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MODIS Data Assessment of the Relationship between Vegetation and Land Surface Temperature for Central Vegetation Zone of Adamawa State, Nigeria

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Abstract

Global concern over climate change has necessitated the need for the study of the impact of the ever-increasing land surface temperature on the greenness of land covers. Grassland phenological events are dependent on land surface temperature. This work is aimed at assessing the spatio-temporal trend of the relationship between vegetation cover and the day and night-times land surface temperatures in the Northern Guinea Savanna vegetation zone of Adamawa state, Nigeria. Twenty years (2000 to 2019) data series of Moderate Resolution Imaging Spectroradiometer (MODIS) surface reflectance data (MOD09A1), the day-time land surface temperature data (MOD11A), and the night-time land surface temperature (MYOD11A1) were used to spatially compute the Normalized Difference Vegetation Index (NDVI) and day-time and night-time Land Surface Temperatures (LST) for each of the respective years of the study period. The day- and night-time LST were correlated with the NDVI using simple linear regression analysis. The temporal analysis of the results indicate nonlinear changes in both the NDVI, day-time LST, and night-time LST. The results also indicate a negative correlation between LST and NDVI in both cases. Regression analyses of the day-time LST as a function of NDVI revealed a vegetation cover reduction of 0.0063 per Kelvin change in LST (R^2 = 0.3026, p > 0005, RMSE = 8.1042) and a night-time vegetation cover reduction of 0.0103 per Kelvin rise in LST (R^2 = 0.3697, p > 0.05, RMSE = 3.7511). The relatively low coefficient of determination and the p values implies a weak relationship between the two variables. The parameters however indicate that the night-time LST is a better predictor of the vegetation greenness of the area. The results revealed that LST is a weak determinant of plant phenological events with respect to the study area.

Keywords: Plant Phenology, Normalized Difference Vegetation Index (NDVI), Northern Guinea Savanna, Climate Change,

INTRODUCTION

The phenomenon of climate change has a significant impact on the overall global ecosystem as it severely affects the mode and levels of interaction between living and nonliving components of the system. Climate change obstructs the natural adaptation mechanism of biodiversity and population distribution in the ecosystem resulting in the depletion and some cases the extinction of some species. The response of biodiversity to global warming is diverse

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and complex. In an attempt to develop a climate model in response to the ever-increased greenhouse gasses in the atmosphere, Dusenge *et al.* (2019) observed that the CO_2 absorbed by the green plant during photosynthesis and the subsequent release of O_2 and water in the processes of plants' evapotranspiration cool the surrounding air, leading to the moderation of the atmosphere. Excessive CO_2 however shrinks the plant's stomata, leading to a decrease in the amount of water and O_2 released by the plant and hence reducing the cooling effect. Furthermore, changes in the diffused reflection of solar radiation (the albedo) result in increased variation in the distribution of green vegetation (Durand *et al*., 2021). Studies on the impact of solar radiation and surface temperature of specific leaf areas of various plants indicate a complex relationship that significantly varies with the temperature range and plant type (Rosbakh *et al.,* 2015).

Being an indicator parameter of solar radiation, Land Surface Temperature (LST) is an important factor of great influence on the effective biodiversity of an ecosystem in general, and a specific indicator of the availability of the albedo for green vegetation. It plays an important role in heat energy exchange between land surfaces and the atmosphere (Haghighi *et al.,* 2018), and therefore influences vegetation cover dynamics. Studies on the correlation between the LST and vegetation index carried out by many authors (Guha and Govil, 2021; Alshaikh, 2015; Kumar and Shekhar, 2015) indicate that the relationship between the two parameters is nonlinear and site-specific due to the increase in the intensity of urban heat island. It is therefore recommended that the LST –vegetation cover relationship should be calibrated for specific local climate zone (Ferreira and Duarte, 2019).

Spatiotemporal changes in climatic parameters have a significant relationship with plant development. Studies have shown that phenological parameters such as the length of seasoning, start and end of the season, and the position of peaks and troughs in plant development is affected by the Spatio-temporal changes in land surface temperature (Le *et al.,* 2021; Han and Xu, 2013; Shen *et al.,* 2022). The degree of variability of the above-mentioned phenologic events with LST differs spatially with latitude mainly due to the variation in the cooling effect of the albedo and evapotranspiration with latitude (Shen *et al.,* 2022).

