

AN ANALYSIS OF THE DYNAMICS OF LAND SURFACE TEMPERATURE ON LAND USE/ LAND COVER IN KANO METROPOLIS, KANO STATE, NIGERIA

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ABSTRACT

The rapid urbanisation and associated land use changes have profound impacts on the local climate and environmental conditions in urban areas. This study aims to analyse the dynamics of land surface temperature (LST) and its relationship with land use/land cover (LULC) patterns in Kano Metropolis, Kano State, Nigeria. The research utilizes remote sensing data and geospatial techniques from multiple sensors, such as Landsat MSS, ETM + and OLI/TIRS, spanning a period of 38years (1984 – 2022), to processed, analysed and investigate the spatiotemporal variations in LST and their drivers. Statistical analyses, such as correlation and regression models, are employed to quantify the associations between LST and LULC variables. Findings show that urban area increased from 7% in 1984 to 32% in 2022, while bare land decreased from 82% in 1984 to 49% in 2022. Vegetation also increased slightly from 11% in 1984 to 19% in 2022. The LST increased with a mean value of 16°C in 1984, 25°C in 2003, and 30.5°C in 2022. Results still revealed a negative correlation between vegetation health and land surface temperature, indicating that as vegetation health declines, land surface temperature increases due to the lack of cooling effects from transpiration while a positive correlation exist between the built-up index and land surface temperature, signifying that as urban areas expand, land surface temperature rises due to the urban heat island effect. The research emphasises the significance of implementing land use planning and management strategies to address the adverse effects of urban heat and improve the urban microclimate. The findings offer valuable guidance for policymakers, urban planners, and environmental practitioners, assisting them in making informed decisions for sustainable urban development and enhancing the residents' quality of life in Kano Metropolis.

Keywords: Land Surface Temperature, Land Use/land Cover, Urban Heat Island, Remote Sensing, GIS, Kano Metropolis, Nigeria.

INTRODUCTION

Land Surface Temperature (LST) is an important measure of energy exchanges between the Earth's surface and the atmosphere. It plays a crucial role in understanding environmental changes and estimating energy transfers. Rapid urbanization has led to the replacement of natural land surfaces with impervious

structures, resulting in increased anthropogenic activity and negatively impacting urban areas. These changes have altered the physical and natural environments, affecting biodiversity, ecosystem functions, and local climate. Nigeria's land use patterns have significantly changed due to population growth and economic expansion, putting stress on the environment. Urban heat islands, where urban areas are hotter than surrounding rural areas, are a result of reduced vegetation and water-pervious surfaces. The Urban Heat Island effect has various impacts, including increased air temperature and altered rainfall patterns. Kano metropolis, a fast-growing city in Nigeria, has experienced significant land use changes and population growth, leading to elevated temperatures. The rise in urban temperature affects human comfort, energy consumption, and can contribute to global warming. Urban areas also face increased air pollution and health risks due to intense heat. The loss of vegetation and land conversion have influenced the local and regional climate in Kano metropolis. To address these issues, this research aims to investigate the relationship between human-induced impacts and land surface temperature changes in Kano and propose measures to mitigate urban heat.

The Study Area:

The study area is located in Kano, Nigeria, between latitudes 11°.52'N and 12°.07'N and longitudes 8°.24'E and 8°.38'E (Figure 1). It is centrally located in northern Nigeria, about 900 kilometres from the Sahara Desert and 1140 kilometres from the Atlantic Ocean. It covers an area approximately 499 km² (Mohammed *et al.*, 2019; Mujahid *et al.*, 2022; Agan *et al.*, 2021). The area consists of six urban and two peri-urban local government areas. The climate is classified as tropical wet and dry savannah, with distinct wet and dry seasons. The wet season usually occurs from June to September, while the dry season lasts from October to May. The average annual temperature ranges from 26°C to 28°C, and the vegetation types are Sahel, Sudan, and Guinea savannah. The drainage pattern is dendritic, primarily running in the north-south direction, with the Jakara and Kano Rivers being the major river systems. The area is predominantly residential but also includes commercial, institutional, and educational land uses. Industrial activities are concentrated in Dakata, Sharada, and Bompai areas. Kano Metropolis is the second-largest industrial and commercial center in Nigeria after Lagos, with a population density of about 20,000 inhabitants per km².

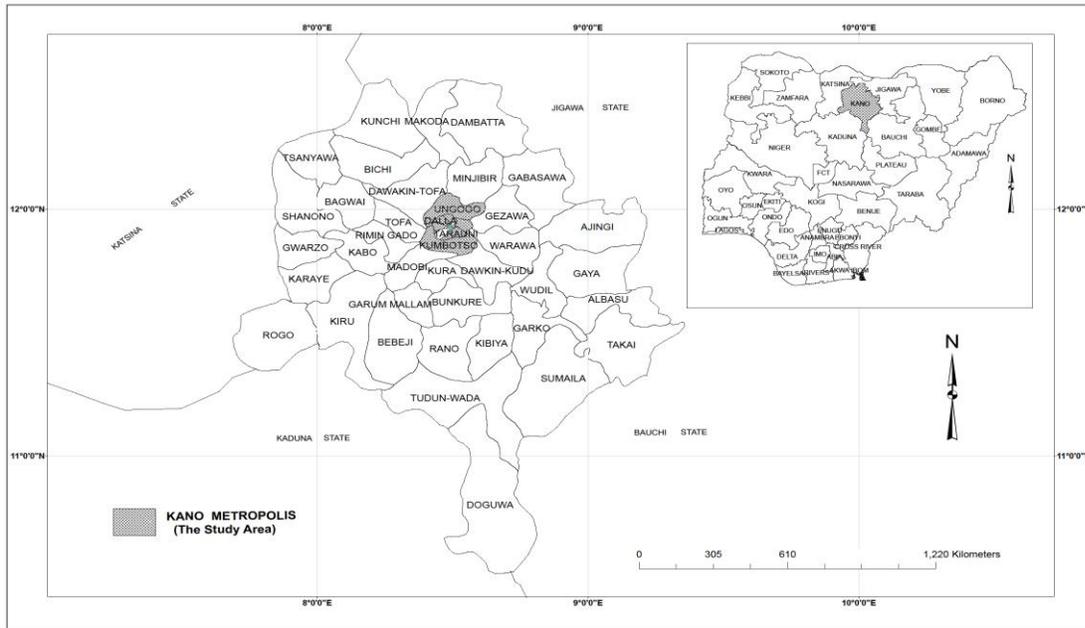


Figure 1.: Kano Metropolis in Kano State
Source: Ministry of Lands and Survey, Kano State

MATERIALS AND METHOD

Figure 2 shows the methodology workflow of the study. The workflow is implemented in order to achieve the aim and objectives

of this research, which includes analysing and understanding land use /land cover change patterns and land surface temperature changes overtime.

