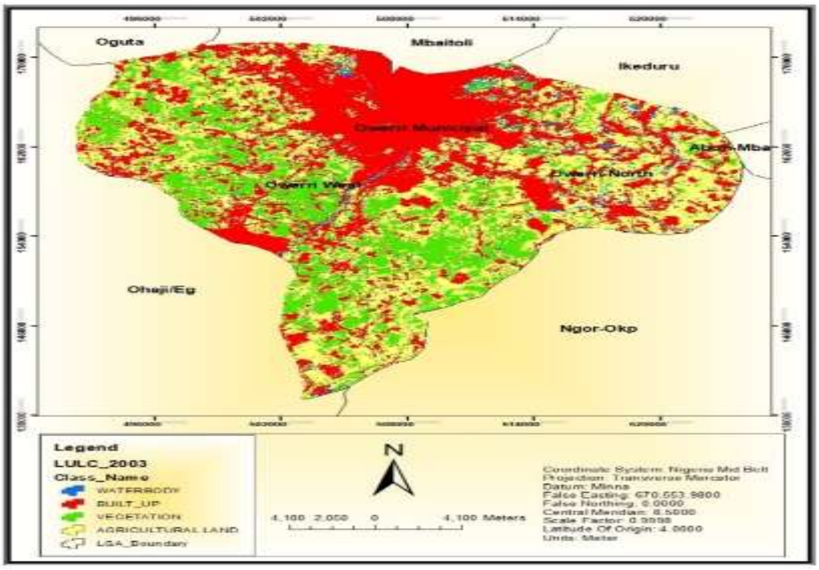


Figure 3: Land use/Land cover map of the study area for (a) 2003, (b) 2013, and (c) 2023

Table 2: Land Use Land Cover Changes Analysis Between 2003-2023

LULC classes	2003	2013	2023	Change Area	Change Area	Change Area
	AREA(Km^2)	AREA(Km^2)	AREA(Km^2)	2013-2003	2023-2013	2023-2003
Waterbody	8.5	5.4	2.8	-3.1	-2.6	-5.7
Built-up	146.7	185.7	254.6	+39	+68.9	+107.9
Vegetation	135.6	175.7	124.8	+40.1	-50.9	-10.8
Agricultural	244.7	168.7	153.3	-76	-15.4	-91.4
Total	535.5	535.5	535.5			