On the temporal scale, time series of remote sensing products were used by Yu *et al*. (2022) to study the effect of the changes in the day and night-time LST on crop greening. The results indicate that the cooling effect of crop greening due to the day-time LST is stronger than that due to the night-time LST. They attributed this variation to the aerodynamic and surface resistance as the major driving factors for the day-time LST cooling effect whereas the night-time cooling effect is induced by ground heat flux and ambient temperature. Studies of the alpine grassland of the Tibetan plateau, Western China, by Li *et al*. (2021) show that the day-time LST played a dominant role compared to the night-time LST. They further observed that the Start of the Season (SOS) is delayed with an increase in day-time LST and enhanced with an increase in night-time LST.

Since both the length of the day and night, the cooling effect of albedo and the evapotranspiration as well as the degree of phenological events are all functions of latitude, the need for baseline data for the study of the relationship between the day and night-time LST with grassland greening of a tropical vegetation zone cannot be overemphasized. Despite its richness in agriculture and relevance in agro-industries, literature and baseline data on the impact of the day and night-time LST variation on vegetation greenness relative to the tropical vegetation zones are scanty, especially in the northern Guinea Savanna zones of Northeastern Nigeria, which host major agro-industries within the region.

This work is aimed at examining the relationship between day-time and night-time LST, and the vegetation density of the Adamawa arm of the Northern Guinea Savanna vegetation zone of Nigeria. The Adamawa portion of the climate zone is defined by the Benue valley which is the area's most significant feature and transects through its center. The goals of the work are to observe the Spatio-temporal trends of the vegetation cover, as a response to day and night changes in the LST relative to the low latitude climate zone. The work will serve as an effective tool for monitoring the impacts of high-frequency temporal changes in climatic parameters on the grassland greenness of the region. The results will serve as vital information necessary for modeling and estimating plant phenological events with LST within the study area.

METHODOLOGY

In this work, we used optical remote sensing data to monitor both the day and the night-time land surface temperature and the vegetation density of the study area. Remote sensing satellite systems provide a unique opportunity for continuously monitoring of the earth's atmospheric parameters and processes on a global scale. Before the development of the remote sensing satellite system, measurements and observations of atmospheric parameters are accomplished using land-based meteorological instruments where the records are characterized by low spatial resolution, cumbersomeness in large-scale mapping, and high cost of equipment deployment. With the space-borne earth observation satellite system, a wide range of atmospheric parameters can be monitored continuously at a regular intervals of time on a global scale. This leads to an enhanced understanding of the earth's atmospheric processes and dynamics. Various satellite platforms and sensors provide data in different spatial and temporal resolutions. Taking into cognizance the size of the study area and the temporal resolution requirement, Moderate Resolution Imaging Spectroradiometer (MODIS) data was used for both the LST retrieval and the green vegetation mapping.

Study Area

The study covered a central portion of Adamawa state, Northeastern Nigeria, defined by one of the three classes of the vegetation belts of the state, the Northern Guinea Savanna. It is geographically located between latitudes 8°49′48″ N - 9°57′09″ N and longitudes 11°11′17″ E – 13°20′51″ E. (Figure 1). The vegetation of Adamawa state of Nigeria is roughly classified into three major zones (Akosun *et al.,* 2020): the Northern Guinea Savanna, the Southern Guinea Savanna, and the Sudan Savanna. The study area is limited to the Northern Guinea Savanna region, which constitutes the largest landmass in the state. The area is centrally located and follows the trends of the Benue River. The vegetation of the area is therefore defined by the Benue valley characterized by the combination of thick trees, open grassland, and the fringes of forest along the river valleys. The region is a beehive of agricultural activities, especially in areas close to settlements, a factor that influences the magnitude of its vegetation cover. The dominance of vegetation cover within the study area is mainly due to the large-scale all-season sugarcane plantation of the Savanna Sugar Company and the famous Lake Gerio irrigation farming activities within the area. The Adamawa segment of the Northern Guinea savanna vegetation is characterized by a mean annual rainfall of 900 – 1100 mm and a rainy season that lasts for about 4 – 5 months (Akosun *et al.,* 2020). The area is moderately vegetated with a wide variety of species ranging from woody to grasses.

Data Acquisition and Interpretation

MODIS is a satellite-based remote sensor used for observation of the earth and climate parameters. The sensors are aboard the Terra and Aqua satellites. It is described by Phan and Kappas (2018) as a significant tool for global studies of the atmosphere, land, and ocean processes. MODIS scans the earth's surface from the nadir in 36 bands. Bands 1-19 and band 26 correspond to the visible and near-infrared range while the remaining bands correspond to the thermal infrared (3-15 μm). However, only seven MODIS emissive bands are useful for land surface remote sensing (Wan, 2014).

