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ASSESSMENT OF THE RELATIONSHIP BETWEEN LAND SURFACE TEMPERATURE AND VEGETATION USING MODIS NDVI AND LST TIMESERIES DATA IN KADUNA METROPOLIS, NIGERIA

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ABSTRACT

This study assessed the relationship between land surface temperature (LST) and vegetation using MODIS NDVI and LST timeseries data in Kaduna Metropolis. MOD13Q1 and MOD11A2 datasets were accessed using Google Earth Engine. Mann-Kendall trend test was used to analyse the trends in LST and NDVI. Pearson Moment Correlation Coefficient and Linear Regression were used to examine the relationship between LST and NDVI. Mann-Kendall trend test revealed monotonic downward trend in NDVI with a Z-statistics of -1.2758, but upward trend in daytime and nighttime LST, with a Z-statistics of 0.567 and 2.107 respectively. For the relationship, vegetation showed strong negative relationship with daytime LST with -0.704. Vegetation also showed weak positive relationship with nighttime LST. The linear regression analysis revealed that vegetation was able to predict 49.5% of LST in Kaduna Metropolis, with R^2 value of 0.495 and a standard error of estimate is 2.459. The study concluded that loss of vegetation is responsible for the increase in land surface temperature. The study therefore recommended regulatory agencies should ensure that trees are planted whenever they are removed due to infrastructural development in order to prevent UHI phenomenon and planting of trees should be encouraged in order to regulate the urban climate.

Keywords: Land Surface Temperature, NDVI, MODIS, Google Earth Engine

INTRODUCTION

Land surface temperature (LST) is a key indicator of environmental resources and environmental change (Chi et al., 2020). It plays a significant role in controlling the physical, chemical, and biological processes at the interface between the earth and atmosphere and greatly affects the vegetation condition and soil water (Urqueta et al., 2018). Despite the fact that solar radiation, atmospheric conditions, and land use can all have a significant impact on LST spatial distribution (Hadria et al., 2018; Zhang et al., 2015), rapid urbanization has been identified as a major cause of a city's temperature increase in comparison to rural areas adjacent to it, resulting in the urban heat island (UHI) effect (Ayanlade, 2016; Oke et al., 2017). The urban heat island (UHI) effect significantly raises city temperatures in comparison to adjacent areas (around 4°C), resulting in deterioration of air quality, which is harmful to human health (Pataki et al., 2011; Xu, 2009). Additionally, the urban heat island has the potential to increase the number of hot days in a specific region significantly (Wang et al., 2016).

As a critical feature of UHI, high land surface temperature (LST) will lead to increased water consumption and energy use, and alter species composition and distribution, affecting ecosystem functions (Zhou et al., 2017). Researches have revealed that this high-energy demand affects human health and wellbeing due to air pollution and greenhouse gas (GHG) emissions (Koko et al., 2021). Globally, urbanization is considered a driver of environmental, demographic and socioeconomic transformations (Choudhury et al., 2019). Locally, settlement growth alters the geometric and physical properties of the land surface, resulting in changes to surface energy and the overall radiation budget (Choudhury et al., 2019). Increased impervious surfaces such as buildings, roads, and industries will increase solar radiation absorption while decreasing energy lost through long-wave infrared radiation (Oke, 1976). This uncontrolled conversion of one LULC feature to another has a substantial influence on the local and regional environment (Das et al., 2020; Rakib et al., 2020; Rousta et al., 2018). These transformations have the potential to alter the hydrological, thermodynamic, and radiative activities of the earth surface, thereby amplifying the effects of climate change and heatwaves (Kafy et al., 2021). Consequently, unmonitored alteration of LULC expands built-up areas by displacing vegetation cover, resulting in environmental degradation and increase in UHI effects.

Within the urban area, wetlands such as rivers, intermittent streams, lakes, ponds etc are considered urban cooling islands (UCI) (Bera et al., 2021). These wetlands regulate runoff, mitigate floods and improve water quality (Zhang et al., 2021). They also provide ecosystem services such as provisioning, regulation, spiritual and cultural values (Liu et al., 2020). Furthermore, urban water areas also provide a cooling effect which in turn helps in reducing human exposure to heat stress (Broadbent et al., 2017). Compared to surrounding regions, vegetated areas have little thermal response and creates evaporative cooling, and the influence of surface water on the transmission of latent heat is an important indicator of urban climate (Bera et al., 2021). Town planners globally consider green areas in regulating urban temperature (Coutts et al., 2013). Although urban wetlands have a larger cooling effect than vegetation and lawn (Xueru et al., 2018), urban greenspace has significant cooling effects on urban heat.

Kaduna Metropolis has witnessed rapid settlement expansion, which has led to increase in impervious surfaces (Tini & Light, 2020). These changes have led to the removal of vegetation (Akpu et al., 2017), loss of urban agricultural lands (Saleh et al., 2014), and encroachment of riparian vegetation (Baba et al., 2020). Also, the Kaduna State Government in 2016 started the Urban Renewal Program. This involves massive infrastructural development, which involved road constructions and expansions, construction and upgrade of markets and so on. This has led to the removal of vegetation in some places within the metropolis. Thus, this study will seek to understand the changes in vegetation and their resultant effect on daytime and nighttime land surface temperature in Kaduna Metropolis.