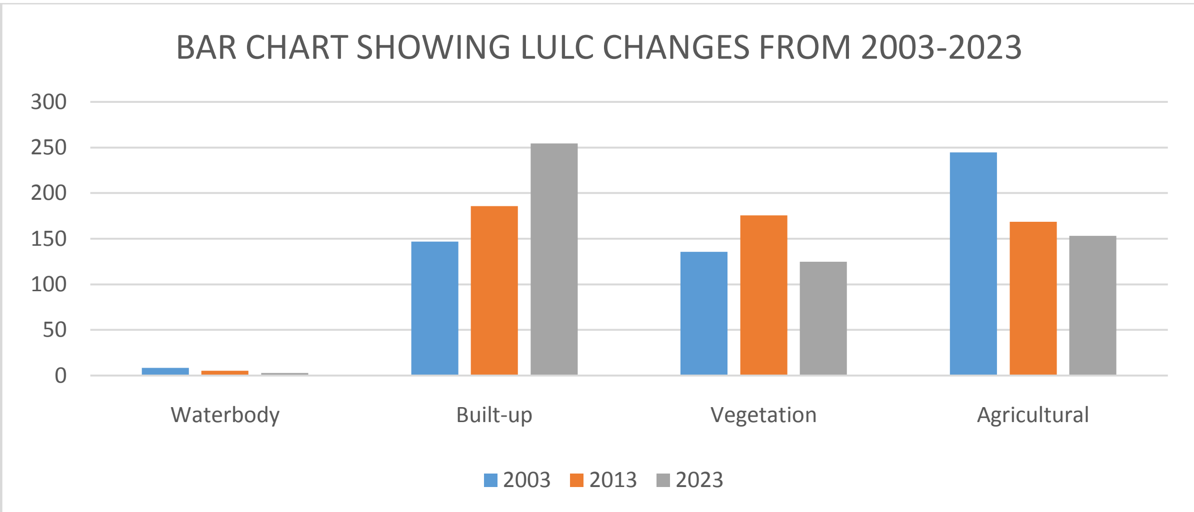


Figure 4: Bar chart showing LULC from 2003-2023

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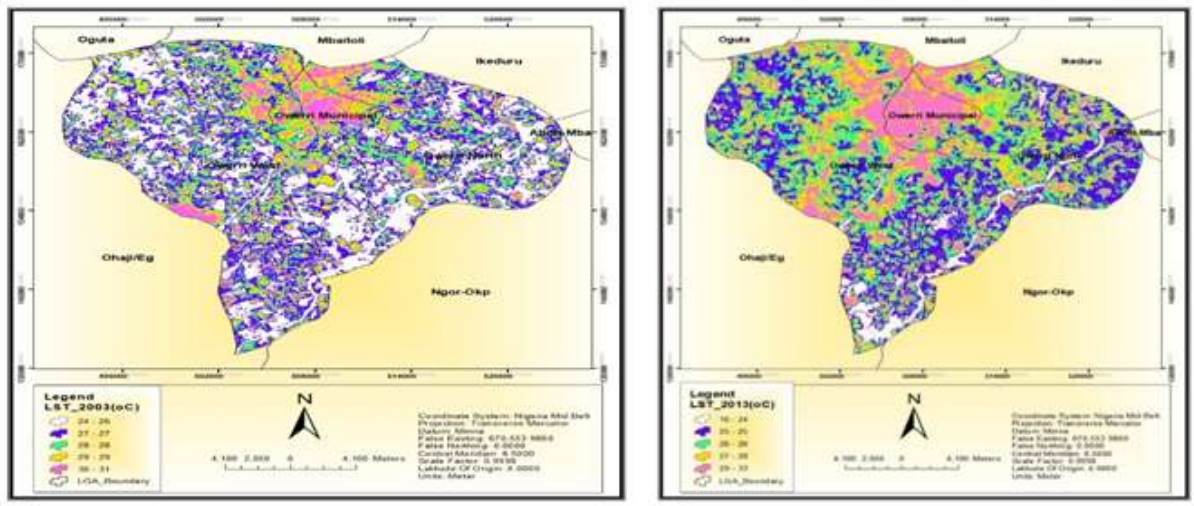
Based on the results derived from Landsat 7 and 8 of from2003to 2023, the images were classified into four classes, built_up, waterbody, vegetation, and agricultural land. Table 2 shows Agricultural land areadecreasedfrom 244.7 km^2 to 168.7 km^2 and further decreased to 153.3km^2 in 2023 which indicated the activities of farming practices in the area. The area occupied by the built-up area rapidly increased from 146.7 km^2to185.7 km^2 in 2003 - 2013 and gradually increased to 254.6 km^2 in 2023. A slightlossofvegetationcovercanbeobservedin2013 and2023 compared to 2003. The built-up area continued to increase while vegetation and agricultural land were reduced drastically, this is attributed to the urban growth of the metropolis. This also reveals that Owerri metropolis has undergone serious development in terms of infrastructures like buildings and roads which have almost the same reflectance from the remotely sensed data.

3.2 **Spatial Distribution of Land Surface TemperatureDistribution(2003-2023)**

TheLSTmapsofOwerri metropolisarea of Imo statefortheyears 2003,2013, and 2023 areshowninfigure (5a,b.c) respectively. Here Tuscan red, green, and whitecolorsindicate the highest, moderate,and lowest temperature classes, respectively in the study area. In 2003 and 2013 areas with the highest LST were concentrated in the Owerri metropolis. But in 2023 the areas with the highest LST have greatly expanded towards northern, eastern, central, and southeast regions of the city following the spatial pattern of urban development, high building density, and paved surfaces as well as high vehicle traffic. The high surface temperatures in urban areas are influenced by various factors, including high energy consumption rates, air-conditioning systems, and emissions from industries and vehicles. Also, urban areas are predominantly characterized by impervious surfaces like concrete, metals, and asphalt on roads, which do not allow for evaporation or transpiration.Additionally, it demonstrates a high capacity for both absorbing and radiating heat similar to blackbodies, resulting in elevated temperatures.



a) b)

