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Effect Of Land Use Land Cover Changes on Land Surface Temperature in Gombe Metropolis, Gombe State, Nigeria

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Abstract

The study assessed the effects of LULC change on surface temperature in the Gombe metropolis. A comprehensive LULC and LST maps were created and analyzed using ArcGIS software version 10.4.1 after obtaining the remotely sensed Landsat data from the USGS domain. The result revealed that farmlands occupied the highest portion of the area in 1991 with a percentage of 16.04km² (42%) of the total area. Bare surfaces covered an area of 12.08km² (31%) in 1991 but declined to 4.27km² (11%) by 2021. Vegetation cover reduced from 6.62km² (17%) in 1991 to 0.29km² (1%) in 2021. However, built-up areas became the only class with an overall increase from 3.89km² (10%) in 1991 to 23.78km² (62%) in 2021. Furthermore, the LST analysis shows that there was a sustained increase in Mean LST records as revealed by 6.2°C, 23.8°C, 31°C, and 64.6°C for 1991, 2001, 2011, and 2021 respectively. The linear regression analysis showed an inverse relationship between vegetation, bare surfaces and farmlands with R^2 values of 0.4559, 0.2707 and 0.1495 respectively. A positive relationship was however obtained between built-up areas and LST with an R^2 value of 0.8331 which indicates that built-up areas are the major predictor for an increase in LST in the study area. The study therefore recommended that temperature-friendly materials such as green infrastructures should be encouraged by the construction industry to mitigate the impact of higher LST in the area.

Key Words: LULC, LST, Temperature, Gombe, Class

1.1 Introduction

Land Use and Land Cover (LULC) changes induced by human or natural processes drive the biogeochemistry of the earth influencing the climate at global as well as regional scales. The rapid growth of urbanization is one of the dominant and noticeable man-made changes in the world more so than natural forces. Anthropogenic factors are continually involved in the energy transition from the Earth's surface to the atmosphere via LULC changes (Cohen, 2004). Drastic changes in the land cover with the decline in vegetation and water bodies due to anthropogenic activities that enhance the heat emission from land surface and atmospheric temperatures increase Land Surface Temperature (LST).

LST is the radiant temperature of the land's surface, and it is affected by geographical conditions, land, scraping structure, land cover, and urban sprawl, according to the existing literature (Alemu, *et al.*, 2015). Rapid urbanization has become a key challenge for urban sustainability, as seen by the formation of an Urban Heat Island (UHI) and the depletion of urban health states (Liu *et al.*, 2020). It leads to the substitution of the natural land by the man-made landscape, which would lead to greater temperatures in the urban area than in the nearby suburban or rural areas (Mirzaei, *et al.*, 2020; Boehme, *et al.*, 2015).

In recent years, most regions across the world are experiencing major LULC changes. Numerous studies have reported that the observed changes in LULC are mainly driven by human activities including agriculture and rapid urbanization. Urbanization plays a pivotal role in the transition of LULC all over the globe. The increase in population demands to sustain their livelihoods leads to LULC change (Aruya, 2019).

Globally, change in LST is one of the major issues that affect human populations, and often results from human induced LULC changes. The extreme change in LULC increases the related effects of LST. Therefore, for the mitigation of the impact of high temperatures in the proximate environment, the implementation of alternative solutions is necessary. Therefore, accurate and updated information on the changes in surface characteristics of villages and cities is necessary to allow proper implementation of strategies related to sustainable management of the natural environment.

Previous studies have reported the relationship between LULC changes and the rise in LST. For instance, Rimal (2011) conducted research on urban growth and LULC change in Pokhara sub-metropolitan city, Nepal and concluded that settlement growth reduces vegetative cover, thus, adding heat-absorbing surfaces such as rooftops, asphalts and other concrete surfaces. Similarly, Ayanlade (2016) reported that LST was highest in urban residential areas where there were low vegetative covers while the lowest LST occurred in farmlands where there were high vegetative covers. It is worth noting that each LULC category has its properties that are related to the absorption and radiation of solar energy. Other studies have pointed out that changes in LULC due to urbanization, deforestation, and land degradation significantly affected the urban ecosystem (Alemu, et al., 2015; Thapa, 2020). These artificial changes in LULC can lead to an increase in LST due to the expansion of impervious surfaces.

LULC changes are evident in Nigerian cities as with other developing nations of the world. Being one of the most urbanized countries on the African continent with an estimated urbanization rate of 3.5% annually, Nigeria has witnessed tremendous urban expansion over the years (Aruya, 2019). Geo-information and remote-sensing technologies present the most suitable tools for monitoring and planning land use, as well as examining LULC change from a local to a global scale.

Given, the increase in urbanization in the Gombe metropolis, being a growing city characterized by the influx of people for commercial, educational and developmental purposes cannot be overemphasized. Massive urbanization has altered the LULC characteristics of the urban fabrics and invariably altered surface temperature. There is therefore the need to assess these changes in the urban characteristics of LST. The specific objectives of the study are to, determine the LULC changes from 1991 to 2021 in the study area, determine the LST characteristics in the study area from 1991-2021 and assess the effects of LULC change on LST in the study period.

2.1 Study Area

The study area is Gombe metropolis, Gombe State. It is located between latitudes 10°16’4"N and 10°17’24"N of the equator and between longitudes 11°14’0"E and 11°4’4"E of the Greenwich meridian (Figure 1). It has a total land mass of approximately 52km^2 (Federal Survey, 1968). The area is found in the northeastern region of Nigeria and at the Centre of Gombe state. The study area serves a dual role as the administrative headquarters of Gombe state and the traditional headquarter of the Gombe Emirate. Situated at the center of the state, the local government is bordered to the North by Kwami LGA, to the East by Yamaltu Deba LGA, and to the South and west by Akko LGA.