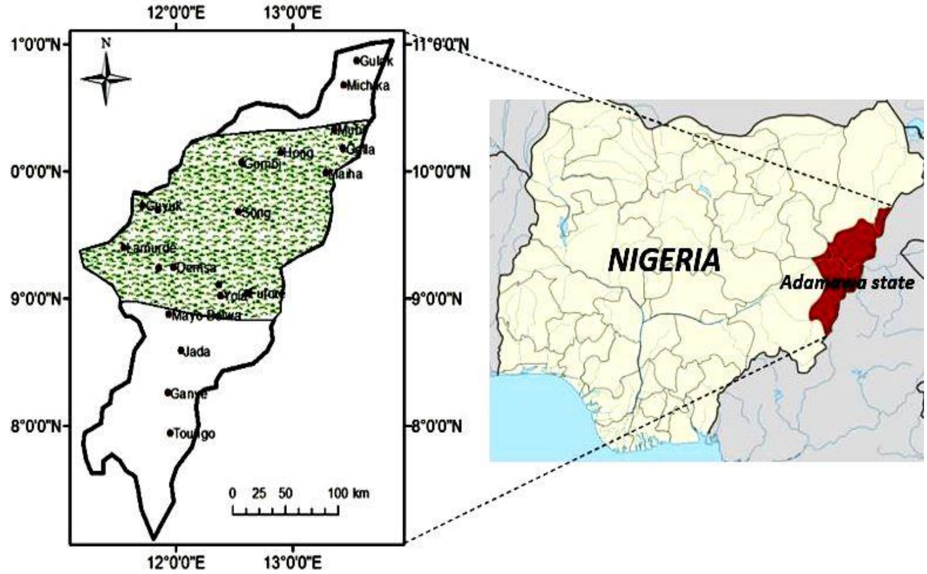

Figure 1. Map of Nigeria, showing Adamawa state and the study area

The improved version (version 6) of MODIS produces data consisting of surface reflectance (MOD09A1), day–time land surface temperature (MOD11A2), and night-time land surface temperature MYOD11A2. MOD09A1 is a product that provides a spatial estimate of the surface spectral reflectance with a sufficient spatial and temporal resolution for mapping the spatial variation in vegetation density with reasonable accuracy (Skakun et al., 2017). The set of data relative to the study area was obtained from the United States Geological Survey (USGS) Earth Resource Observation Systems Data Center (https://earthexplorer.usgs.gov). The sensor records 8-day surface reflectance at a spatial resolution of 500 m in seven bands (MODIS Bands 1 to 7). The level three (L3) products used for this study were atmospherically corrected for cloud cover and aerosol. Table 1 gives a list of the seven reflectance bands and their bandwidth description.

Table I. The 7 bands of MOD09A1surface reflectance

	Bandwidth(nm)	**Band Description**
Band 1	630 - 670	Shortwave/VIS
Band 2	841 – 876	Shortwave/NIR
Band 3	459 – 876	Shortwave/VIS
Band 4	545 - 565	Shortwave/VIS
Band 5	1230 - -1250	Shortwave/NIR
Band 6	1628 - 1652	Shortwave Infrared/SWIR
Band 7	2105 - 2155	Shortwave Infrared/SWIR

MOD11A1 and MYOD11A1 (day and night-time respectively) are two standard daily LST products generated from the products of the sensor radiance data, the geolocation product, the atmospheric temperature, water profile, cloud mask, and the land cover (Wan, 2013). The LST product is generated using the generalized split-window algorithm (Wan 2014). The two provide per-pixel daily records of the day–time and night-time land surface temperatures in kelvin at a spatial resolution of 1 km with a scale factor of 0.02. The LST band pixel values are therefore converted into LST in ^{0}C by multiplying the pixel values with the scale factor of 0.02 and subtracting 273.15 from the result (Idi *et al,* 2022).

The Normalized Difference Vegetation Index (NDVI) is a sufficiently good indicator of vegetation density and greenness of land surface because of its ability to optimally discriminate between the chlorophyll-absorbed visible red light and the reflected near-infrared light. The photosynthesis activity associated with a healthy plant of dense vegetation will results in minimal reflectance in the red band and high reflectance in the near-infrared band. Thus comparative analysis of the reflectance spectra could lead to a reliable detection and spatial mapping of the vegetation cover. The vegetation density was computed in this case using the NDVI. Using the MODIS MOD09A dataset, NDVI is computed as the ratio of the reflectance in the near-infrared NIR band ρ_{nir} to the reflectance in the red band ρ_r. That is

$$NDVI = \frac{\rho_{nir} - \rho_r}{\rho_{nir} + \rho_r} \quad (1)$$

From table 1, it can be observed that the NIR band corresponds to band 1 (630 – 670 nm) while the red band corresponds to band 2 (841 – 876 nm). Thus NDVI computation is accomplished by computing the ratio

$$NDVI = \frac{band\ 2 - band\ 1}{band\ 2 + band\ 1} \quad (2)$$

Both MOD09A1, MOD11A1, and MYOD11A1 products were downloaded from the NASA earth data home page (https://search.earthdata.nasa.gov). We downloaded the sets of data acquired within the first two weeks of December for the years 2000 to 2019 and used them to compute the LST and the correspondent NDVI. We compared the computed LST and NDVI using a regression analysis for each of the two correspondent images.