MATERIALS AND METHODS

Study Area

Kaduna Metropolis is composed of Kaduna North and Kaduna South Local Government Areas and parts of Chikun and Igabi Local Government Areas (Akpu et al., 2017). Kaduna Metropolis lie between latitudes 10º20′00″ and 10º39′00″ North of the Equator, and Longitude 7º20′16″ and 7º35′00″ East of the Greenwich Meridian, with an area of 3156 km^2 (see figure 1). The metropolis is bordered from the north, north-east and north-west by the rest of Igabi Local Government Area, and from the south, south-east and south-west by the rest of Chikun Local government area (Baba et al., 2020).

Kaduna is situated in a tropical wet and dry climate (Abdussalam, 2020). The wet season runs for about six to seven months, mostly between April and October, with an average rainfall of 1400mm. The dry season denotes Harmattan, having severe dust haze, with northerly winds blowing from the desert (Omonijo, 2014). Maximum temperature in Kaduna metropolis can be over 30ºC, with the hottest months being March, April and May. Relative humidity typically ranges 25% and 90% depending with the month of the year, with the lowest humidity between December and February (Nigerian Meteorological Agency [NIMET], 2018).

The relief of Kaduna as a plain, comprising extensive tracts of almost level to gently undulating lightly dissected land, broken in places by groups of rocky hills and inselbergs. Much of the area lies between 600 and 800m with scattered hills rising 50-200m above the surrounding land (Bennett et al., 1979). The drainage net is predominantly tributary to the Niger via the Kaduna and Gurara Rivers. Downcutting by rivers is most active in the southern and western margins of the Kaduna Plains (Bennett et al., 1979).

The area lies in Northern Guinea Savannah zone. Therefore, it has Savannah grassland type of vegetation which is made up of tall grasses, scattered trees and gallery. Fringe forests "*Kurmi*" in Hausa in some localities which are presently at the mercy of increasing demands for fuel wood in the fast-growing towns and urban centres (Ajibade & Okwori, 2009).