The area is influenced by the tropical savannah climatic type (A_w). It has two distinct seasons which are the rainy and dry seasons. The dry season begins from November and ends in March while the rainy season commences from April to October. Rainfall usually last for 5-6 months with mean annual rainfall of 933mm. Over the course of the year, the temperature typically varies from 18°C during the months of November/December to a maximum of 37°C around March/April.

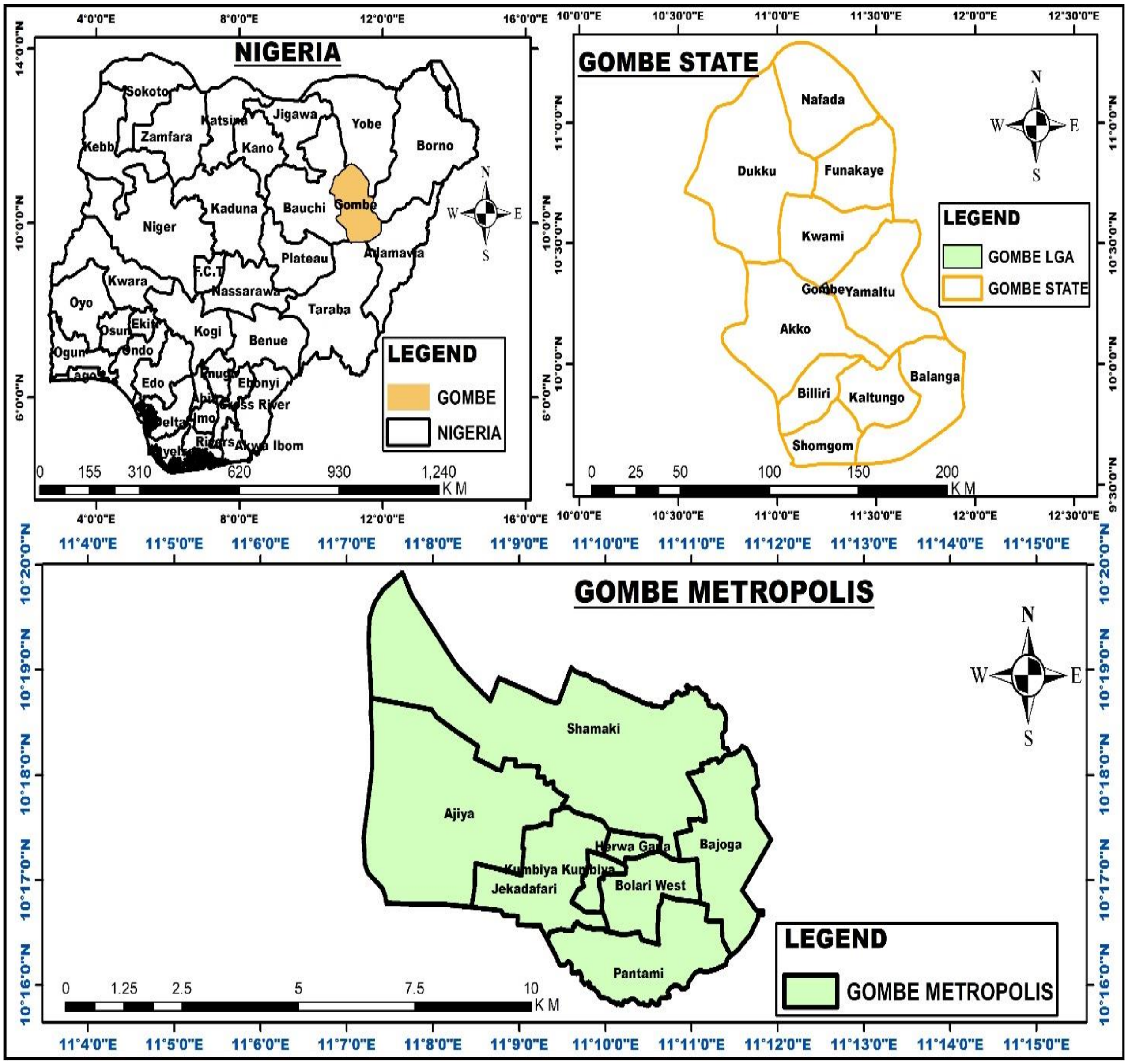

Figure 1: Study Area Map
Source: Adapted and modified from the administrative map of Gombe state (2023)

The geology of the Gombe metropolis consists of ancient crystalline basement complex rocks which comprise the remnants of highly metamorphosed sedimentary rocks. There are eleven soil units in the area with Nitisols almost covering half of the state (Ikusemoran *et al.*, 2017). Major geologic units in Gombe are sandstone, siltstone, shale, coal and ironstone. According to NPC (2006), the population of the Gombe metropolis was 266,844 and is projected to be 446,800 in 2022.

3.1 Methodology

The research employed secondary data sources. Satellite imageries were downloaded from the United States Geological Survey (USGS) Earth Explorer website (http//earthexplorer.usgs.gov). The data that was used in the study includes Landsat imageries for LULC and LST computation and analysis. The study period is 30 years, at an interval of 10 years from the reference year of 1991 to give three epochs. Therefore, imageries were acquired and computed for 1991, 2001, 2011 and 2021 and used for LULC and LST analysis (Table 1). Image enhancement was performed to improve the quality of the satellite imageries.