RESULTS

Both the computed LST and the vegetation index according to this study indicate significant nonlinear variation with time at least within the relatively short period of the study. Figure 2 are maps of the spatial variation of the day-time LST for the years 2000, 2005, 2009, 2013, 2017 and 2018. The maps indicate significant variation in LST. It is however observed that there is consistency in the magnitude of variation of the LST with the spatial location for all the years. This can be understood based on the variability of the emissivity values of the different permanent land cover types. The day-time LST for the twenty-year study period ranges from a minimum value of 31.79^{0}C (which occur in 2015) to a maximum value of 37.71^{0}C (which occur in 2001). This indicates nonlinear changes in the surface temperature with time. As expected, the night-time LST is comparatively lower in magnitude compared to the day-time LST.

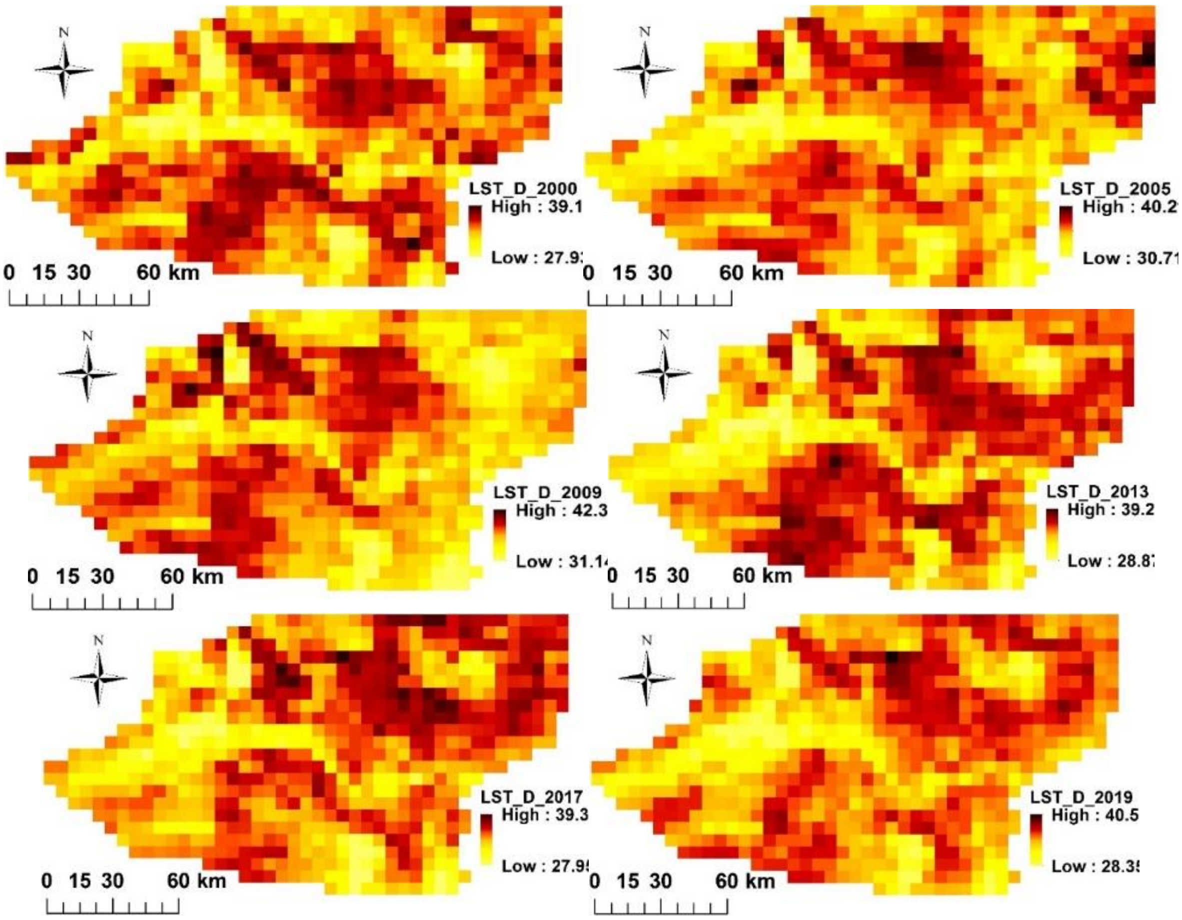

Figure 2. Day-time Land Surface Temperature of the study area for the years 2000, 2005, 2009, 2013, 2017 and 2018.