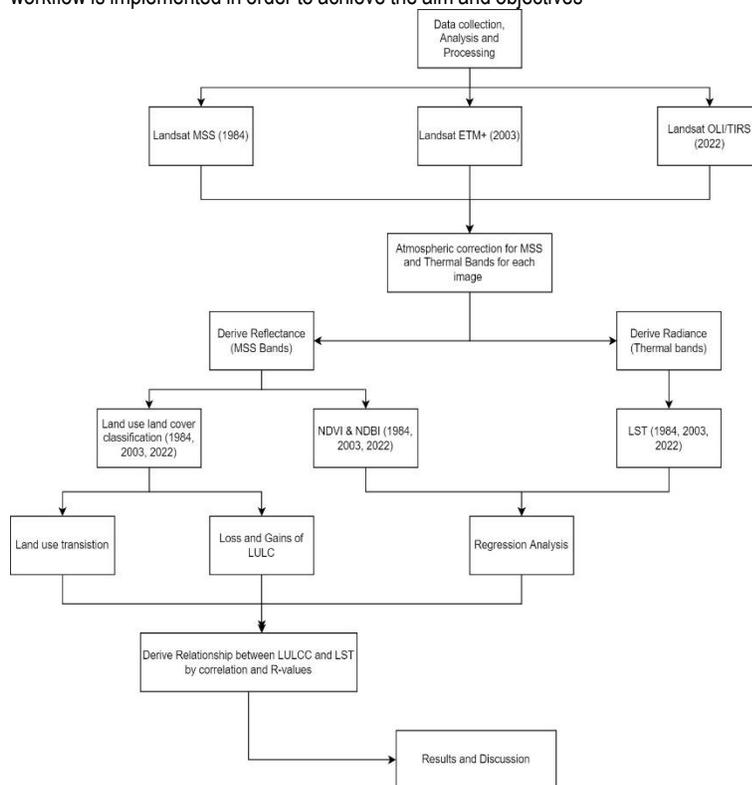


Figure 2.: Methodology workflow

The data type used for this research involves satellite imageries of the years under consideration (1984, 2003 and 2022). Table 1 highlights the data source and image bands used for the analysis.

Table 1: Data Sources and Description

Data (Type)	Band (µm)	width	Source	
Landsat MSS (1984) (raster)	Green (0.52-0.6)	(0.52-0.6)	USGS Explorer	Earth
	Red (0.63-0.69)			
	NIR (0.77-0.9)			
	TIR (10.40-12.0)			
Landsat ETM+ (2003) (raster)	Green (0.52-0.6)	(0.52-0.6)	USGS Explorer	Earth
	Red (0.63-0.69)			
	NIR (0.77-0.9)			
	TIR (10.40-12.0)			
Landsat OLI/TIRS (2022) (raster)	Green (0.53-0.59)	(0.53-0.59)	USGS Explorer	Earth
	Red (0.64-0.67)			
	NIR (0.85-0.88)			
	TIR-1(10.60-11.19)			
Administrative boundary (vector)			Open Source Map	

MSS = Multispectral Scanner, ETM+ = Enhance Thematic Mapper Plus and OLI = Operational Land Image

Table 2: Classification Scheme

Code	Land use/Land cover	Description
1	Agricultural land	Lands used for farming (Plantation, cropland orchard)
2	Built-up land	Lands used for residential, industrial, commercial, etc.
3	Grassland/ forest cover	Lands covered with natural vegetation (any plant species)
4	Bare surfaces	Lands devoid of vegetation, exposed soil
5	Water body	Areas with lakes, rivers, streams.

Source: Umar and Kumar, (2014)

Land Change Transition and Estimation of Loss and Gains

Land change transition looked into conversions of land cover from one class to another within the time period. This was achieved using the Tabulate Area which helps to estimate how much area was changed from one class to another. This result was also used in estimating the loss and gains of each land use class overtime – in essence, area of a land cover lost to another land cover class represent loss. This was produced in forms of tables and graphs.

Derivation of Land Surface Temperature

This was derived from the thermal bands as depicted in Table 1 above. The study made use of mathematical equations shown from equation 1 – 9 (Abidin *et al.*, 2021; Ajayi *et al.*, 2022; Akomolafe *et al.*, 2020; Awuh *et al.*, 2018; Olofin *et al.*, 2022; Şekertekin *et al.*, 2015; Varadarajan and Rajani, 2021). Using the mono-window algorithm, the following steps were followed to generate LST from thermal bands. The first task was conversion of the digital number

Data Preprocessing and Processing

The administrative boundary of the metropolis was used to clip each image band for the prospective years in view before they were mosaic to create a color composite. The clipped images were subjected to histogram Equalization: This technique redistributes the pixel intensities in the image to enhance the overall contrast. It stretches the intensity range, making the dark areas darker and the bright areas brighter thereby enhancing the image contrast and removing obscurity for proper identification.

Determination of Land Use /Land Cover Change

During layer stacking, the Universal Traverse Mercator (UTM) system with WGS84 as a datum were assigned as a preference as far as projection is concerned. The bands of MSS, ETM+ and OLI-TIRS, excluding the thermal band, were considered for Layers stacking. The nature of these different bands had to be considered to decide as to which three band combinations would be most helpful for classification and visual interpretation. False color composite of band 432 was employed for the Landsat MSS and ETM+ while 543 was used for Landsat OLI/TIRS image. The band combinations are consistent with green, red and near infrared bands.

Image Classification and Analysis

In this study, the following sequences of operations were used which includes defining of the training sites, extraction of signatures and supervised classification. These were performed on false color composites (bands 4, 3 and 2 for Landsat 5 and 7 and bands 5, 4 and 3 for Landsat 8) into the land use and land cover classes.

(DN) of the thermal band to top of the atmosphere (TOA) radiance (L_{λ}). Satellite sensors measures reflectance from the earth surface as digital numbers (DN) representing every pixel of the image. Due to this, the step is a prerequisite for the upcoming activities.

A. The first step was Conversion to spectral radiance

For Landsat MSS and ETM+ –

$$L_{\lambda} = \frac{(L_{max} - L_{min}) \times (Q_{cal} - Q_{cal\ min})}{(Q_{cal\ max} - Q_{cal\ min})} \quad (1)$$

L_{λ} = Spectral radiance (watt m⁻² ster⁻¹)

L_{max} = Spectral radiance scaled to $Q_{cal\ max}$ (watt m⁻² ster⁻¹)

L_{min} = Spectral radiance scaled to $Q_{cal\ min}$ (watt m⁻² ster⁻¹)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

$Q_{cal\ max}$ = maximum value pf DN

$Q_{cal\ min}$ = minimum value of DN

For Landsat 8 OLI,

$$L_{\lambda} = M_L \times Q_{cal} + A_L \quad (2)$$

Where:

L_λ = TOA spectral radiance (Watts / (m² * srad * μ m))
 M_L = RADIANCE_MULT_BAND_x
 A_L = RADIANCE_ADD_BAND_x
 Q_{cal} = Quantized and calibrated standard product pixel values (DN)
 Note: "x" is the band number

B. The next step was Conversion to Spectral Reflectance

$$\rho_p = \frac{\pi \times L_\lambda \times d^2}{ESUN_\lambda \times \cos\theta_s} \quad (3)$$

ρ_p = spectral reflectance
 L_λ = spectral radiance at sensor
 d = Earth-sun distance in astronomical units
 $ESUN_\lambda$ = Mean solar exoatmospheric irradiance
 θ_s = solar zenith angle in degrees
 The mean solar exoatmospheric irradiance ($ESUN_\lambda$) is computed as –

$$ESUN_\lambda = (\pi \times d^2) \times \frac{RADIANCE_MAXIMUM}{REFLECTANCE_MAXIMUM} \quad (4)$$

C. Further step involved the Conversion to At-Satellite Temperature

Thermal Infrared bands can be converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file

$$BT = \left(\frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \right) - 273.15 \quad (5)$$

Where –

BT = At-satellite brightness temperature (K)
 L_λ = TOA spectral radiance (Watts/ (m² * srad * μ m))
 K_1 = K1_CONSTANT_BAND_x,
 K_2 = K2_CONSTANT_BAND_x.