Table 1: Details of Multi-temporal Satellite Data

Data	**Satellite**	**Spatial Resolution**	**Radiometric Resolution**	**Path/Row**	**No of Bands**	**Date of Acquisition**
LULC/LST 1991	Landsat-5 TM	30mx30m	8bit	186/053	7	27-07-2023
LULC/LST 2001	Landsat-7 ETM+	30mx30m	16bit	186/053	9	27-07-2023
LULC/LST 2011	Landsat-7 ETM+	30mx30m	16bit	186/053	9	27-07-2023
LULC/LST 2021	Landsat-8 OLI, TIRS	30mx30m	16bit	186/053	11	27-07-2023

Source: Modified after USGS (2023).

Landsat imageries captured during the dry seasons and cloud coverage of less than 20% were selected to reduce cloud obstruction and achieve better image quality. Data for dry seasons are especially more accurate for the computation of LST (Aruya, 2019).

3.2 Data Analysis

Atmospheric and radiometric adjustments are the most significant phases in the processing of satellite imagery for image classification and LST retrieval (Bokaie *et al.*, 2016). To determine the LULC characteristics of the study area, multispectral bands of Landsat 7, Landsat 8, and Landsat 9 imageries and a support vector machine algorithm (supervise classification) were used for classification detection and of LULC changes during the study periods). Gombe metropolis was categorized into four major LULC classes encompassing bare surfaces, built-up areas, vegetation, and farmlands as shown in Table 2.

Table 2: LULC Classification Used in the Study

LULC Class	Description
Built-up areas	Residential, commercial services, industrial, recreational, transportation, communication and utilities, educational institutes, cantonments, reclaimed land, Hospitals, Churches and Mosques.
Farmlands lands	Crop Land, fallow land, and Plantations.
Vegetation	Deciduous Forest Land, Mixed Forest Land, Shrub/degraded vegetation and other naturally existing vegetation.
Bare surfaces	Salt-affected area, gullied/ravenous land, undulating land with or without scrub, sandy area, rock outcrops.

Source: Author's Data Analyses (2023)

To retrieve the LST information of the study area, raw thermal band data (band 6 in Landsat 5 (TM) and Landsat 7 (ETM+), and band 10 in Landsat 8 (TIRS) were used because of its potential of sensing electromagnetic energy emitted by any terrestrial objects. This was converted into top of atmospheric spectral radiance using the following formula in (Eq.1).

$$L\lambda = M_l \, Q_{cal} + A_l \qquad (1)$$

Where:

$L\lambda = \text{TOA spectral radiance}(\text{Watts}/(M_2 \times \text{s} \times \text{srad} \times \mu\text{m}))$

M_L = Band specific multiplicative rescaling factor from the metadata (radiance multi-band x, where x is the band number)

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

A_L = Band specific additive rescaling from the metadata (radiance add band x, where x is the band number). After the conversion of DN to spectral radiance the next thing was to convert the spectral radiance to top of atmosphere brightness temperature using the thermal constants provided in the metadata file and the formulae used are provided in (Eq.2).

$$BT = \frac{K2}{Ln(\frac{K1}{L\lambda} + 1)} \qquad (2)$$

Where:

BT = top of atmosphere brightness temperature in degree Kelvin (K)

$L\lambda$ = TOA spectral radiance (Watts/(m_2*srad*µm)

Ln= landa

K1 = Band specific thermal conversion constant from the metadata

(K1_CONSTANT_BAND_x, where x is the thermal band number)

K2 = Band specific thermal conversion constant from the metadata

(K2_CONSTANT_BAND_x, where x is the thermal band number)

For LANDSAT-5 TM value of K 1 for band 6 is 607.76 and K 2 for band 6 is 1260.56 respectively. For LANDSAT-8 TIRS values of K 1 for band 10 and 11 are 774.8853 and 480.8883 respectively and K 2 for band 10 and 11 are 1321.0789 and 1201.1442

Kelvin (K) to Celsius (degree): Degree Kelvin was then converted to degree Celsius using the formulae;

$BT =$

3.2.1 Normalized Difference Vegetation Index (NDVI)

Estimating NDVI at this point is necessary because the Proportion of Vegetation (PV) which is highly related to the NDVI and Emissivity (Ɛ) are needed for further estimation of LST. NDVI was estimated from the NIR and R bands using the formulae in (Eq 3.1)

$$NDVI=\frac{NIR-R}{NIR+R} \quad (3)$$

Where: NIR represent the near-infrared band (band 5) and R represent the red band (band 4) when using Landsat 8.

3.2.2 Proportion of Vegetation (PV)

PV is calculated according to Wang *et al.* (2015). A method for calculating PV suggested using the NDVI values for vegetation and soil ($NDVI_v$ =0.5 and $NDVI_s$ =0.2) to apply in global conditions (Eq. 4).

$$PV=\left[\frac{NDVI-NDVIs}{NDVIv-NDVIs}\right]^2 \quad (4)$$

Where:

$NDVI_v$ = average maximum value and $NDVI_s$ = average minimum value.

Therefore, PV= Square ((“NDVI” – 0.2) / (0.5 – 0.2)).

3.2.3 Land Surface Emissivity (Ɛ)

The land Surface Emissivity (Ɛ) is needed to calculate the LST. The determination of the ground emissivity is calculated (Eq. 5) conditionally as suggested by Sobrinoa *et al.* (2004).

$$\varepsilon = 0.004 * PV + 0.986 \quad (5)$$

3.2.4 Land Surface Temperature (LST)

The LST was computed as follows (Eq. 6)

$$LST = BT/(\lambda \times BT / C_2) * Ln(\varepsilon)) \quad (6)$$

Where:

BT = Brightness Temperature (°C)

ƛ = wavelength of emitted radiance for which the peak response and the average of the limiting wavelengths.