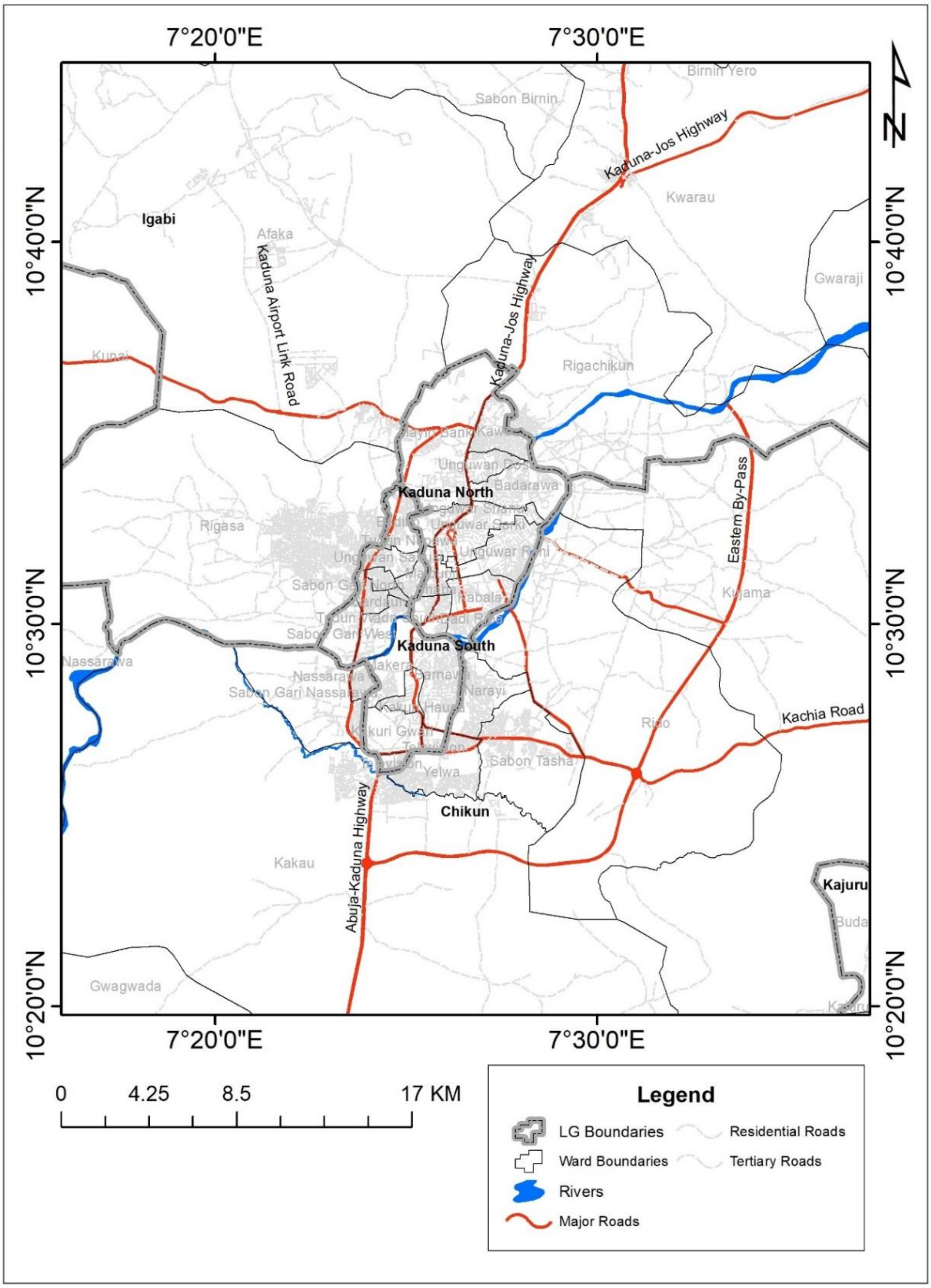


Figure 1: The study area showing the elevation of Kaduna Metropolis
Source: GRID3 - Nigeria, (2022)

Data Sources

MODIS Normalized Differential Vegetation Index (MOD13Q1.006), with a 250m spatial resolution (Didan et al., 2015), and MODIS Land Surface Temperature (MOD11A2.006), with 1km Daytime and Nighttime LST spatial resolution and 8 days temporal resolution (Wan, 2007). These datasets were used to generate monthly timeseries of NDVI and LST using Google Earth Engine cloud computing platform. The datasets from January 2003 to December 2023 were used. The MOD11A2 were resampled to 250m, in order to have the same spatial resolution.

LST and NDVI trend using Mann-Kendall trend test

To analyze the trends of LST and NDVI in Kaduna Metropolis, the extracted monthly LST and NDVI values were subjected to monotonic trend test using XlStat package on Microsoft Excel. Mann-Kendall trend test (Kendall, 1975; Mann, 1945) has been widely used to detect trends in hydro-climatic time-series data (Asfaw et al., 2018; Baffour-Ata et al., 2021; Bekele et al., 2017; Frimpong et al., 2022; Harka et al., 2021; Sa'adi et al., 2023; Shigute et al., 2023; Umar et al., 2019). It is applicable to detect non-normally distributed data and is not sensitive to outliers (Hamed, 2008). The test is applied by accepting or rejecting the null or alternative hypothesizes. The null hypothesis (H_0) of the test assumes that the data are independent and identically distributed with no trend and the alternate hypothesis (H_1) is that there has been an increasing or decreasing trend in the series. The test statistic S is given as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

where, n is the number of observations, x_i and x_j are the ith and jth $(j > i)$ observations in the time-series, respectively, and $sgn(x_j - x_i)$ is the sign function computed as:

$$sgn(x_j - x_i) = \begin{cases} +1, if(x_j - x_i) > 0 \\ 0, if(x_j - x_i) > 0 \\ -1, if(x_i - x_j) > 0 \end{cases}$$

The test statistic S is assumed for the series where sample size $n > 10$ is asymptotically normally distributed with mean $E(S)$ and variance $Var(S)$ as:

$E(S) = 0$, and

$$Var(S) = \frac{n(n-1)(2n+5)}{18}$$

If there is a possibility of a tie in the value of x, and when n is greater than 10, the distribution of statistics S tends to normality (Kendall, 1975); therefore, the variance is computed as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)}{18}$$

where, m is the number of tied groups, t_k is the number of ties of extent k. The standard normal test statistic Z used for detecting a significant trend is expressed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if S > 0 \\ 0, if S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if S < 0 \end{cases}$$

In a two-tailed test, the null hypothesis of 'no trend' should be accepted at the α significance level for $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is the standard score (z-score) of the standard normal distribution with the cumulative probability of $1 - \alpha/2$. Otherwise, the null hypothesis should be rejected and a monotonic trend has been identified at the α significance level. Hence, the positive and negative values of Z show an upward and downward trend, respectively.

Assessing the Relationship Between LST and NDVI

To assess the relationship between LST and NDVI, Pearson Product-Moment Correlation Coefficient was computed using Metan Package on R Studio. Furthermore, to examine the extent of the relationship, Linear Regression was computed with LST as the dependent variable, while NDVI is the independent variable.

RESULTS AND DISCUSSION

Land surface temperature and vegetation of Kaduna Metropolis were subjected to Mann-Kendall trend test, Pearson Correlation Coefficient and linear regression to determine the relationship, and the extent to which vegetation influences land surface temperature in Kaduna Metropolis.