D. The next step was Deriving Land Surface Emissivity

Before it is computed, NDVI of the images are first derived. The Normalized Difference Vegetation Index (NDVI) is a measure of the amount and vigor of vegetation at the surface. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. The index is defined by the equation below –

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (6)$$

Higher values of NDVI indicate the richer and healthier vegetation in contrast with water and urban areas have larger visible reflectance than near-infrared reflectance. Thus, these features yield negative index values. Using NDVI for the estimation of land surface emissivity (e) according to (Sobrino, *et al.*, 2004) – Proportion of vegetation (P_v), is first calculated by;

$$P_v = \left(\frac{[NDVI - NDVI_{min}]}{[NDVI_{max} - NDVI_{min}]} \right)^2 \quad (7)$$

Where NDVI_min = minimum value of NDVI and NDVI_max equals its maximum value

Land surface emissivity e, is then computed as

$$e = 0.004 \times P_v + 0.986 \quad (8)$$

E. The last step was estimating Land Surface Temperature Computation

F.

According to Akomolafe *et al.*, (2020), land surface temperature is calculated as –

$$LST = \frac{BT}{[1 + W \times \left(\frac{BT}{P}\right) \times \ln(e)]} \quad (9)$$

Where:

W = wavelength of emitted radiance
 BT = Brightness temperature
 $P = 1.438 \times 10^2$ m K = **P = 1438**
 h = Planck's constant (6.626×10^{-34} Js)
 s = Boltzmann constant (1.38×10^{-23} J/K)
 c = velocity of light (2.998×10^8 m/s)
 e = land surface emissivity

Data analysis and software used

The raster calculator tool in the ArcGIS software and Microsoft excel were used to analyse the Landsat images, generate data, and prepare map layout. Zonal statistics was also conducted to generate the value of LST in each land use/ land cover class. Correlation analysis was used to evaluate the relationship between NDVI and LST.

Relationship between LULCC and LST

The land use changes overtime was compared visually to the land surface temperature derived. Areas with increased imperviousness and reduced natural cover like vegetation were considered to be regions where LST values are higher, indicating the tendency for increased urban heat (Aduah *et al.*, 2012; Agbor and Makinde, 2018; Dang *et al.*, 2020; Obiefuna *et al.*, 2021). In the same vein, the relationship was evaluated statistically using regression analysis and statistical plots between LST and vegetation index (NDVI) as well as built up index (NDBI). The built up index explain the building density overtime and also range from -1 to +1 like the NDVI (Umar and Kumar, 2014). The relationship was evaluated using scatter plot of values derived from the images. The R-value and coefficient were used to determine if there is a relationship and whether they are positive or negative. Also, the average LST for each land use class at different years was used to compare and derive relationship of how increasing urbanization has impacted urban temperature.

Deriving Remedies to Curb Increasing Urban Heat

This looked at options and creative ways in which increasing urban heat island and impacts on urban climate can be prevented or reduced. With the relationships studied, this objective looked at the outcomes of the analysis such as how increasing urbanization have affected vegetation health and even urban temperatures and derive ways in which the increasing temperature trends can be reduced with the help of research from literatures. In another instance, an in-depth look at the trend of land cover and temperature changes overtime will be helpful in mapping out the 'ups and downs' of unplanned development and what needs to be done to reduce its effects on the environment and the climate in general.

RESULTS

The results below showed the Land use /land cover of Kano metropolis in 1984, 2003 and 2022 and the Percentage extent of land use (Figure 3, Figure 4, Figure 5 and Figure 6); Land use

transition between 1984 and 2003, Land use transition between 2003 and 2022, Loss and Gain Transitions between 1984 and 2003 and Loss and Gain in land use (2003 – 2022) (Table1, Table 2, Table 3, Figure 7 and Figure, 8); Normalized Difference Vegetation Index (1984), Normalized Difference Vegetation Index (2003) and Normalized Difference Vegetation Index (2022); NDBI Image of Kano Metropolis in 1984, NDBI Image of Kano Metropolis in 2003, NDBI Image of Kano Metropolis in 2022 (Figure 12 to Figure 14); LST Image of Kano Metropolis in 1984, LST Image of Kano Metropolis in 2003, LST Image of Kano Metropolis in 2022(Figure 15 to Figure 17); Relationship between NDVI and LST in 1984, Relationship between NDVI and LST (2003), Relationship between

LST and NDVI in 2022 (Figure 18 to Figure 20); Relationship between NDBI and LST (1984), Relationship between NDBI and LST (2003) and Relationship between NDBI and LST (2022) (Figure 21 to Figure 23). By implication, the relationship between NDBI and LST in Kano metropolis highlights the presence of the urban heat island effect and underscores the need for effective urban planning, green infrastructure, and climate adaptation measures. By addressing these issues, the negative impacts on local climate, human comfort, energy consumption, and environmental health can be mitigated.