C2 = h*c/s= $1.4388*10^{-2}$Mk = 14388µm K (radiation constant)

Ɛ = land surface emissivity

Statistical analysis was also employed to quantify the relationship between LULC changes and LST temporal variability. Linear regression analysis which shows the relationship betw two variables (x and y) was used to test the strength of the relationship between the dependent variable (LST) and the predictor (LULC). 6 linear regression curve was computed for mean LST against each LULC class to show the relationship between both variables. Statistical Tables were also used to graphically represent the distribution of LULC and LST during the epochs.

4. Results and Discussion

4.1 LULC Changes from 1991 to 2021 in the Study Area

The land use pattern maps of the study area produced by the band's combination of remotely sensed image classification have yielded imperative LULC information. Figures 2 to 5 shows the land use pattern of Gombe metropolis in the reference year of 1991 and the epochs of 2001, 2011 and 2021. The changes in LULC of the study area for the period of study is evident. Farmlands initially occupied the highest portion of the area at the onset of the study (1991) with a percentage of 42% but gradually reduced to 26% by 2021. Bare surfaces class also had a significant spatial coverage as at 1991 (31%).

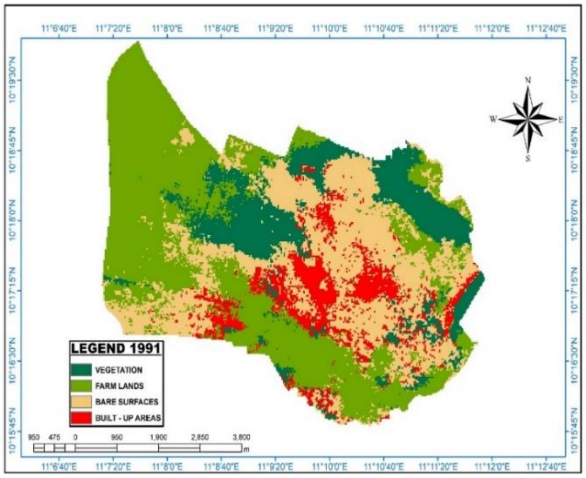

Figure 2: LULC of the Study Area for 1991
Source: Author's Data Analysis (2023)

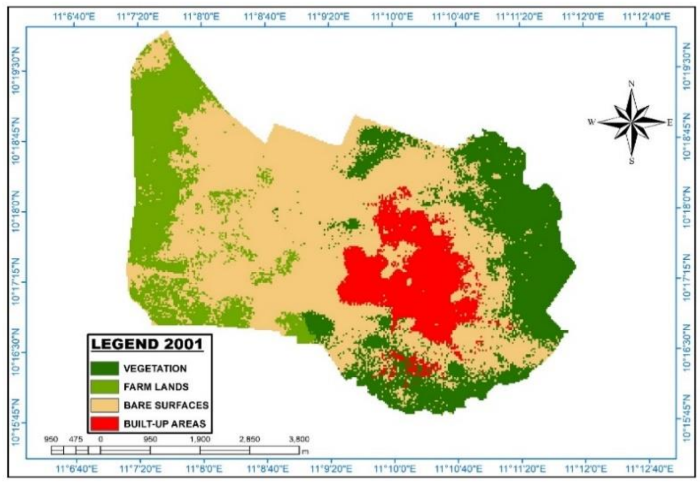

Figure 3: LULC of the Study Area for 2001
Source: Author's Data Analysis (2023)

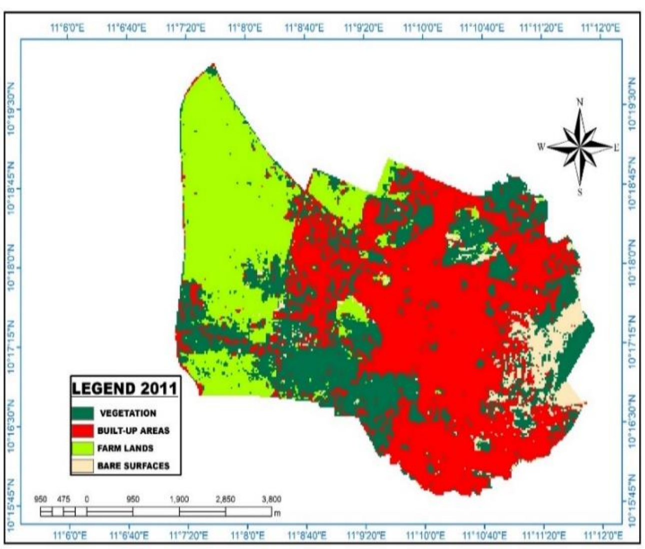

Figure 4: LULC of the Study Area for 2011
Source: Author's Data Analysis (2023)

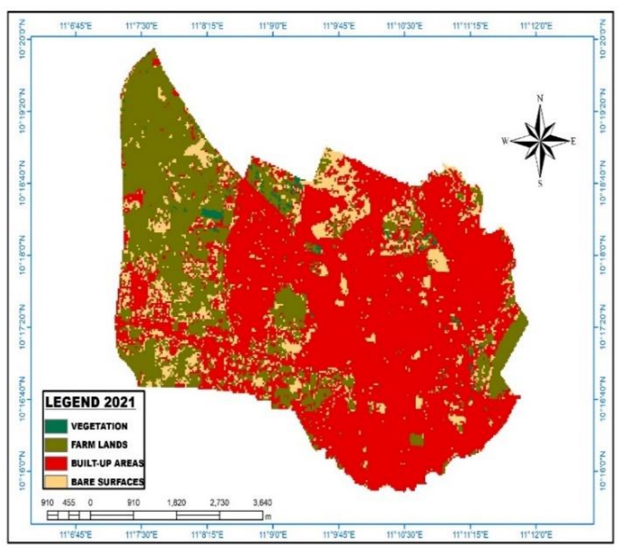

Figure 5: LULC of the Study Area for 2021
Source: Author's Data Analysis (2023)

Vegetation initially had a percentage of 17% in 1991 but it gradually increased to 22% in 2001 and to 28% in 2011. The vegetation class however suffered a decline by 2021 to only 1% and became the LULC class which saw the most decline for the period of study. Built up areas on the other hand was 10% in 1991 but has over the period gained in percentage as it occupied 62% of the total area in 2021.