Trend of Vegetation in Kaduna Metropolis Using Normalized Differential Vegetation Index (NDVI)

Monthly Normalized Differential Vegetation Index (NDVI) values of Kaduna Metropolis were computed using MODIS datasets on Google Earth Engine. The monthly NDVI was subsequently used to calculate the trend using Mann-Kendall trend test for monotonic trends. Out of the 245 observations, the minimum NDVI value is 0.267, the maximum is 0.642, the mean NDVI is 0.425 and the Standard Deviation is 0.114. The timeseries is shown in figure 2. Mann-Kendall trend test summary is shown in table 1.

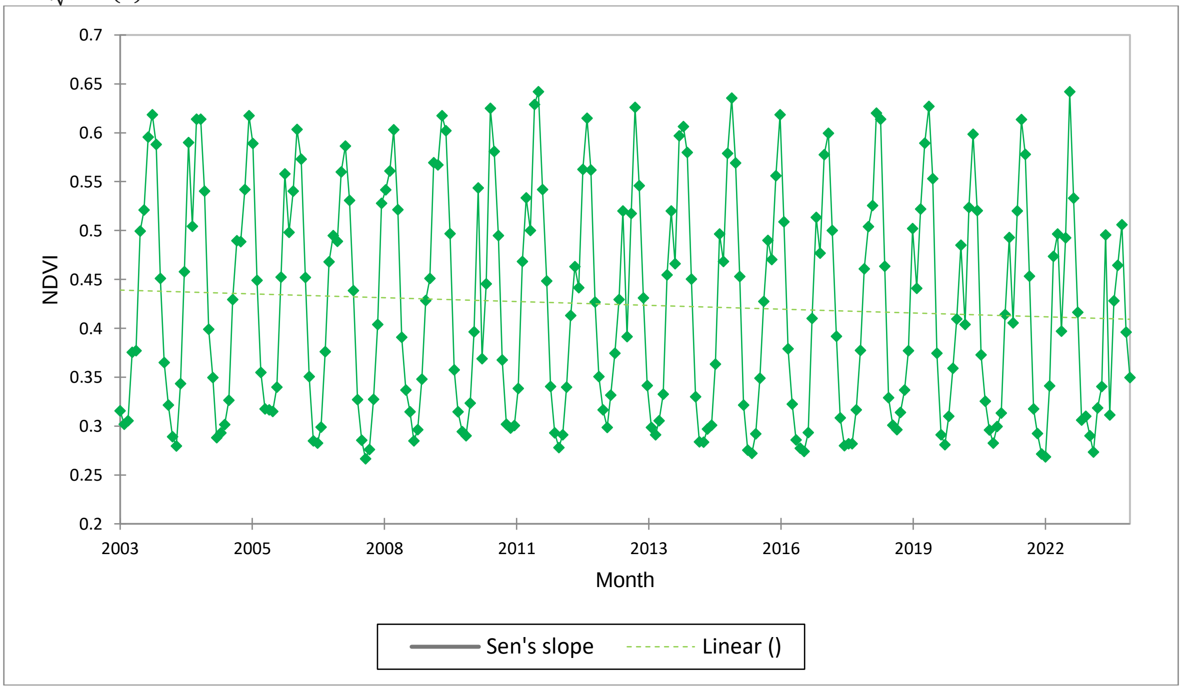


Figure 2: MODIS-Derived NDVI in Kaduna Metropolis from 2003 to 2023

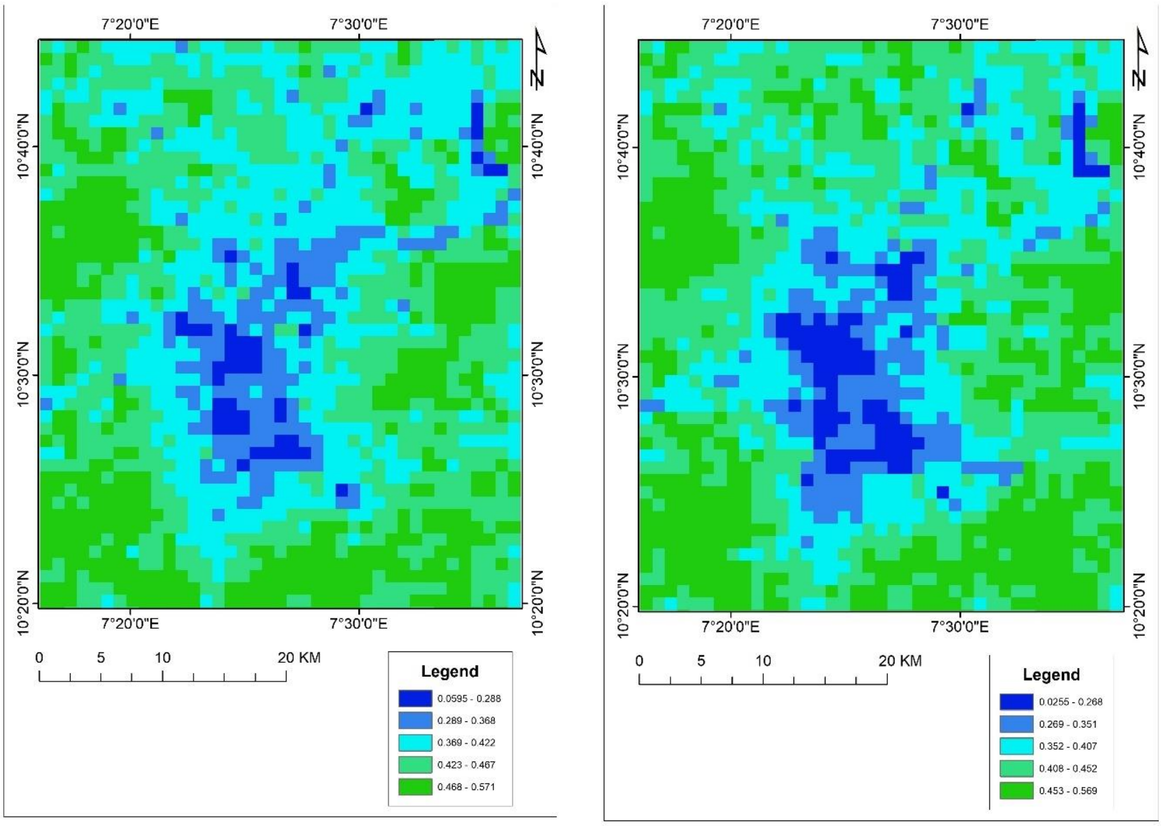
Table 1: Mann-Kendall trend test / Two-tailed test (NDVI)