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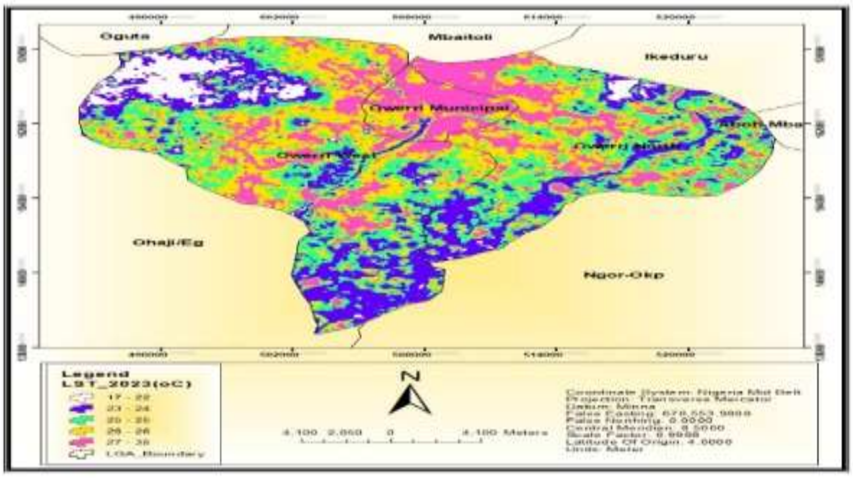
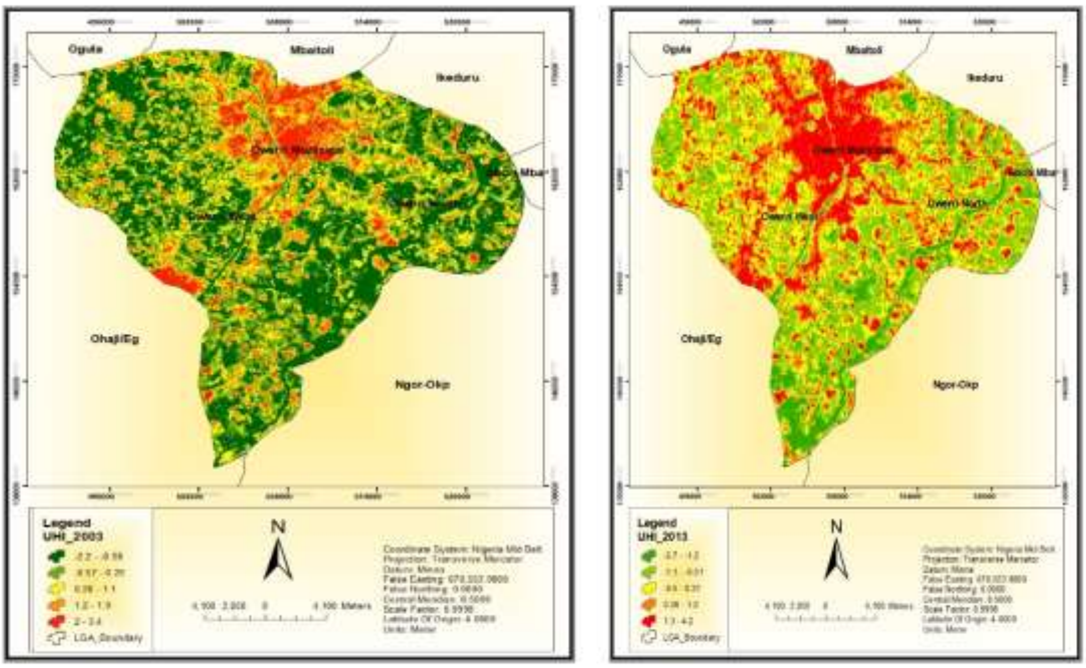


c)

Figure 5: Land Surface Temperature map **of the study area for (a) 2003, (b) 2013, and (c) 2023**

3.3 **Spatial Distribution of Urban Heat IslandDistribution(2003-2023)**

The study's results review that UHI spatial distribution followed virtually the same pattern during the study period (2003-2023). Throughout the study period, the northern part has the highest density of UHI areas, as shown in fig. 6, whereas the temporal pattern of UHI areas has remained consistent across the study period, their intensity has grown toward the northern part of the study area because of the growth of built-up regions and decreasing vegetation. Additionally, the Thermal signatures of each land use land cover studied revealed the average values of surface temperature for each of these land use/cover type is shown in Table 2. The most extensive UHI was distributed in the northern part of the Central Business District, comprising the Owerri municipal, and extended toward Owerri West in 2023 due to urbanization.