The comparison between 1991 and 2021 as shown in Figure 6 demonstrates the significant decrease in the vegetation cover and increase in built-up areas. The dramatic decline in vegetation and continuous increase in built up areas may be attributed to urban expansion taking place in the area during the period which converts natural vegetation into urban built types arising from the need for more space to cater for housing and commercial needs of the population. This agrees with the findings of Collins *et al.* (2021) where the researchers asserted that there is often an inverse relationship between built up areas and vegetation cover when studied over period of years as increase in built up usually reduce vegetation of an area resulting from the continuous conversion of other land use classes to urban built types.

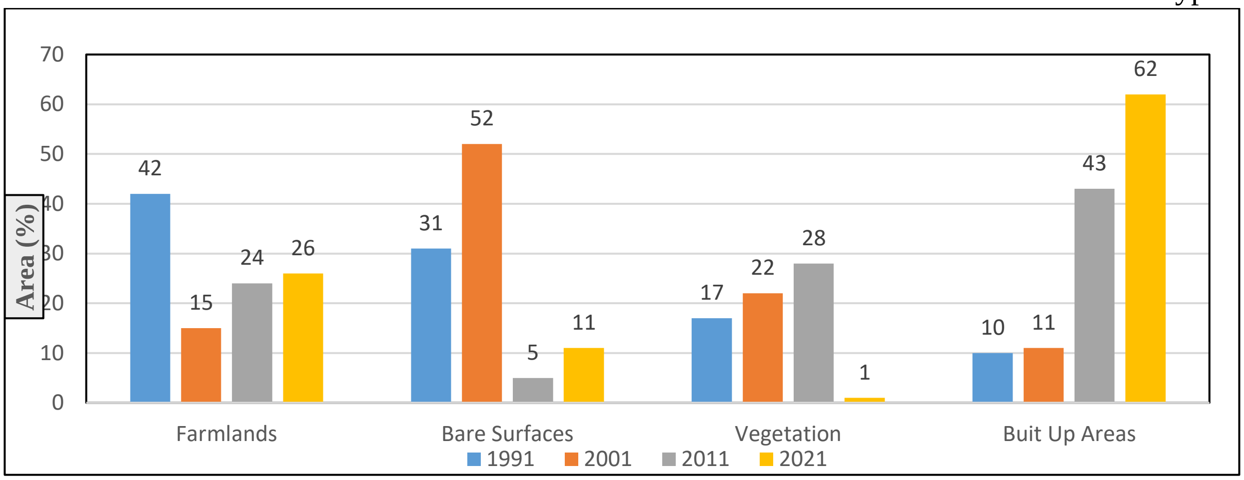

Figure 6: LULC Spatial Distribution (1991-2021).
Source: Author's Data Analysis (2023)

4.2 LST Changes from 1991 to 2021 in the Study Area

The LST analysis of the study area reflects a continuous increase over the study period. Figure 7 and Figure 8 shows the LST for 1991 (reference period) and 2001 respectively. For the period of 1991, the area recorded a minimum LST of -8.6°C and maximum LST of 7.9°C while the mean LST gave a value of 6.2°C. The epoch of 2001 recorded LST values of 20.2°C and 27.3°C for minimum and maximum respectively with a mean LST of 6.2°C.

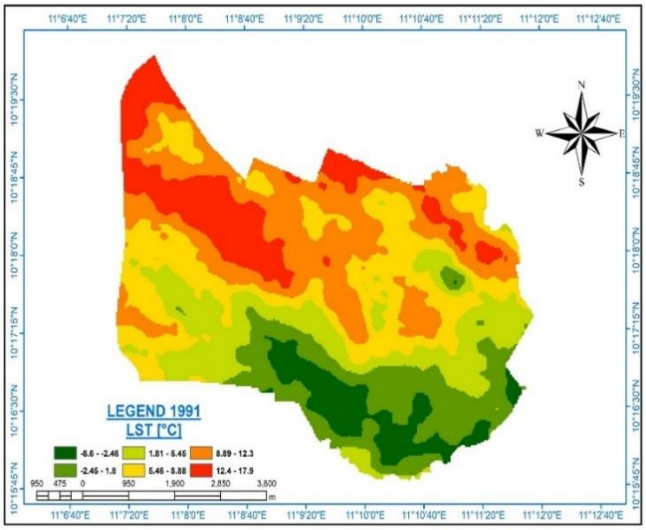

Figure 7: LST of the Study Area for 1991
Source: Author's Data Analysis (2023)