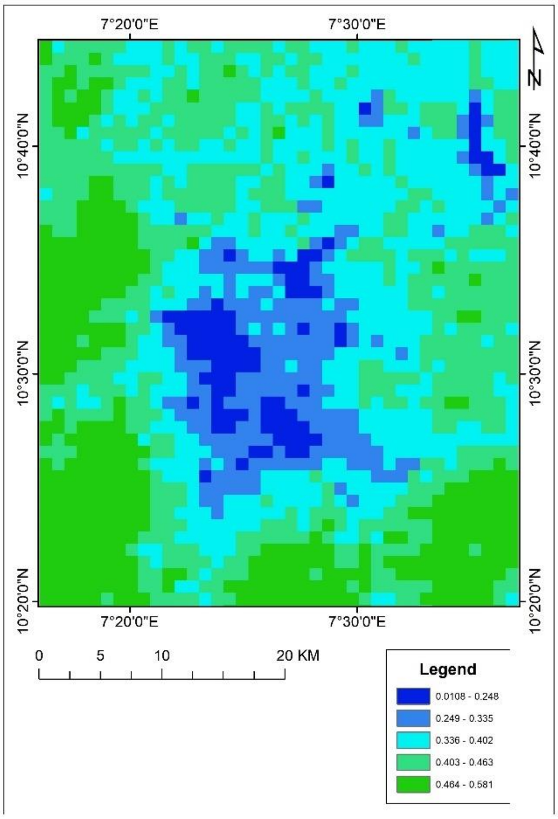
Kendall's tau	-0.219
S'	-498.000
Z	-1.2758
p-value (Two-tailed)	0.001
alpha	0.05
Sen’s Slope	-0.001

From table 1, the Kendall’s tau correlation coefficient of -0.219. Given that the Z score is -1.276, and the p-value (0.001) is less than the significance level (alpha, 0.05), it shows that there is a significant trend in the Normalized Differential Vegetation Index in Kaduna Metropolis. The Sen’s slope value is -0.001, which is the magnitude of trend. This shows that vegetation is decreasing in Kaduna Metropolis.

Furthermore, from the extracted NDVI of 2003, 2013 and 2023, the spatial variation is shown in figure 3. For the NDVI value of 2003, the lowest value was 0.059, while the highest value was 0.571. The mean NDVI for 2003 was 0.427, and the standard deviation was 0.057. For the year 2013, the lowest NDVI value was 0.025, while the highest NDVI values was 0.569, the mean NDVI was 0.410. Finally, for the year 2023, the lowest value of NDVI was 0.011, while the highest recorded was 0.581. The mean NDVI was 0.402. This result disagreed with the findings of Zaharaddeen et al. (2016) which revealed a temporal decline of NDVI in Kaduna Metropolis.

a) b)





(c)

Figure 3: MODIS Derived Normalized Differential Vegetation Index (NDVI) in Kaduna Metropolis in a) 2003, b) 2013 and c) 2023

Trend of Land Surface Temperature in Kaduna Metropolis

Monthly day and night Land Surface Temperature (LST) values of Kaduna Metropolis were computed using MODIS datasets on Google Earth Engine. The monthly LST Day and LST Night were subsequently used to calculate the trend using Mann-Kendall trend test for monotonic trends. For the LST Day, the minimum LST value is 26.050 ºC, the maximum is 40.959 ºC, the mean LST is 32.018 ºC and the Standard Deviation is 3.443. For night time LST, the minimum LST value is 14.707 ºC, the maximum is 23.062 ºC, the mean LST is 19.307 ºC and the Standard Deviation is 1.747. See figure 4.