The night-time LST varies from a minimum value of 17.11^{0}C (2006) to a maximum value of 20^{0}C (2013). Fig 3 depicts the plots of the spatial distribution of the night-time LST, serially arranged for the selected 6 years within the study period.

Careful observation of the figure indicates that the night-time LST is more spatially consistent compared to the day-time LST. The vegetation index of the study area for the period was estimated using equation (2). Figure 4 is the plots of the NDVI map, depicting the spatial distribution of the vegetation cover for some selected 6 years within the study period. The figure indicates erratic changes in the vegetation cover of the area which implies significant changes in the vegetation density over time. Statistical distribution of both the day and night-time LST as well as the NDVI indicate a nonlinear variation of the three parameters on a time scale.

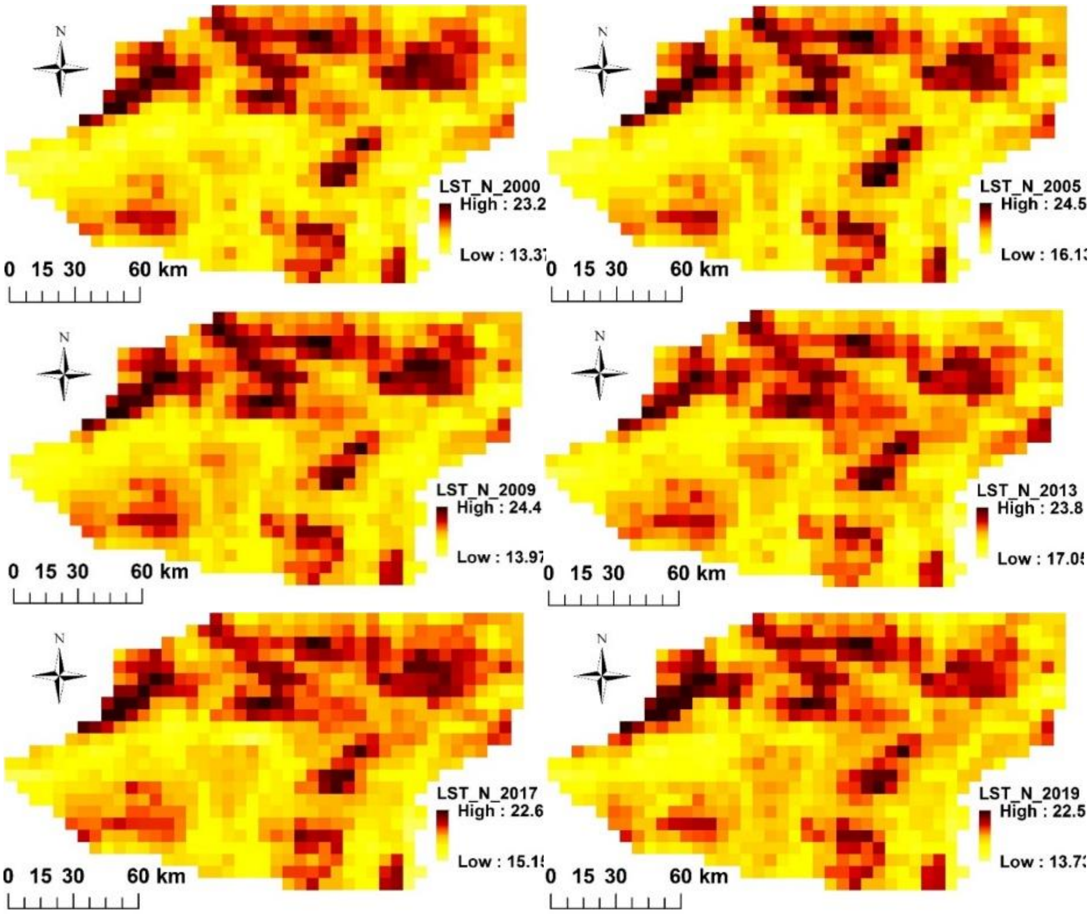

Figure 3. Night-time Land Surface Temperature of the study area for the years 2000, 2005, 2009, 2013, 2017 and 2018.