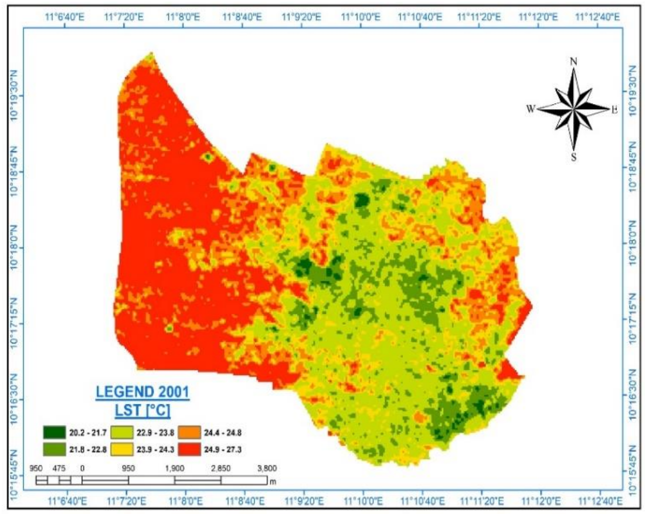

Figure 8: LST of the Study Area for 2001
Source: Author's Data Analysis (2023)

Furthermore, Figure 9 ad 10 shows LST for 2011 and 2021. The record of LST in the study area for 2011 shows values of 24.5°C and 35.6°C for minimum and maximum LST respectively while mean LST was 31°C. Also, the year 2021 had an LST record of 60.5°C, 67.6°C and 64.6°C for minimum, maximum and mean LST respectively.

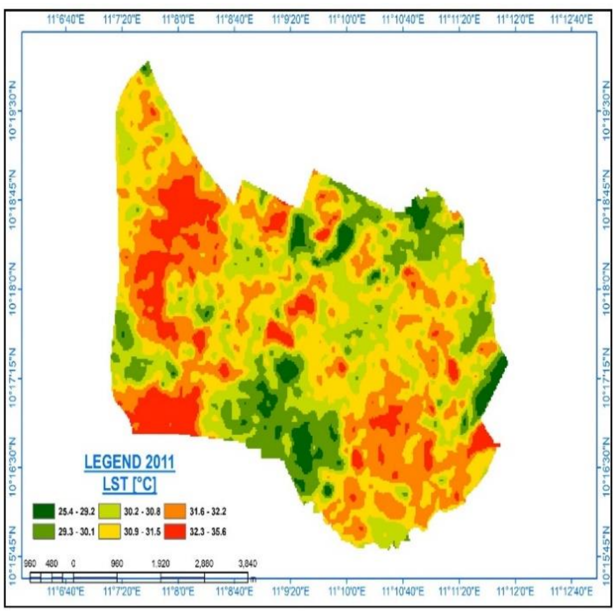

Figure 9: LST of the Study Area for 2011
Source: Author's Data Analysis (2023)

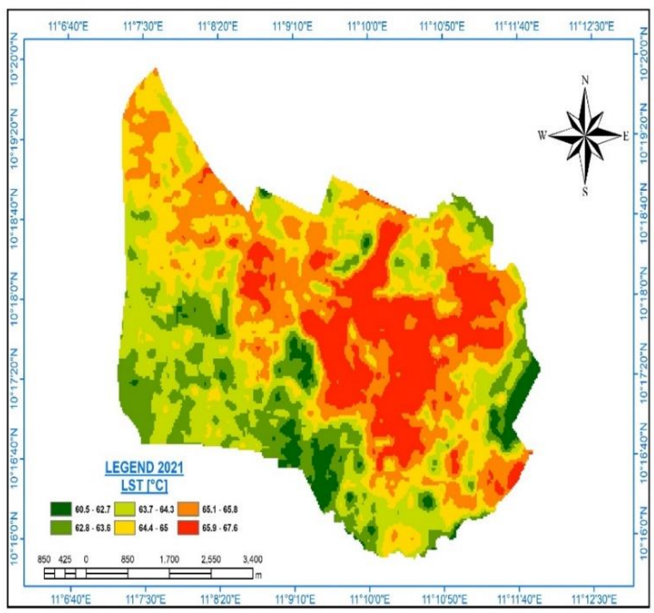

Figure 10: LST of the Study Area for 2021
Source: Author's Data Analysis (2023)

The increasing situation of LST is evident in the mean LST values of 6.2°C, 23.8°C, 31°C and 64.6°C for 1991, 2001, 2011 and 2021 respectively. This is not unconnected to the growing urbanization taking place in the area as seen by the space occupied by built-up areas from 2011 to 2021. This corroborates the findings of Rehman *et al.* (2022) where the researchers opined that increasing percentage of built-up areas arising from human activities and urbanization creates impervious and other heat absorbing surfaces which significantly increases LST.

4.3 Relationship between LULC Changes and LST in the Study Area

The quantitative relationship between the changes in each LULC class and the mean LST for the period of study is determined using linear regression analysis. Figure 11 shows the degree of relationship between percentage changes in farmlands and mean LST. From the analysis there is an inverse relationship and an R^2 value of 0.1495. The implication of this result is that as farmlands increases, mean LST decreases. Also, farmlands are responsible for 14% of the changes in LST