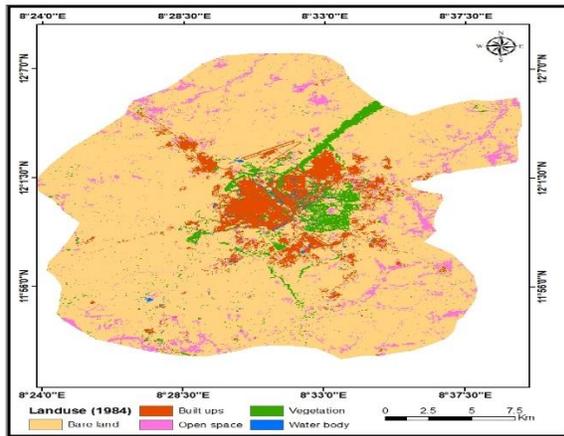


Figure 3: Land use /land cover of Kano metropolis in 1984

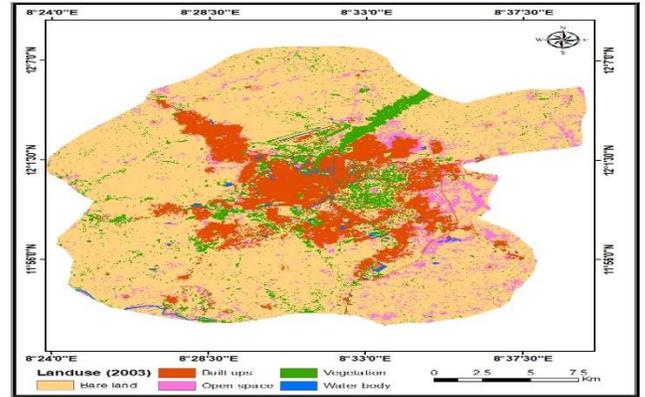


Figure 4: Land use land cover of Kano Metropolis in 2003

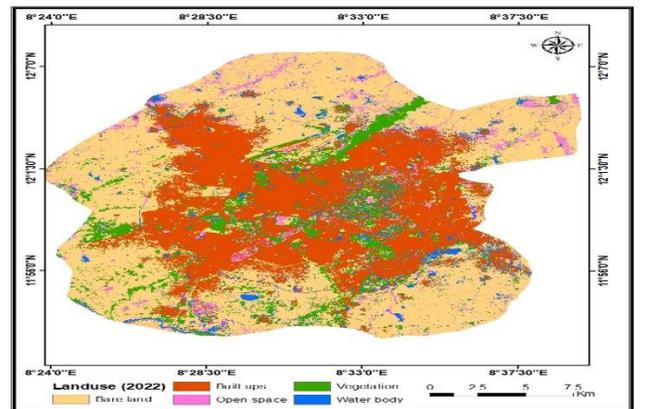


Figure 5: Land use land cover of Kano Metropolis in 2022

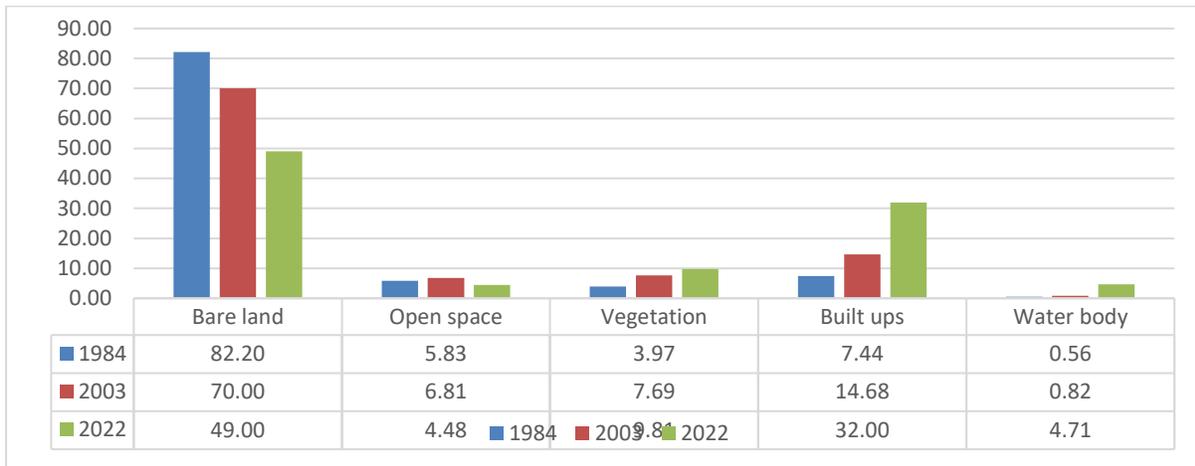


Figure 6: Percentage extent of land use (1984 – 2022)

Table 1: Land use transition between 1984 and 2003

		Area in sq. km (2003)				
Area in sq km (1984)	Land use	Bare Land	Open Space	Vegetation	Built Ups	Water Body
	Bare land	377.865	25.9074	27.1863	40.2651	1.6011
	Open space	17.3079	12.4965	0.7173	2.3922	0.639
	Vegetation	5.0409	0.2907	15.1632	1.8504	0.5067
	Built ups	1.7649	0.04752	0.63	38.5434	1.3644
	Water body	0.684	0.0234	0.5346	1.377	0.6111

NB: Amount of areas unchanged appear in bold

Table 2: Land use transition between 2003 and 2022

		Area in sq. km (2022)				
Area in sq km (2003)	Land use	Bare Land	Open Space	Vegetation	Built Ups	Water Body
	Bare land	253.6236	16.9335	31.6602	85.0464	15.399
	Open space	14.3901	6.1074	1.7478	12.8205	4.1274
	Vegetation	11.9529	1.3905	20.0853	7.0641	3.7386
	Built ups	1.6083	1.1583	2.1501	77.1597	2.3517
	Water body	0.3114	0.1809	0.765	1.9881	1.4769

NB: Amount of areas unchanged appear in bold

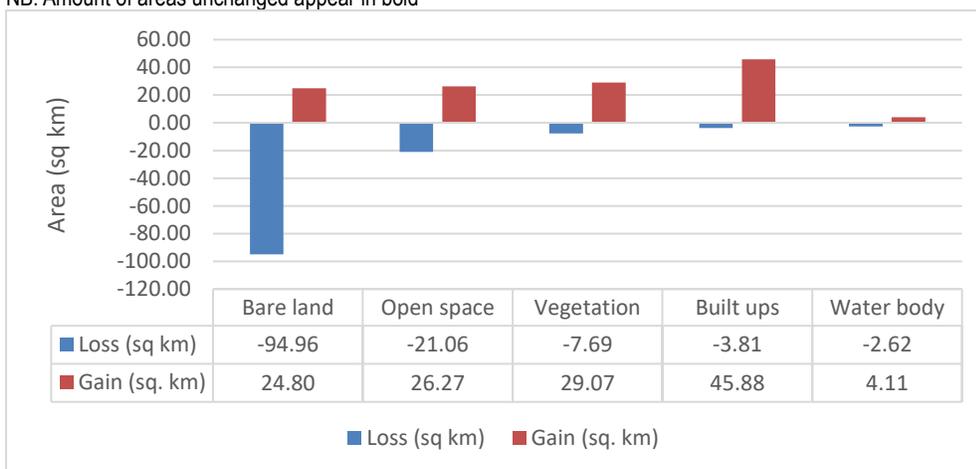


Figure 7: Loss and Gain Transitions between 1984 and 2003

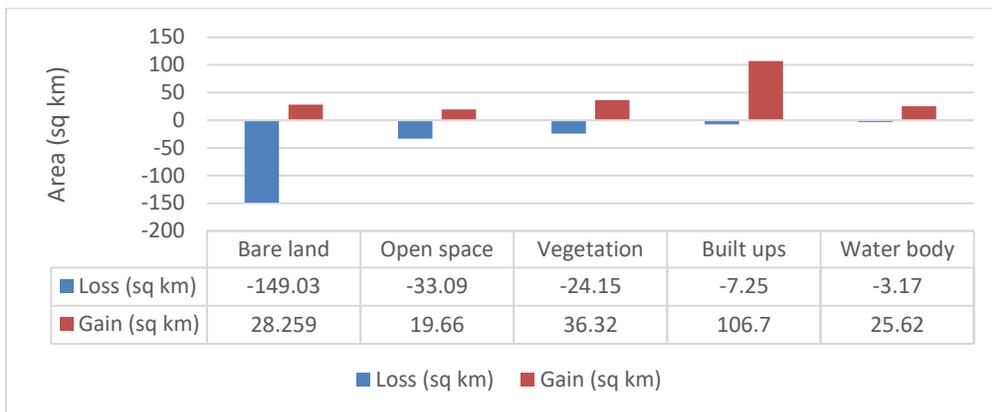


Figure 8: Loss and Gain in land use (2003 – 2022)

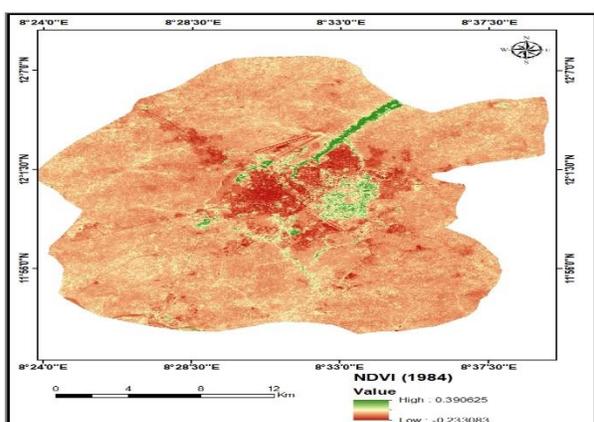


Figure 9: Normalized Difference Vegetation Index (1984)