Figures 5,6 and 7 are respectively the boxplots of the statistical distribution of the three parameters. The plots give a pictographic view of the observed inter-annual variability of the three parameters within the study area. The nonlinear variability may not be unconnected with the high level of human activities within the area which tends to affect the land cover type at different times. From the spatial distribution of the NDVI map (Figure 4), it is observed that the marshy areas within the banks of the Benue and its distributaries are consistently characterized by vegetation density in contrast with the built-ups and rocky upland areas.
Observations of Figs 5 and 6 show that LST peaks were recorded for both day-time and night-time in the year 2001. The high values of LST are good demonstration of how factors such as heat waves can affect the temporal distribution of the surface temperature. The occurrence of intermitted drought on the other hand could be responsible for the temporal variability of NDVI as shown in Fig 7 where low records were observed in 2016 and 2017.

We used regression analysis to observe the pattern of the interrelationship between the day-time LST and the NDVI on one hand and the night-time LST and the NDVI on the other hand. The analysis is done based on per-pixel correlation to analyze the relationship in the spatial rather than temporal domain. Corresponding pixels from two images were randomly sampled using create random point functions of the ArcToolbox in the ArcGIS environment. The raster images were converted from float to integer type and the pixel values at the sampled points were extracted in each of the images. The corresponding DN of the sampled pixels were compared based on statistical metrics by computing regression parameters for both the day and night-time data. Figure 8 shows the plots of the day-time and night-time LST with the NDVI respectively. The regression equations in each case indicate a negative slope, which means a negative correlation or inverse relationship between LST and the vegetation indices. This implies that an increase in land surface temperature has a negative effect on the vegetation cover. Regression analysis of the day-time LST-NDVI dataset gives a slope of -0.0063 with a fitting coefficient R^2 value of 0.30a 26, a p-value of 0.6048 (> 0.05) and an RMSE value of 8.1042. This indicates an NDVI reduction of 0.0063 per kelvin change in land surface temperature. The result is significantly different from the night-time LST-NDVI dataset where a slope of -0.0103 is recorded with an R^2 value of 0.3697, a p-value of 0.8181 (> 0.05) and an RMSE value of 3.7511. this indicates a reduction of 0.0103 vegetation cover per kelvin change in night-time temperature.