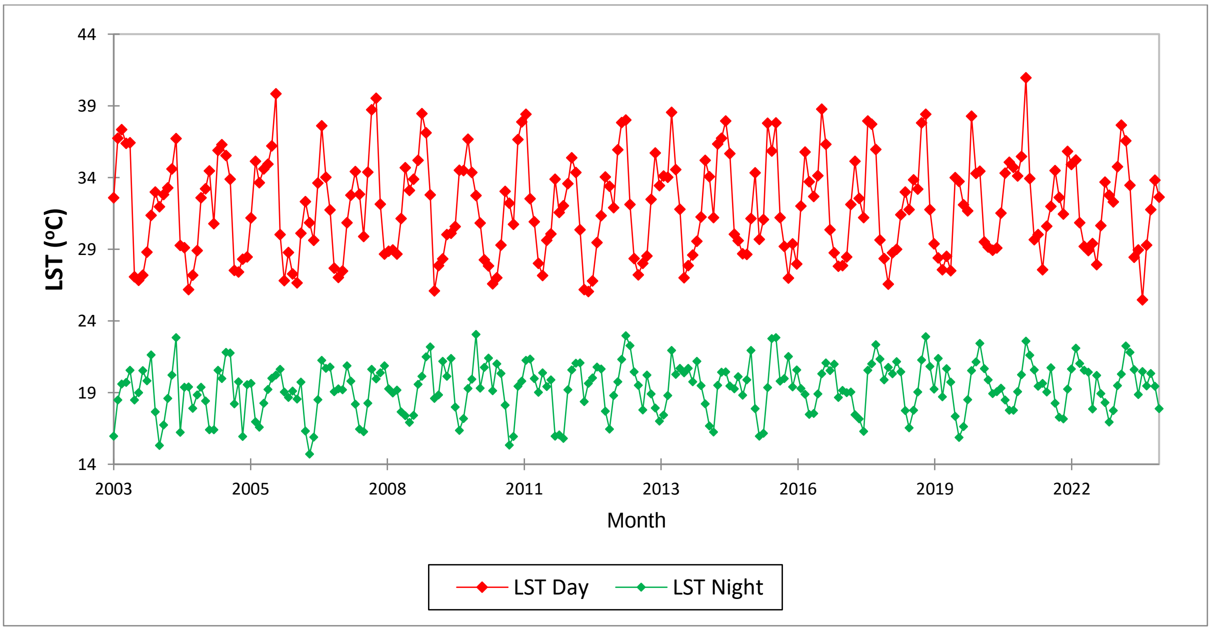
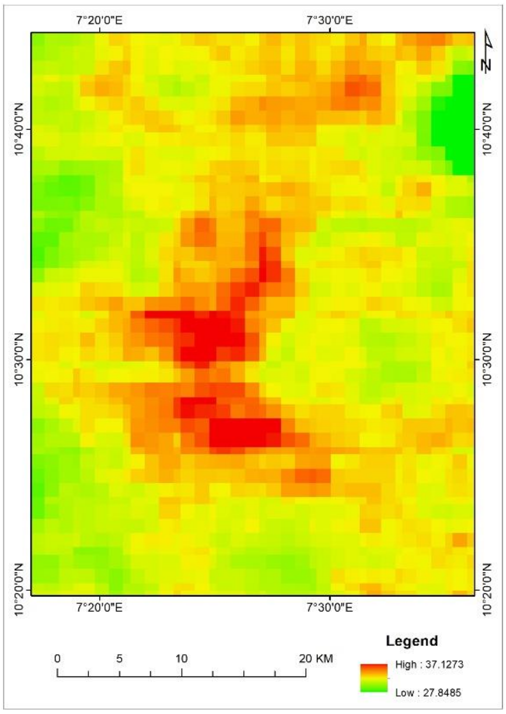


Figure 4: MODIS Derived Land Surface Temperature (Day and Night) in Kaduna Metropolis from 2003 to 2023

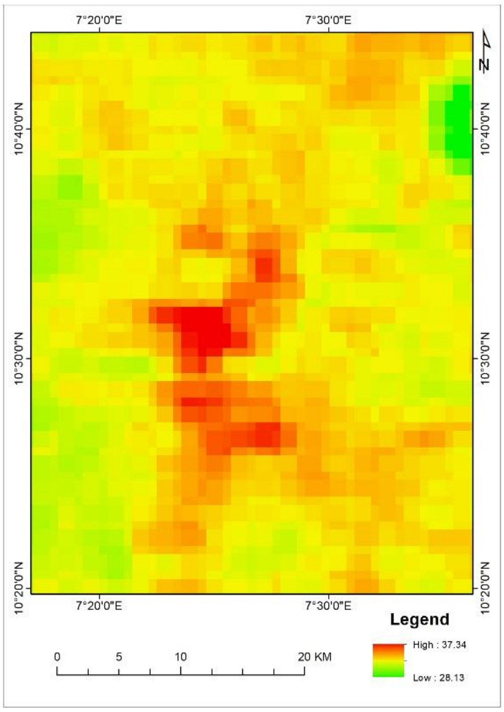
Table 2: Mann-Kendall trend test / Two-tailed test (Day and Night time LST)