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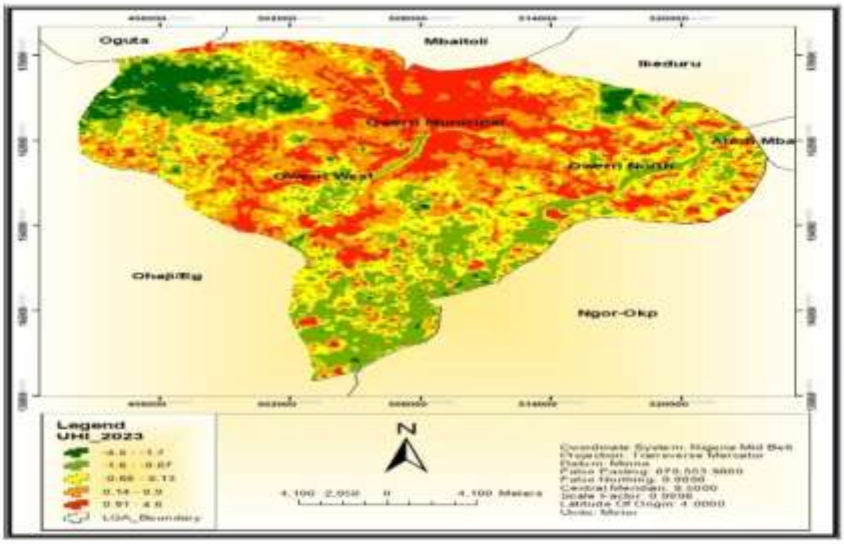

c)

Figure 6: Urban Heat Island map **of the study area for (a) 2003, (b) 2013, and (c) 2023**

3.5 Impact of LULC dynamics on UHI

The study also established that most areas having lower temperatures in 2003 were converted to hot spots in 2013 and hotter in 2023, due to the increase in urbanization over the years and corresponding decrease in vegetation and agricultural land. This signifies that land uses and land cover dynamics may induce changes in the UHI of an area. It went further to establish the relationship between LULC and land surface temperature in the city. It has shown that the surface temperature of the urban environment of Owerri metropolitan center in 2023 and the surrounding has been increasing due to anthropogenic influence on the land use & land Cover. The coverage in the percentage of Urban and vegetated areas within the municipal was observed to be changing from 2003 to 2023. Urban areas have been increasing while vegetation and Agricultural land cover have been decreasing. The LST was increasing with increasing UHI. This is attributed to the fact that the loss of vegetation within the municipality has increased the LST and increased UHIs in the municipality as well (table 3).

Table 3: shows the derived Urban Heat Island for different LULC of the year 2003,2013 and 2023.

S/N	LULC	Max_2003	Max_2013	Max_2023
1	WATERBODY	4.25	2.28	2.21
2	BUILT UP	4.6	4.22	4.10
3	VEGETATION	1.07	2.73	2.52
4	AGRICULTURAL LAND	2.27	3.03	2.81

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4.6 Correlation Analysis between UHI & LULC