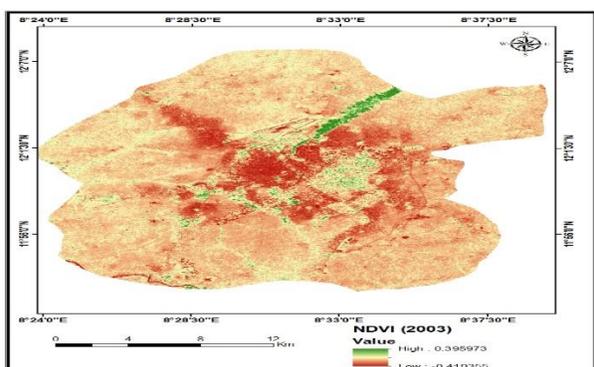


Figure 10: Normalized Difference Vegetation Index (2003)

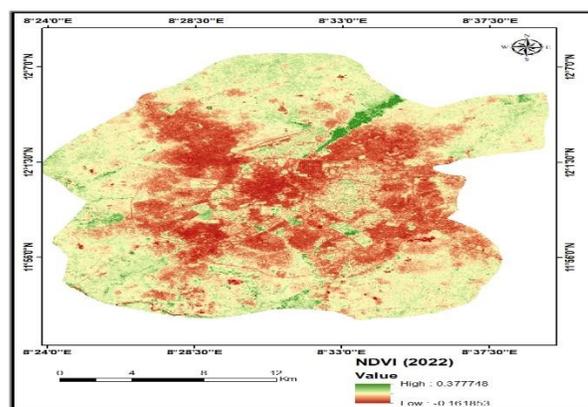


Figure 11: Normalized Difference Vegetation Index (2022)