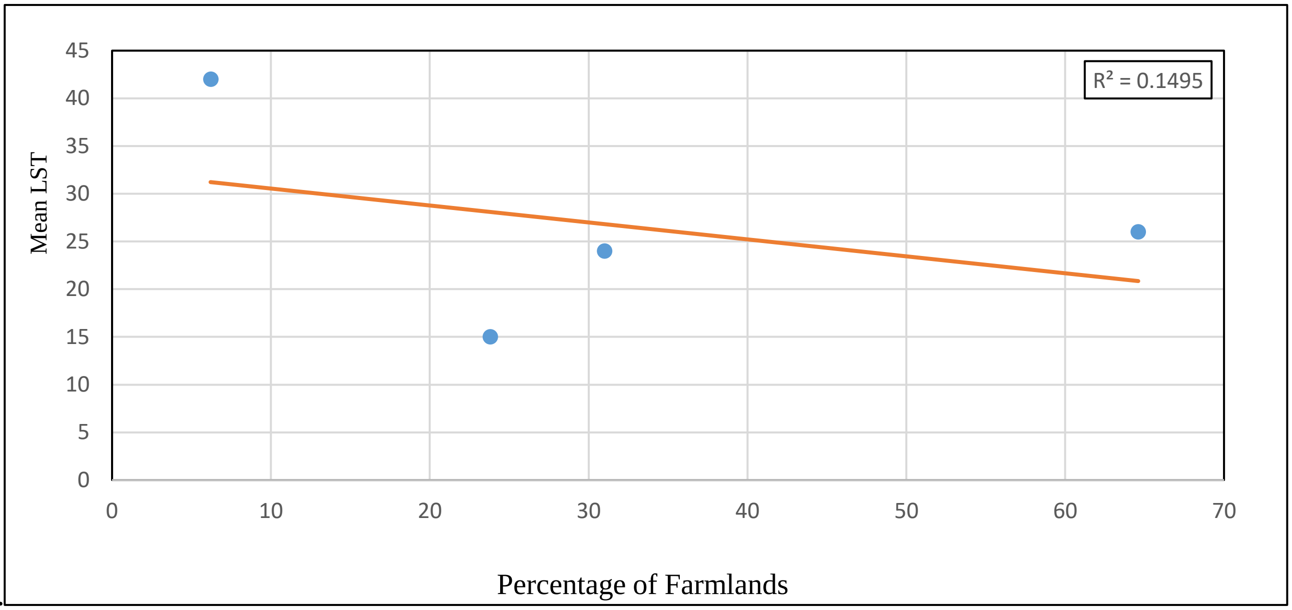

Figure 11: Linear Regression Analysis showing Relationship between Farmlands and LST
Source: Author's Data Analysis (2023)

Furthermore, Figure 12 shows the degree of relationship between percentage changes in bare surfaces and Mean LST for the period of study as derived from linear regression analysis. It is seen from the analysis that there is an inverse relationship between bare surfaces and mean LST with an R^2 value of 0.2707. This implies that as bare surfaces increases, mean LST decreases. The R^2 value derived means that bare surfaces are responsible for 27% of changes in LST for the study period.

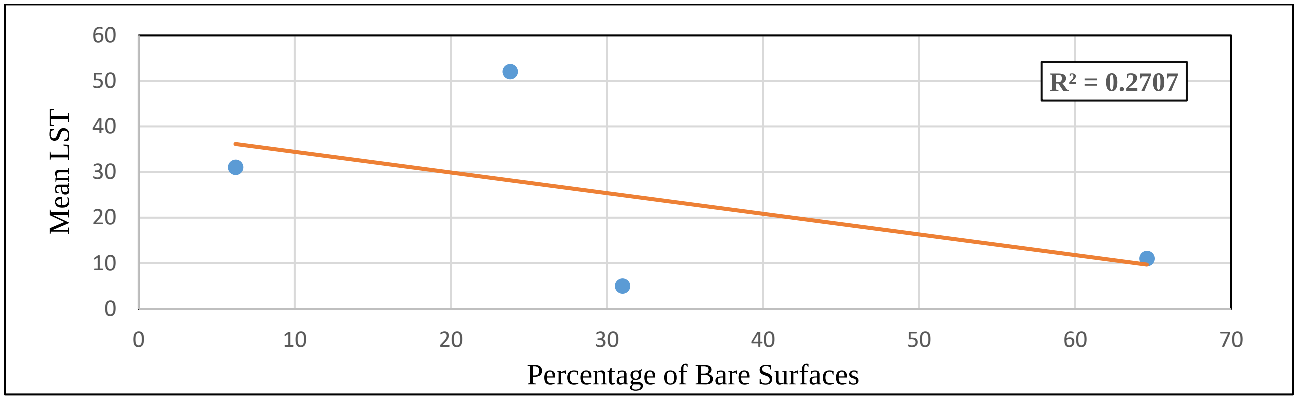

Figure 12: Linear Regression Analysis showing Relationship between Bare Surfaces and LST
Source: Author's Data Analysis (2023)

In the same vein, the degree of relationship between vegetation LULC class and the Mean LST is shown in Figure 13. Linear regression analysis further explains the rate at which the changes in the space occupied by vegetation impacts LST. Since vegetation saw the most decline among other LULC classes, it is no surprising that an inverse relationship exists between the two variables as the continued decline in vegetation results in increasing LST. The linear relationship between the variables shows an R^2 value of 0.4559 which indicates that vegetation accounts for 45% of the changes in LST.