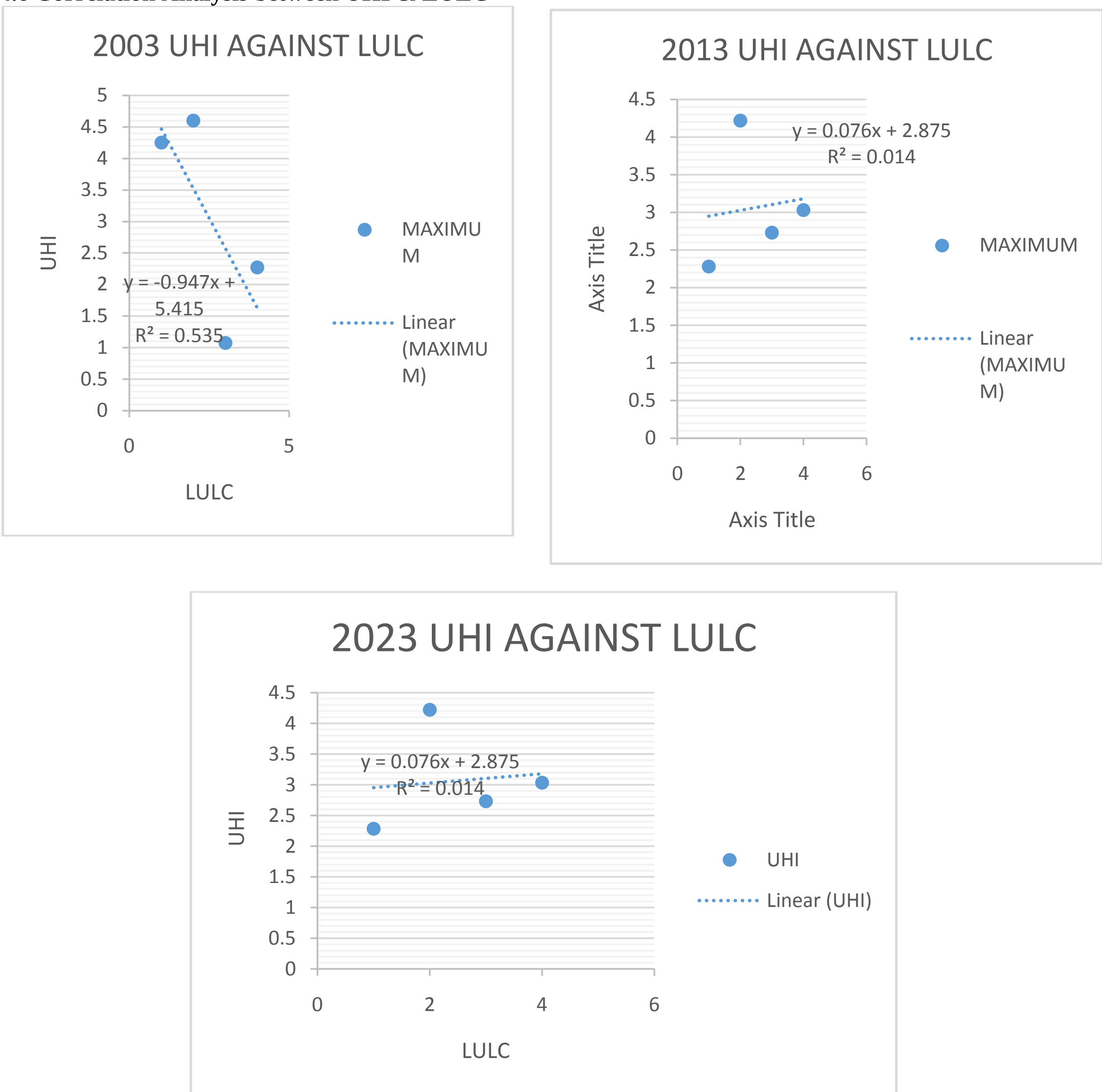

Figure 7: Correlation Analysis of UHI against LULC**for 2003, 2013, and 2023**

III. CONCLUSION

The study highlights the increasing impact of urban development and climate change on land surface temperature (LST) and the Urban Heat Island (UHI) effect in Owerri, Nigeria, over two decades (2003–2023). Using Landsat imagery, it reveals a strong positive correlation between built-up areas and LST, while vegetation shows a negative correlation. Urban expansion has led to a significant increase in UHI, as agricultural and vegetated lands have been converted into urban zones, contributing to rising temperatures. This trend poses risks such as food insecurity due to diminishing agricultural land and adverse environmental effects due to heat concentration in urban areas. The study underscores the utility of remote sensing and GIS techniques in analyzing these changes and stresses the need for better satellite data collection to improve research precision. Moreover, it suggests that incorporating additional environmental factors, such as precipitation and humidity, could enhance future studies and inform better urban planning strategies. Policymakers are encouraged to consider these findings to manage urban growth and mitigate UHI, emphasizing the role of advanced remote sensing technologies in improving monitoring and decision-making for sustainable urban development. From the findings made by the study, the following are recommended:

I. Cities should evaluate LST and UHI to address rising temperatures and human discomfort, with strategies like adhering to urban master plans, creating green spaces, and using reflective materials.
II. Policymakers can mitigate the effects of urbanization by considering environmental factors like precipitation and humidity in their planning decisions.
III. Finally, incorporating green infrastructure, such as rooftop gardens and climbing plants, improves thermal comfort, sustainability, and air quality, fostering a more environmentally conscious urban design.