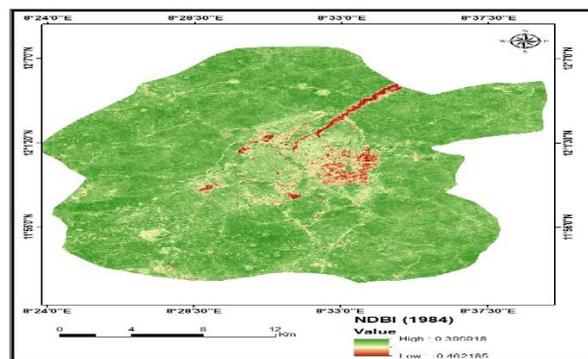


Figure 12: NDBI Image of Kano Metropolis in 1984

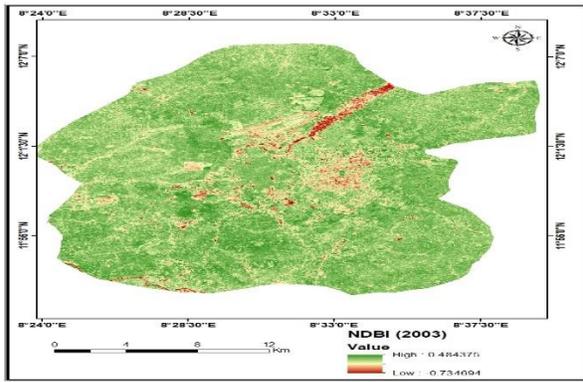


Figure 13: NDBI Image of Kano Metropolis in 2003

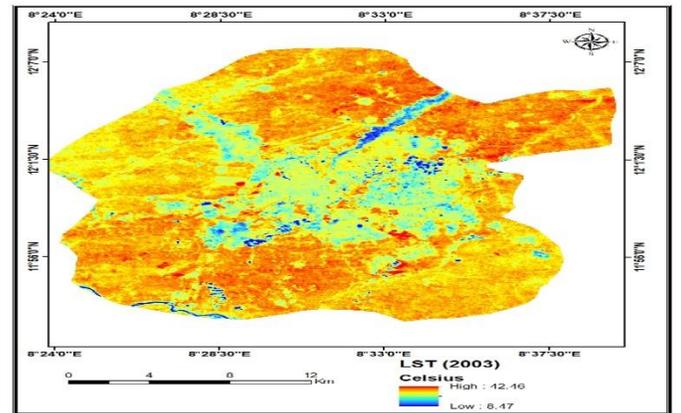


Figure 16: LST Image of Kano Metropolis in 2003

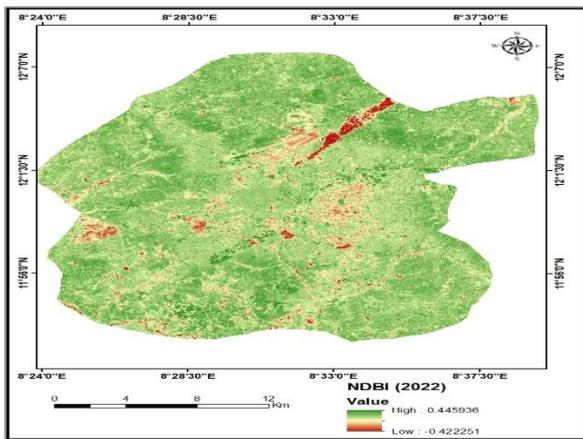


Figure 14: NDBI Image of Kano Metropolis in 2022

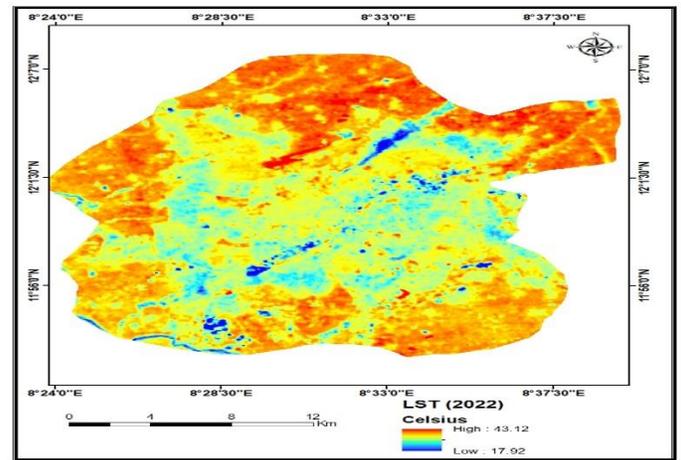


Figure 17: LST Image of Kano Metropolis in 2022

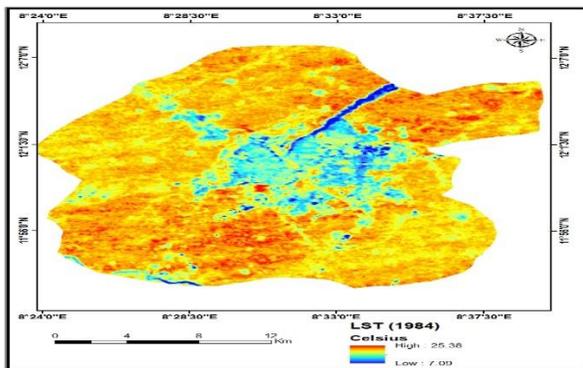


Figure 15: LST Image of Kano Metropolis in 1984

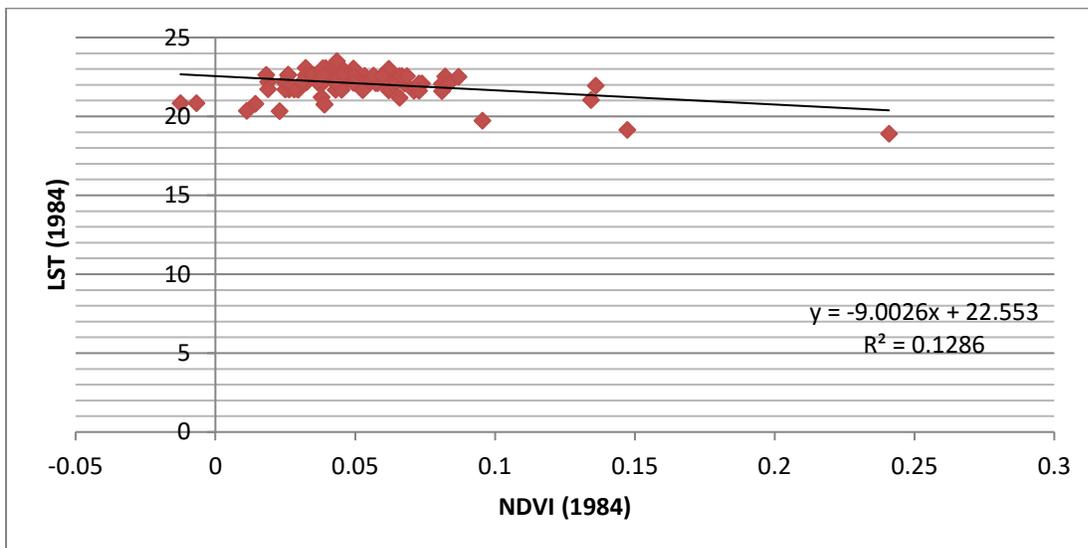


Figure 18: Relationship between NDVI and LST in 1984

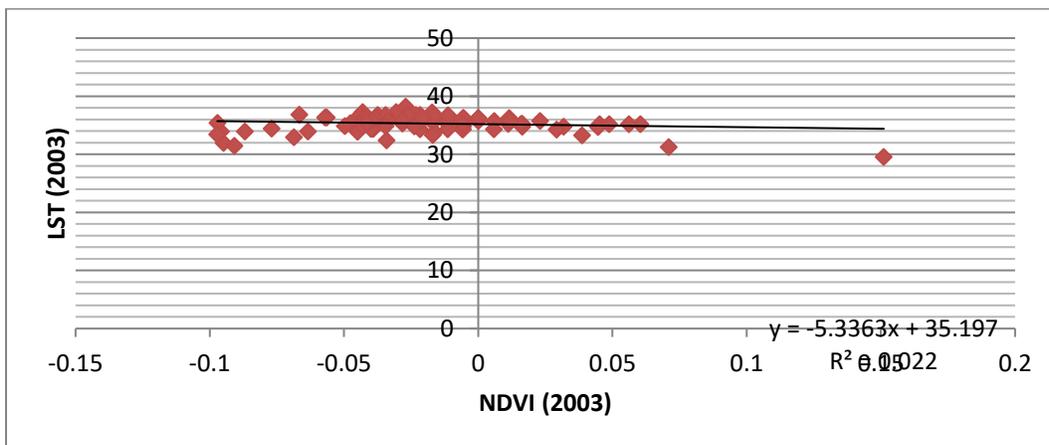


Figure 19: Relationship between NDVI and LST (2003)

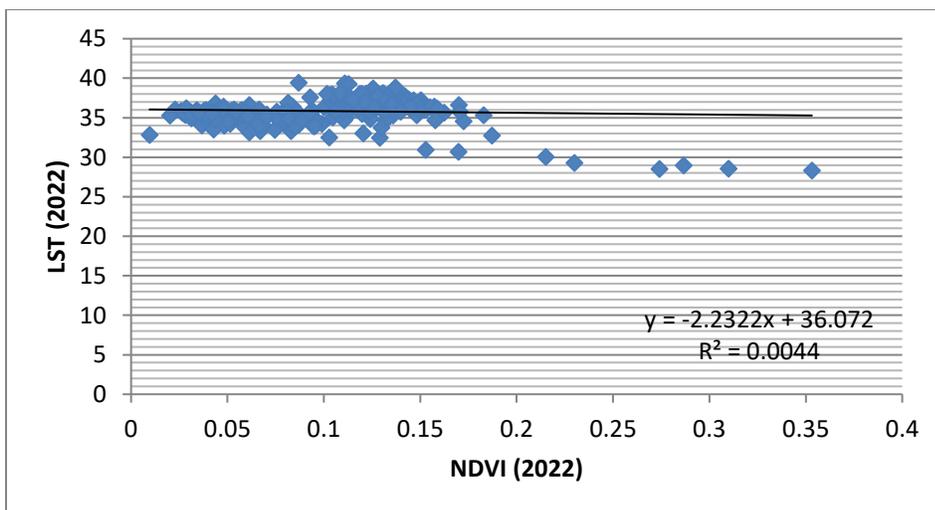


Figure 20: Relationship between LST and NDVI in 2022

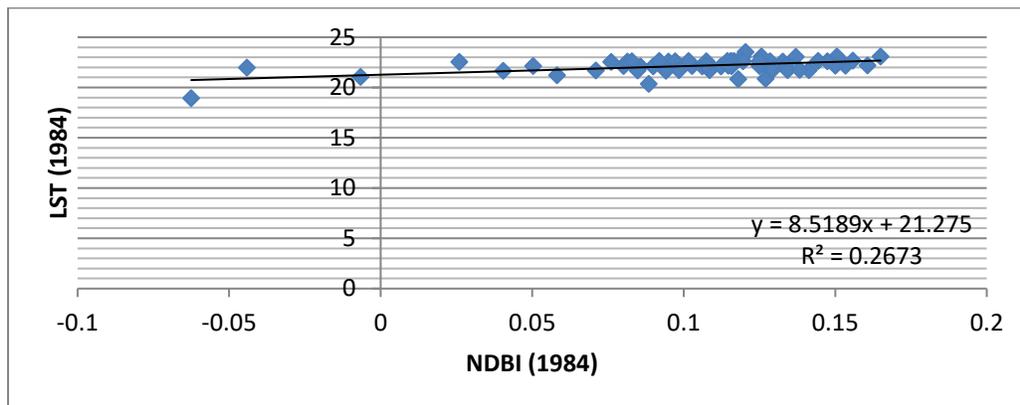


Figure 21: Relationship between NDBI and LST (1984)

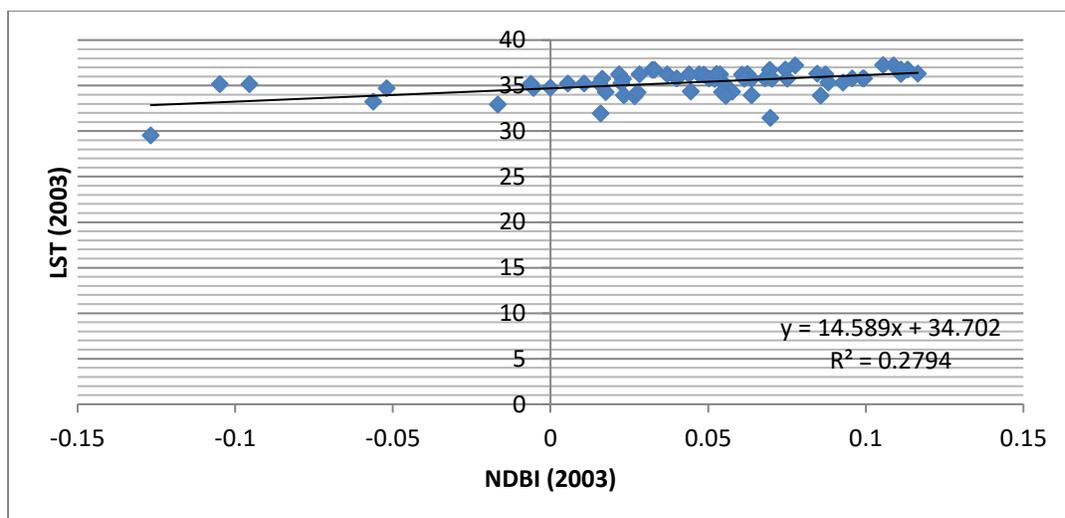


Figure 22: Relationship between NDBI and LST (2003)