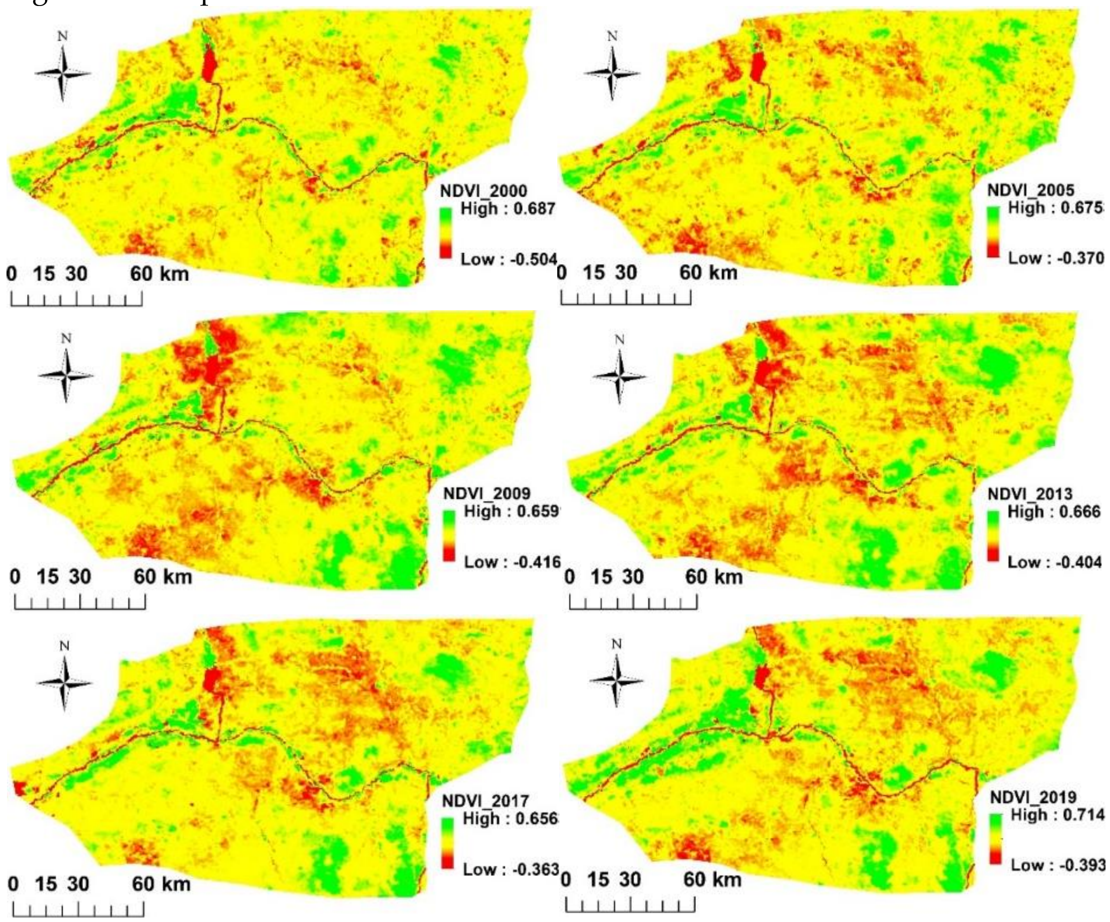

Figure 4. NDVI maps of the study area for the years 2000, 2005, 2009, 2013, 2017 and 2018.

The night-time's records of higher value of coefficient of determination implies that the response of the vegetation density to night-time LST is more significant and consistent than that of the day-time.

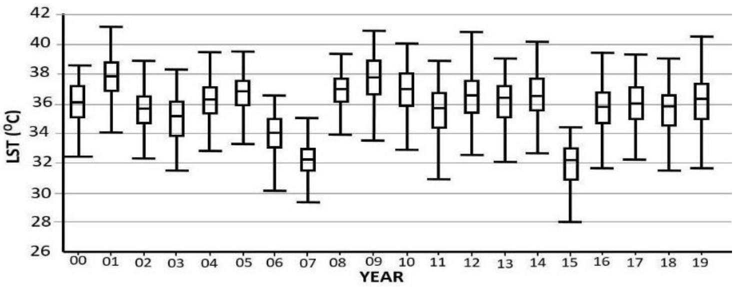

Figure 5. Boxplot of the distribution of day-time LST.

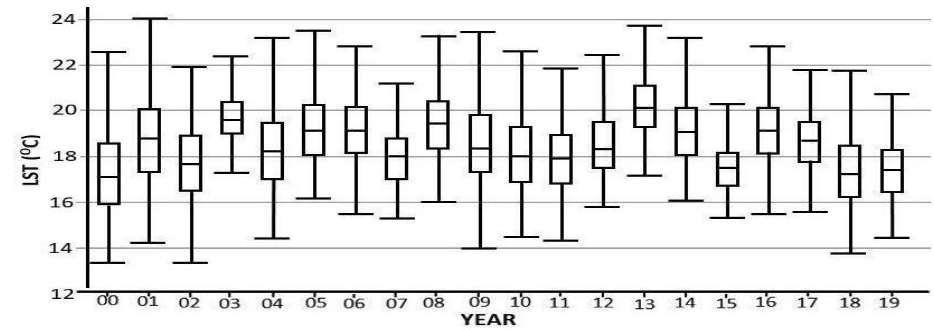

Figure 6. Boxplot of the distribution of night-time LST.