	LST Day	**LST Night**
Kendall's tau	0.101	0.207
S'	255.000	522.0
Z	0.567	2.107
p-value (Two-tailed)	0.049	0.0002
alpha	0.05	0.05
Sen’s Slope	0.014	0.048

From table 2, for the daytime Land Surface Temperature, Kendall’s tau correlation coefficient of 0.101. Given the Z score of 0.567 and the p-value of 0.046, which is less than the significance level (alpha, 0.05), it shows that there is a significant trend in the daytime Land Surface Temperature in Kaduna Metropolis. The Sen’s slope value is 0.014, which is the magnitude of trend. Also, for night time LST, the Kendall’s tau correlation coefficient of 0.207. Given the Z score of 2.107, and the p-value of 0.0002, which is less than the significance level (alpha, 0.05), it shows that there is a significant trend in the night time Land Surface Temperature in Kaduna Metropolis. The Sen’s slope value is 0.044, which is the magnitude of trend.



(a)



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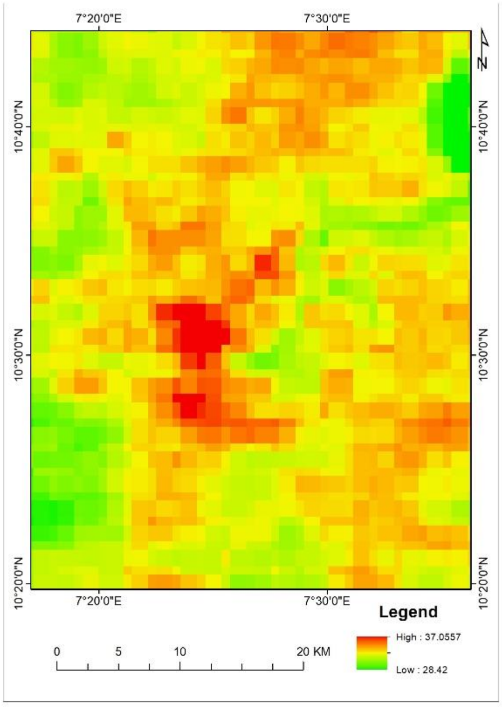

(c)

Figure 5: Land Surface Temperature Characteristics in Kaduna Metropolis in a) 2003, b) 2013 and c) 2023

Figure 5 revealed the spatial variation of LST (Day) in Kaduna Metropolis from 2003 to 2023. Starting from the year 2003, the lowest LST value was 11.59 ^{o}C, while the highest was 39.29 ^{o}C. In 2013, the lowest LST was 19.38 ^{o}C, while the highest LST recorded was 40.23 ^{o}C. In 2023, the minimum LST recorded was 17.94 ^{o}C, while the highest was 45.07 ^{o}C. This result agrees with findings of Zaharaddeen et al. (2016) which revealed increase in LST in Kaduna Metropolis. This increasing trend can be attributed to settlement expansion and urban renewal projects in the study area, which is responsible for the increase in impervious surfaces, and a reduction of vegetation cover.

Relationship Between Land Surface Temperature and Vegetation in Kaduna Metropolis

In order to assess the relationship between the Normalized Differential Vegetation Index (NDVI) and Land Surface Temperature (LST) in Kaduna Metropolis, Pearson Moment Correlation Coefficient was used. The result is shown in table 3.

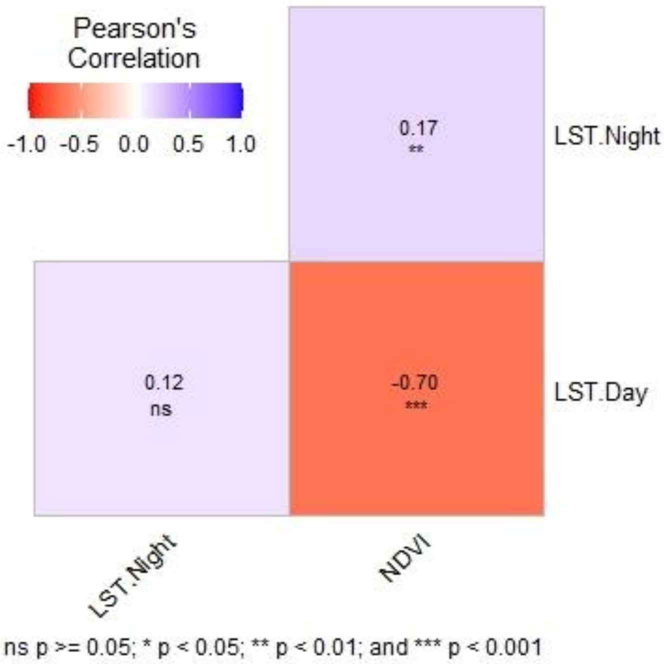

Figure 6: Relationship Between LST and NDVI in Kaduna Metropolis from 2003 to 2023