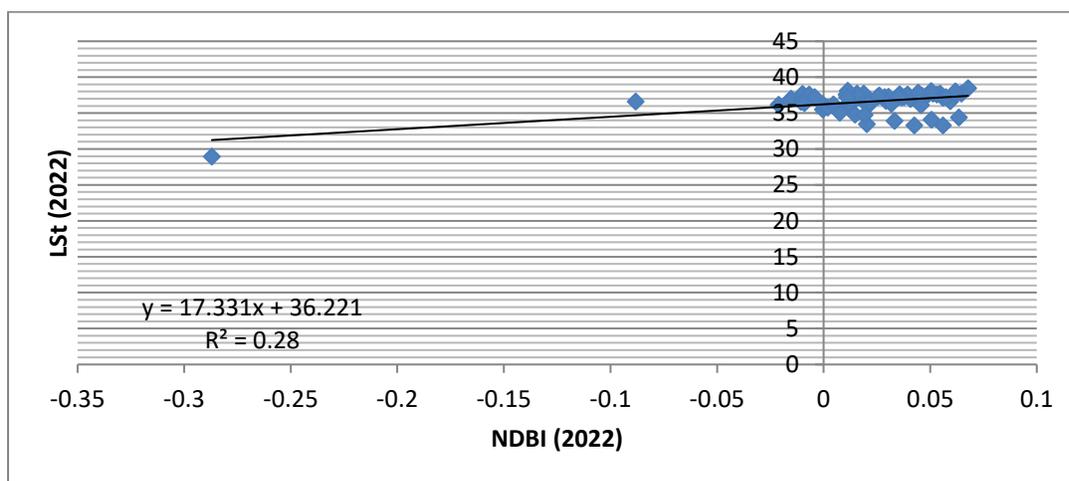


Figure 23: Relationship between NDBI and LST (2022)

DISCUSSION

An Analysis Of The Dynamics Of Land Surface Temperature On Land Use /Land Cover In Kano Metropolis, Kano State, Nigeria

The result from Figure 3 depicts urban areas or built-up areas lesser in area extent accounting for 7% of the total areas as at 1984. According to Koko *et al.*, (2021), the metropolis has an urban areas extent of 11% in 1991. This indicates that the development of urban area in the metropolis was more progressive between 1984 and 1991 (within a space of 7 years). This also corresponded with the extent of bare land that was seen in the metropolis in 1991, which was about 72%. This inferred that between 1984 and 1991, as considered by Koko *et al.* (2021), bare land lost about 11% of its area extent. However, an increase of about 15% was recorded as urban area expansion in 2003 (Fig 6).

Results in Fig 4, shows a reduction in the amount of bare land which is often attributed to the increase in urban land (Ajayi *et al.*, 2022; Olofin *et al.*, 2022; Şekertekin *et al.*, 2015). Also, there was an increase in vegetation as described by Koko *et al.* (2021) where an increment of about 7.6% was recorded, in comparison with 7.1% recorded in 2000. Bare land reduced further to 69%, recording a loss of about 13% in the last 19 years. In 2000, barren land covered approximately 71.32% of the metropolis, indicating a massive further decline. Factors such as increase in population and migration contributed more to the urban area increase (Awuh *et al.*, 2018; Varadarajan and Rajani, 2021; Zemba *et al.*, 2010).

Result in Figure 5 showed a rapid urban area increase in 2022, with a 32% increment from the last 19 years. The Figure also depicts the extent of the urban spread throughout the core and peripheral local government areas. In general, between 1984 and 2022, urban development has increased so far with a slight increase in vegetation and a loss in open space. Bare land reduction was recorded further with more gains in built-ups – it reduced further down to 49% in 2022 from 69% in 2003. In comparison with the study by Koko *et al.* (2021), increment in vegetation was associated with the enormous investment in agricultural activities over the last ten years, which contributed significantly to the alteration of land use. Therefore, the trend shown in the analysis result of the land use and land cover change is that there was a progressive increase in urban area and vegetation while there was a reduction in bare land and open space. Water body also showed a slight increase which might be due to different environmental condition shown overtime (Koko *et al.*, 2021).

Land Use Change Transition (1984 – 2022)

This section looked at the land use change transitions as well as loss and gains that have been seen in the metropolis. Between 1984 and 2003, over 90 km² of bare land was lost, with about 40 km² lost to urban land/built-ups. Also, only 38 km² of urban area remained unchanged in 19 years (Table 1). About 21 km² of open space and 8 km² vegetation was also lost. In all, bare land loss and transition was more massive because a fraction had transitioned to other land use, especially built-ups (Figure 7). In the same way, about 86 km² of bare land was lost to urban area between 2003 and 2022 (Table 2) while about 106 km² of area was gained by urban land (Figure 8). In both eras, there was a significant loss of bare land and open space while there was more increase in built-ups and vegetation (Figures 7 and 8). The main push and pull factors responsible for this growth are related to the city's commercial and agricultural activities.

Land Use and Land Cover; Impact on Vegetation Health (1984 – 2022)

The NDVI was used as an indicator to evaluate the vegetation cover or amount of greenness in satellite images using the red and

near-infrared bands. In this study, NDVI was used as a measure to show vegetation health and vigor that have occurred as a result of development overtime. As shown in the land use and land cover changes, there was a slight increment in vegetation in the last 38 years due to increment in agricultural activity and productivity. In the same vein, the NDVI values between 1984, 2002 and 2022 showed high values ranging between -0.23 – 0.39, -0.41 to 0.39 and -0.16 – 0.37 (Figures 9 – 11).

However, the mean values of the NDVI i.e., 0.08, -0.01 and 0.11 depicted a slight reduction in health of vegetation, as also depicted by (Koko *et al.*, 2021). In the same way, the slight reduction in the NDVI value between 2003 and 2022 also indicates that the impact of development such as increase in urban expansion have often affected the decline of vegetation in the metropolis, despite increase in agricultural productivity in the city. In relation to land use and land cover change, although there is increment in area extent for vegetation which is shown in land change transition, the health of the vegetation which include parameters like greenness and density (Agan *et al.*, 2021) was greatly impacted and with further development, a decline in vegetation health is inevitable in the future.

Spatial Distribution of Urban Cover (1984 – 2022)

The NDBI images explained the extent of the built-up coverage between 1984 and 2022 (Figures 12 – 14). The result showed that there was an increase in built-up extent between 1984 and 2003, with values ranging from 0.39 to 0.48 and a slight reduction to 0.45 in 2022 (which can be due to the difference in time of acquisition of the satellite images used for the analysis as described by Koko *et al.*, (2021) but with the values of the NDBI within the same range, it can be inferred that the building coverage have increased so far. From the images below, vegetation, water and urban spaces have low NDBI values while built-ups and bare land area corresponds with high values. This also showed that the NDBI values corresponds with the rate of development – for instance, bare land areas have a little bit lower NDBI value than areas with actual buildings. This is also reflected with the variation of greenness shown in the NDBI images.