REFERENCES

[1] Adegoke, J. O., Ajayi, V. O., &Adejumo, A. O. (2019). Urban heat island intensities over major cities in Nigeria. Remote Sensing, 15.
[2] Alkasim, A., Hayatu, A. A., &Salihu, M. K. (2018). Estimation of land surface temperature of Yola, north eastern Nigeria using Landsat-7 ETM+ satellite image. Energy and Power Engineering, 10(10), 449–456. https://doi.org/10.4236/epe.2018.1010028
[3] Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International Journal of Climatology: A Journal of the Royal Meteorological Society, 23(1), 1–26. https://doi.org/10.1002/joc.859
[4] Atuanya, E. I., &Iwu, C. U. (2018). Land use/land cover change and its influence on urban heat island formation in Owerri, Imo State, Nigeria. International Journal of Remote Sensing, 39(13), 4139–4154.
[5] Javed, M., Yogesh, K., &Bharath, B. D. (2008). Estimation of Land Surface Temperature of Delhi Using Landsat-7 ETM +. Journal of Industrial Geophysics Union, 12, 131–140.
[6] Jabbar, H. K., Hamoodi, M. N., & Al-Hameedawi, A. N. (2023). Urban heat islands: a review of contributing factors, effects and data. IOP Conference Series. Earth and Environmental Science, 1129(1), 012038. https://doi.org/10.1088/1755-1315/1129/1/012038
[7] Li, D., Bou-Zeid, E., Oppenheimer, M., & Sailor, D. J. (201 C.E.). Urban heat island impacts on building energy consumption: A review of methodologies and results. Energy and Buildings, 201.
[8] Li, J., Gong, P., Li, X., Zheng, Y., Zhan, Y., & Li, Z. (2019). Identifying key factors influencing the urban heat island effect: A case study of Beijing, China. China. China. Building and Environment.
[9] Lu, D., Wang, S., Xu, T., Mao, Z., & He, C. (2014). Spatiotemporal change of urban heat island effect and its contributing factors in Nanjing, China. China. China. International Journal of Climatology, 34(4), 1236–1249.
[10] Nnadi, E. C., &Eboh, E. C. (2020). Geospatial analysis of urban heat island and land cover change in Owerri Municipal, Nigeria. Nigeria. Nigeria. Journal of Environmental Management.
[11] Ogu, V. N., &Igwe, U. (2021). Assessing the Impact of Urban Heat Island on Public Health in Owerri Municipal, Nigeria: A Geospatial Approach. Nigeria: A Geospatial Approach. Nigeria: A Geospatial Approach. Remote Sensing, 12.
[12] Oke, T. R. (1982). The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society. Royal Meteorological Society (Great Britain), 108(455), 1–24. https://doi.org/10.1002/qj.49710845502
[13] Okwuashi, O., Opara, I. A., &Nwilo, P. C. (2019). Urban Heat Island Assessment in Owerri Municipal, Nigeria, Using Remote Sensing and GIS. Climate, 6.
[14] Opara, I. A., Okwuashi, O., &Egbueri, J. C. (2018). Assessing Land Cover Changes in Owerri, Imo State, Nigeria Using Remote Sensing and GIS Techniques. International Journal of Scientific Research in Science, Engineering and Technology, 4(2), 246–252.
[15] Weng, Q. (2012). Urban heat islands: Are they a major source of regional air pollution? Environmental Pollution, 167(1), 38–44.
[16] Weng, Qihao. (2009). Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. ISPRS Journal of Photogrammetry and Remote Sensing: Official Publication of the International Society for Photogrammetry and Remote Sensing (ISPRS), 64(4), 335–344.

https://doi.org/10.1016/j.isprsjprs.2009.03.007

[17] Weng, Qihao, Lu, D., &Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. Remote Sensing of Environment, 89(4), 467–483. https://doi.org/10.1016/j.rse.2003.11.005

[18] Wong, N. H., Yu, C., & Li, Y. (2017). Urban heat island and its impact on residential energy consumption in megacities of Southeast Asia. Renewable and Sustainable Energy Reviews, 79, 515–534.

[19] Yuan, F., & Bauer, M. E. (2013). Comparison of impervious surface area and land cover composition as predictors of surface urban heat island intensity. Landscape Ecology, 28(10), 1779–1790.

[20] Zhao, W., Liu, S., Xu, Y., & Zhou, W. (2015). Temporal and spatial changes of urban heat island effect and relationship with land-use patterns in Guangzhou, China. China. China. International Journal of Remote Sensing, 36(20), 5303–5322.