From figure 6, results revealed that there is a positive correlation between daytime and nighttime LST, with correlation coefficient of 0.129, significant at 0.05 level. The result also revealed a positive correlation between nighttime LST and NDVI, with correlation coefficient of 0.167, which is significant at 0.01 level. However, the result revealed a strong negative relationship between daytime LST and NDVI in Kaduna Metropolis, with correlation coefficient of -0.704, which is significant at 0.01 level. This result is also confirmed by the scatter plot (Figure 7), which shows a strongly negative relationship between LST and NDVI time series.

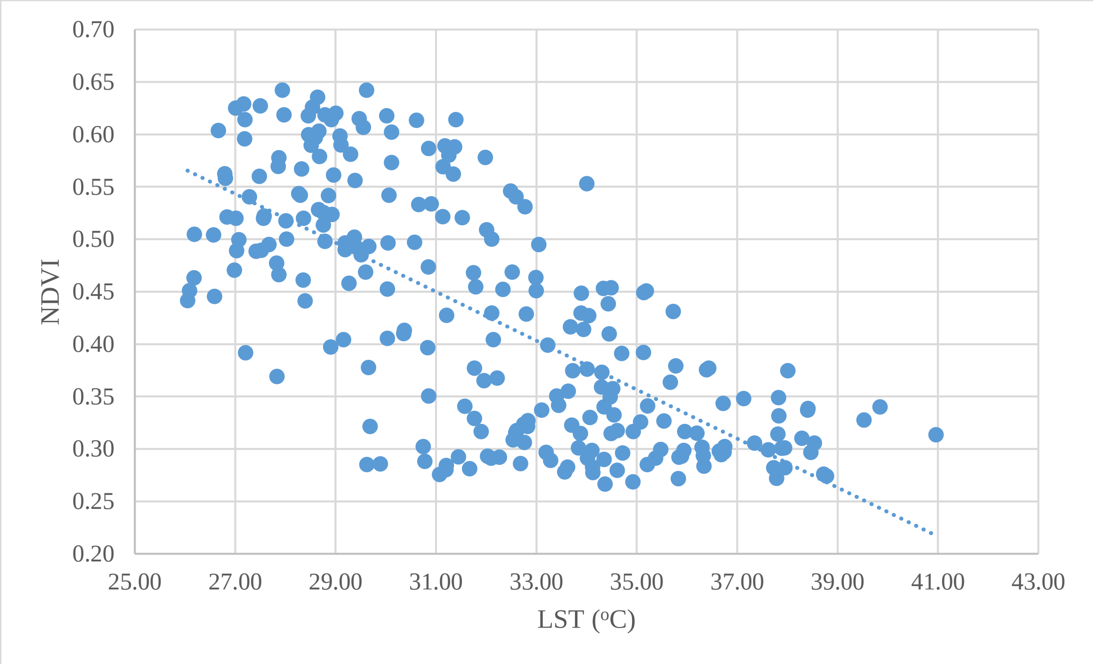

Figure 7: Scatter Plot showing the Relationship Between LST and NDVI

Linear Regression

Table 3 shows the relationship between NDVI as a predictor variable, and LST as the dependent variable.

Table 3: Extent of Relationship between NDVI and LST in Kaduna Metropolis

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.704[a]	.495	.493	2.458

a. Predictors: (Constant), NDVI

From table 3, results revealed that vegetation (NDVI) is able to predict 49.5% of LST in Kaduna Metropolis. The standard error of estimate is 2.458.

Implication

The study revealed that vegetation in Kaduna Metropolis is significantly declining. This is similar to findings of Richards and Belcher (2019) that the global south is experiencing decline in urban vegetation cover, and all over the world, decrease in vegetation health and density is linked in increase in land surface temperature (Ullah et al., 2023). Furthermore, the study also found an increase in the distribution and intensity of land surface temperature. This increase in land surface temperature has several consequences on human health. For example Nse et al. (2020) found that humans suffer from heat waves, heat stress, heat related diseases, heat strokes and many other illnesses related to high surface temperatures. In some cases, high land surface temperature can exacerbate the risk of dying due to the defilement that can result from severe deficiency in organ function (Kovats & Hajat, 2008).

CONCLUSION

From the findings of this study, it can be concluded increase in built up areas is the leading cause of increase in land surface temperature (LST) and decrease in vegetation (NDVI). The increase in land surface temperature is attributed to expansion in built up areas. The study also concluded there is a significant downward trend of the NDVI in Kaduna Metropolis. For the timeseries of daytime and nighttime LST, the study concluded that there is a weak positive trend, with significant increase within the built-up areas. Finally, the study concluded that there is a strong negative relationship between NDVI and LST, which indicates that as vegetation is decreasing, land surface temperature is increasing.

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