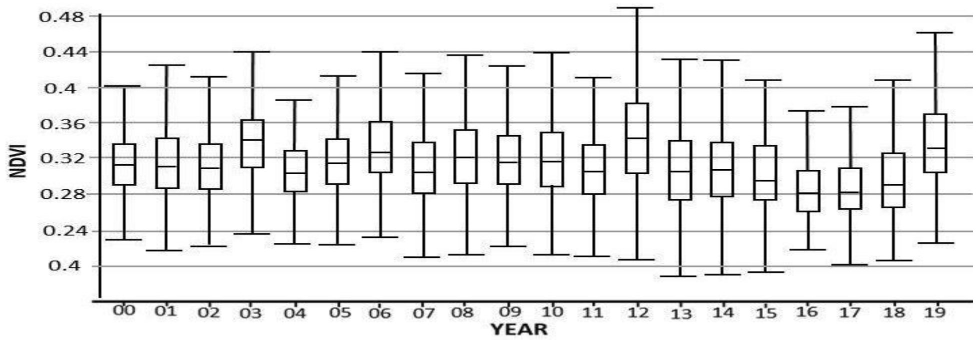

Figure 7. Boxplot of the distribution of NDVI

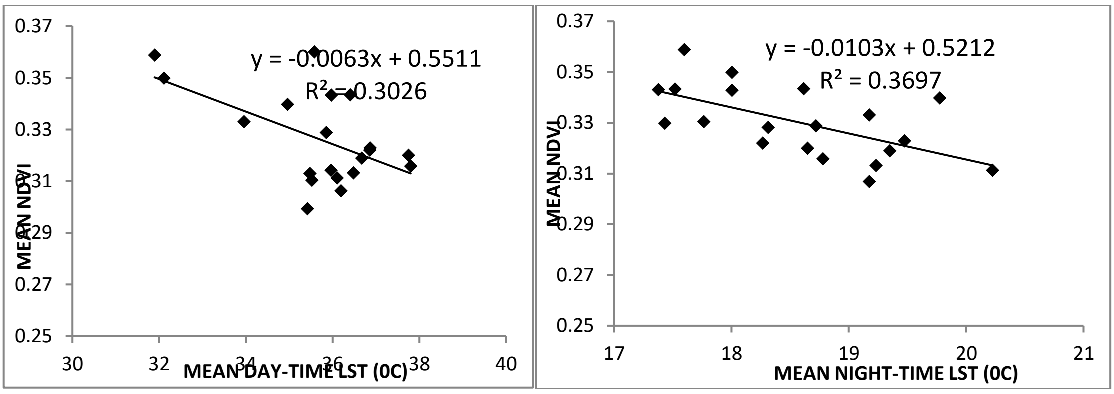

Figure 8 plots of the correlation between LST and NDVI

DISCUSSION

A time series analysis of the 20 – year day and night-time LST-NDVI relationship for the study area presented showed a higher day-time surface temperature than the night-time, obviously due to the influence of solar insolation. A decrease in the trend of the vegetation cover with surface temperature was recorded for both day-time and night–time. With p- values of 0.6048 (>0.05) and 0.81812 (>0.05), statistical evidences indicate that both the day-time and night-time LST could not be good predictors of the greenness of the area. The values of the coefficients of determination indicate that the day-time LST can be used to give account for only about 30% of the changes in the greenness of the area. There is however slight improvement with respect to the night-time data where about 37% of the changes in LST can be attributed to the variation in the vegetation greenness. Additionally, a comparison of the RMSE value of 3.7511 recorded relative to the night-time LST changes with NDVI is relatively smaller than the day-time RMSE value of 8.1042. This implies that the night-time LST could have been a better estimator of the vegetation greenness of the study area.

The spatial distribution of LST and NDVI values obtained from the maps indicates the abundance of vegetation cover along the Benue valleys and its tributaries (Fig 4). This correspondingly coincides with the low values of surface temperature for both day and night-time (Figure 2 and 3). This same trend was observed by many authors in different regions of the world (Imran *et al*., 2021; Alshaikh, 2015; Guha and Govil, 2021). It is observed based on the study that there is a nonlinear trend in the relationship between LST and the degree of vegetation density. This complex relationship can be explained based on the radiant energy balance between the incident short-wave solar radiation on one hand, and the incoming and outgoing-wave radiant energy of the surface albedo and the thermal flux of the round surface. The land surface cools rapidly at night and hence the longer the night-time, the larger the difference between the day and night-times LST.

The nonlinear trend in the relationship between LST and the vegetation cover also suggests the influence of land-use changes such as urbanization and the variation in the level of agricultural activities in the area. Conversely, lower vegetated areas within the north-central and the central portion of the study area correspond to higher values of land surface temperatures. This is however not a perfect inverse relationship as shown in the correlation analysis plot. It could however be attributed to a lot of intervening factors such as the land cover type and elevation of the geographic location.

Based on the degree of changes in both the LST and NDVI with time, LST varies with the different land cover types due to variations in optical properties (emissivities) of the different land covers. Since no land cover type is homogeneous, the LST also differs for different parts of each land cover. Vegetation could serve as a cooling mechanism that will reduce heat flux through shading and evapotranspiration. Vegetation shading in the area decreases the penetration of the sunlight intensity into the soil which helps in cooling the land surface. Hence lower LST is recorded in the highly vegetated areas. Conversely, convection and free air floor are higher in low vegetation density regions. This tends to reduce the LST. Though the impact of this factor depends on the topography of the area, it is considered one of the factors responsible for the low value of the coefficient of determination. It can however be concluded based on the foregoing that the availability of vegetation cover is one of the major factors that control the land surface temperature in the area which in turn, influence the ambient temperature of the environment.

CONCLUSION

The 20-year time series analysis of NDVI and day and night-time LST reported in this work revealed that both the day and the night-time LST are weak predictors of the greenness of the vegetation cover within the study area. The night-time LST however proved to be a better predictor compared to the day-time data. In general terms however, both the day and night-time LST decrease with an increase in vegetation density. The low level of fitting coefficients recorded in both the day-time and the night-time data is attributed to some climatological factors other than LST which include the land cover type (emissivity), topography, station altitude, surface moisture content, etc. This study, therefore, revealed that unlike other (high latitude) regions of the world, LST could not exclusively be used in developing a prediction model for plant phenological events within the study area. The work also demonstrates the capability of MODIS data in the modeling and analysis of climatological parameters.

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