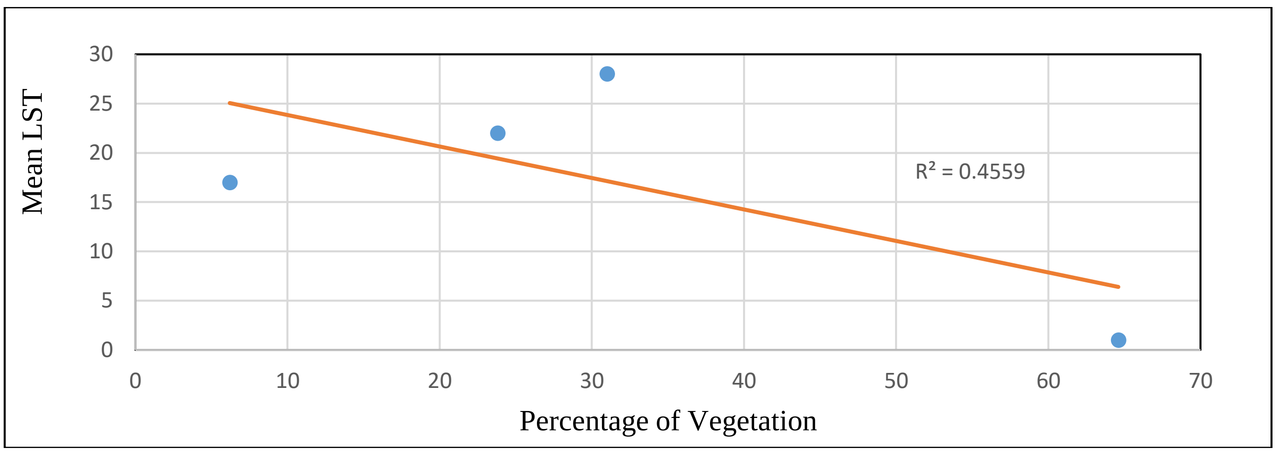

Figure 13: Linear Regression Analysis showing Relationship between Vegetation and LST
Source: Author's Data Analysis (2023)

Finally, the relationship between built-up areas and Mean LST is shown in Figure 14. The result revealed that there exists a positive relationship between Built up areas and LST with an R^2 value of 0.8331. The implication of this result is that as built-up areas increase, LST also increases. The derived R^2 value implies that built-up areas are responsible for 83% of the increase in LST.

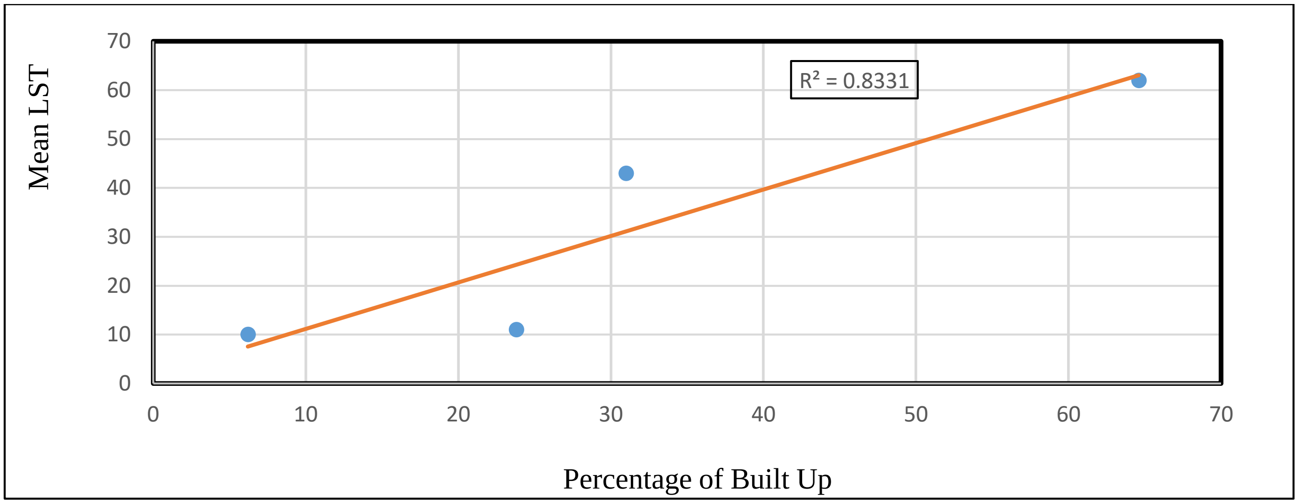

Figure 14: Linear Regression Analysis showing Relationship between Built up Areas and LST
Source: Author's Analysis (2023).

The result of the analysis above reveals that there is a significant impact of changes in LULC on LST. Although vegetation, bare surfaces and farmlands showed an inverse relationship with LST as revealed by an R^2 value of 0.4559, 0.2707 and 0.1495 respectively, it was however observed that built-up exhibited a positive relationship with LST as indicated by an R^2 value of 0.8331. This result implies that the changes in LST in the study area are major because of an increase in built-up which is a product of increased urbanization as most of the buildings are probably made up of concrete, aluminum sheets and glasses which increases internal heating and temperature.

The result corroborates the work of Olofin *et al.* (2022) and Thapa (2020) in which the researchers concluded that an increase in LST is a product of urbanization which in most cases is a result of an increase in built-up areas at the detriment of vegetated surfaces, water bodies and bare surfaces.

5 Conclusion

The results of the study have shown that there is a significant change in LULC and a corresponding change in the LST of the study area. The quantitative relationship between the LULC classes and LST showed an inverse relationship between vegetation, bare surfaces and farmlands. A positive relationship was however seen between built-up areas and LST which indicates that built-up areas is the major predictor for an increase in LST in the study area.

6. Recommendation

The recommendations based on the findings of this study are:

i. Vegetation cover should be increased through green roof and green home approach into the urban environment which will act as a temperature sink and help to provide residential shading.
ii. Light colour (high reflectance and low absorption) building and paved road materials should be encouraged in the study areas to mitigate urban heating and invariably reduce the urban heat island effects.
iii. Temperature-friendly materials such as green infrastructures should be encouraged by the construction industry to mitigate the impact of higher LST in the area
iv. Introducing focused policies on sustainable cities such as the introduction

of urban green belts within the cities and the implementation of the concept of green urbanism by the Government and residents of the study area is highly recommended.

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