Land Surface Temperature Change Trends (1984 – 2022)

As one of the main objectives of this research, the land surface temperature was used in describing the change in urban climate due to urban developments that have occurred so far in the metropolis in the last 38 years. The land surface temperature depicts the inputs of anthropogenic forces in shaping the urban environment such as population increment, industrialization and commercialization, agriculture, migration to name a few (Twumasi *et al.*, 2021). From the LST analysis results, it was shown that there was an increment in the land surface temperature values overtime. As described by Twumasi *et al.*, (2021), land cover plays an important role in land surface temperature. The drivers of land-use/land-cover change were categorized have been so far, categorized into four classes, namely, political, demographic, economic, and environmental forces (Dushi and Berila, 2022). These forces have been known to shape the urban climate of developing countries so far.

In Figure 15, the land surface temperature ranged between 7°C and 25°C, with a mean LST value of 16°C. This showed that the urban heat was less, coupled with the less extent of development shown in the land use land cover of 1984. However, the drastic increment in 2003 showed that there was increase in urban development, resulting in increased urban heat. The value of the

LST ranged between 8°C and 42°C (Figure 16) while in 2022, the urban temperature ranged between 17.9°C and 43°C (Figure 17). This is in accordance with the study by Koko *et al* (2021) where the LST of Kano increased progressively between 1991 and 2020. The mean LST for 2003 was 25°C while in 2022, the mean further raised to 30.5°C. In general, the last three decades for the city represented a great impact in the urban climate, with increments in urban built ups and land surface temperature.

Relationship between LST and Land Use Land Cover (1984 – 2022)

Correlation between LST and NDVI

According to Agan *et al.*, (2021), Khalil *et al.*, (2021), Koko *et al.*, (2021) and Mahanta and Samuel, (2020), there is often a negative relationship between vegetation health and land surface temperature. According to the graph below (Figure 18), there is a negative relationship between the NDVI and LST in 1984 with a slope of -9 and an R-value of 0.357. In the same way, negative relationship was recorded between both variables in 2003 and 2022 (Figures 19 and 20). This further proved the conclusion in the study made by Abdulhamed *et al.*, (2015) and Babalola and Akinsanola (2016) that there is a strong negative relationship and vegetation covers always has a low radiant temperature because dense vegetation can reduce amount of heat stored in the soil and surface structures through transpiration. This is why land surface temperature increases as vegetation health reduces.

Correlation between LST and NDBI (1984 – 2022)

In the same way, there has been positive relationship recorded between LST and built up index as shown in Figures 21, 22 and 23 below. According to Faisal *et al* (2021), increase in urban area or urban expansion have been known to be a main contributor of the urban heat island. This is shown to be same in Kano metropolis. In analysing the dynamics of land surface temperature (LST) and land use/land cover in Kano metropolis, several implications arise from the trends observed in NDVI and NDBI values. A decrease in NDVI values indicates a decline in vegetation cover, which can be attributed to factors like urbanization, deforestation, or land degradation. This has negative consequences for the environment, such as reduced biodiversity, increased soil erosion, and the loss of ecosystem services. Fluctuations in NDVI values over time reflect changes in seasonal vegetation patterns, potentially influenced by variations in precipitation, temperature, or land management practices, providing insights into vegetation resilience and responses to environmental changes.

Rising NDBI values suggest an expansion of built-up areas and urbanization in Kano Metropolis. This leads to increased surface temperatures, the formation of urban heat islands, and alterations in local climate patterns. The loss of natural land covers and associated ecological consequences can also be indicated by increasing NDBI values. NDBI values are often correlated with elevated LST due to the heat-absorbing nature of built-up surfaces. This correlation provides insights into the urban heat island effect, where urban areas experience higher temperatures than surrounding rural areas. Implications of this effect include impacts on human comfort, energy consumption, and environmental health. The presence of the urban heat island effect is further supported by increasing LST values in urban areas compared to surrounding rural areas. This effect is a result of the abundance of built-up surfaces, reduced vegetation cover, and limited evaporative cooling. High LST levels can have adverse effects on human

health, energy consumption, and the overall urban climate. Analysing the relationship between LST and land use/land cover changes helps understand the impact of urbanization and vegetation changes on local temperatures. This knowledge enables the identification of areas that require heat mitigation strategies, such as green infrastructure or urban planning interventions, to mitigate the heat island effect and improve the urban microclimate.

Conclusion

The results of these studies revealed that urban expansion has led to the continuous loss of vegetated lands and the development of impervious surfaces. This has contributed to the higher LST experienced in some urban centers and cities due to the increased absorption of solar radiation and its conversion into heat. The consequence of this development is the creation of urban heat islands that negatively affect urban dwellers (Koko *et al.*, 2021). The areas around the city's central core with built-up areas and urban facilities have higher LST due to the impervious surfaces that expose such areas to greater solar radiation. The findings align with recent studies which have opined that the modification of land use due to various socio-economic factors has influenced local climatic condition in urban areas (Dang *et al.*, 2020; Kestens *et al.*, 2011; Obiefuna *et al.*, 2021; Olofin *et al.*, 2022).

Also, land use change has contributed to the observed UHI intensity over the study areas mainly through the processes of urban sprawl, degradation of cropland and healthy vegetation. This means that in the last 38 years, Kano metropolis have experienced increased urban expansion that have led to urban sprawl. Increased in urban heat as depicted by Abdulhamed *et al.* (2015) have influenced the environment so much that, it has increased urban pollution and an uncomfortable environment.

The level of surface imperviousness in the city center has also increased urban congestion. In general, mostly population or demographic pressure, in the process of urbanization, influences different types of natural land cover to be destroyed and changed or replaced with impervious materials very common in urban areas, such as concrete, asphalt, stone, metal, glass, and other materials which have low albedo values and which absorb heat, causing the released energy to increase in the city. This is why LST have increased overtime in Kano Metropolis.

Therefore, it is essential for stakeholders, including policymakers, urban planners, and residents, to work collaboratively in implementing the following recommendations by addressing the interplay between land.

- i. Urban Planning and Green Infrastructure: The city authorities should prioritize sustainable urban planning practices that promote green infrastructure, including the preservation and creation of parks, green spaces, and tree-lined streets. These measures can help mitigate the urban heat island effect by increasing vegetation cover and providing shade.
- ii. Heat-Resistant Building Design: Architects and developers should incorporate heat-resilient design strategies, such as the use of reflective materials, green roofs, and efficient insulation, in the construction of buildings. This can help reduce the heat absorption and retention properties of urban structures.
- iii. Urban Reforestation and Afforestation Programs: Implementing initiatives to promote urban reforestation and afforestation can help counteract the loss of

vegetation in Kano Metropolis. This can involve planting trees in public spaces, along streets, and in vacant areas to enhance green cover and provide natural cooling benefits.

- iv. Climate-Sensitive Land Use Planning: Land use planning should consider the potential impacts of land cover changes on local temperature dynamics. Integrating climate-sensitive approaches into land use policies can help ensure sustainable development and minimize the adverse effects of urbanization on temperature patterns.
- v. Public Awareness and Education: Creating awareness among the general public about the importance of sustainable land use practices and their relationship to temperature dynamics is crucial. Educational campaigns and outreach programs can promote responsible land management and encourage individuals to adopt environmentally friendly behaviors.

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