Hindawi
Advances in Meteorology
Volume 2019, Article ID 4946127, 15 pages
https://doi.org/10.1155/2019/4946127

Research Article

Vegetation Response to Recent Trends in Climate and Landuse Dynamics in a Typical Humid and Dry Tropical Region under Global Change

Kayode Adepoju,[1] **Samuel Adelabu**,[1] **and Olutoyin Fashae**[2]

[1]*University of the Free State, Qwaqwa Campus, Bloemfontein, South Africa*
[2]*Geography Department, University of Ibadan, Ibadan, Nigeria*

Correspondence should be addressed to Kayode Adepoju; adepojuka@ufs.ac.za

Received 24 July 2019; Revised 25 September 2019; Accepted 24 October 2019; Published 13 December 2019

Academic Editor: Francesco Viola

The influence of global change on vegetation cover and processes has drawn increasing attention in the past few decades. In this study, we used remotely sensed rainfall and land surface temperature to investigate the spatiotemporal pattern and trend in vegetation condition using NDVI as proxy from 2001 to 2017 in a humid and dry tropical region. We also determined the partial correlation coefficient of temperature and rainfall with NDVI and the response of NDVI to changes in landcover categories due to human activities. We found that the mean annual maximum NDVI was 0.42, decreasing at a rate of 0.06 per decade. About 27.4% of the area was found to have experienced a significant negative trend in vegetation cover, while only 0.34% exhibited significant increasing vegetation vigour. Land surface temperature increased at a mean rate of 0.75°C/decade, with higher rates in agriculture, savanna, settlements, woodlands, and riparian vegetation than in forest and mangrove vegetations. Precipitation also reduced at a mean rate of 58.69 mm/decade, with higher rates in agriculture savanna and riparian vegetation than in sahelian grasslands, mangrove, forest, and woodlands. NDVI was negatively correlated with temperature in savanna, settlements, degraded forest, and sahelian grasslands providing confirmation of ongoing land degradation. It was concluded that vegetation vigour will continue to decline under rainfall and increasing temperature conditions especially in dryer regions. The use of land surface temperature in this study is particularly valuable in highlighting areas where changes in NDVI occurred as a result of synergistic action between climate and human-induced landcover changes. Our findings underscore the importance of landuse policies that account for spatial variation in synergistic relationships between the nexus of climate and land conversion processes that influence vegetation cover change in different landcover types in tropical regions.

1. Introduction

Vegetation is considered as an important intermediate link in the earth's atmosphere and hydrosphere, and its dynamics plays a crucial role in maintaining the functioning of the earth's diverse ecosystems and their services provision [1, 2]. Vegetation also exerts significant influence on water balance and on the regulation of carbon cycle [3, 4]. However, a growing number of studies have shown that vegetation growth has been strongly influenced by global change in recent decades [4, 5]. Climate variability and landuse change have been recognized as two important factors influencing vegetation dynamics under global change [4]. While landuse changes are more or less linked to changes in the hydrological processes and biodiversity loss, climate variability, especially precipitation and temperature, is more closely associated with changes in phenology, respiration, and ecological balance [1–4]. In recent decades, satellite remote sensing which depends primarily on reflected or emitted electromagnetic signals from specific targets on the earth's surface has emerged as an important tool for vegetation assessment and monitoring owing to its ability to provide spatially continuous observations and environmental proxies across geographical boundaries and over wide areas [6].

Vegetation indices and other biophysical variables derived from remote sensing therefore have created enhanced opportunities for monitoring vegetation dynamics and land

degradation at multiple scales and across geographical boundaries over wide areas [6, 7]. The remotely sensed Normalized Difference Vegetation Index (NDVI), which is generally used as a proxy for terrestrial vegetation productivity—allowing for continuous and long-term monitoring of information on the relationship between vegetation and climate—is now one of the most widely used indicators in studies involving vegetation dynamics and ecosystem health [6–8]. A large number of studies have been carried out to assess the vegetation patterns around the world based on NDVI time series data [7–14]. Many scholars have explored the relationship between NDVI and climate at varying scales; however, our understanding of these processes and interactions is still limited in many areas [14, 15]. Results from previous studies have suggested that the major climatic factors impacting on NDVI response vary by region, vegetation structure and composition, and research methodologies employed [12, 16]. In the high latitudes of the Northern Hemisphere and western Europe, temperature was found to be the main limiting factor for vegetation growth, whereas in central Asia, South America, and South Africa, decreasing rainfall and increasing temperature have been linked with reducing vegetation vigour [17]. In the African continent, quantitative analysis of NDVI anomalies over Africa in [18, 19] showed significant decrease in biomass production in the southern, eastern, and western parts of Africa, while the central part witnessed increased vegetation activities for different time periods between the years 1981 and 1999. In West Africa, which is characterized mostly by sahelian vegetation with a typical high rate of vegetation dynamics and erratic climate regimes, it is even more difficult to reach a consensus among scholars. Many previous studies in the region have reported a greening situation with positive vegetation development, whereas others indicate no trend or browning since the 1990s [14, 20–24].

Many studies have highlighted differences in NDVI changes [15–18] and their response to climatic factors among different types of landcovers in the broader region. However, few studies have focused on vegetation response to climate and landuse change in Nigeria, which is the continent's most populous country with a high growth rate. The country is located in a region with clearly distinctive characteristics in vegetation types and climatic zones and is bounded between the semiarid zone to the north, south of the Sahara Desert, and the humid tropic zone in the south by the Atlantic Ocean. Analysis of vegetation anomalies within an 18-year period in [18] shows the existence of positive and negative anomalies over various regions across Nigeria, highlighting the Sudan and Sahel savannah as having stronger variations. Other studies have attributed the long-term rainfall variability, which also accounts for vegetation variability to large-scale patterns of atmospheric circulation such as intertropical discontinuity climate mechanism, soil, and anthropogenic factors including landuse change [25, 26]. However, there is still no satisfactory explanation for vegetation response to climate and landuse drivers in this region. Although the importance of anthropogenic landcover change as a driver of ecological impacts is widely recognized [27–31] in many regional and global studies of NDVI trend. However, most studies found in this region [14, 29, 30] using coarse resolution images (1 km) from the Advanced Very High-Resolution Radiometer (AVHRR) have concentrated more on climate drivers without explicitly accounting for the contribution of landcover change. Therefore, it is important to conduct subregional scale study in Nigeria in order to gain insight into how vegetation responds to the combined impact of climate and landuse change. This is important for making well informed choices on management regimes that can ensure the sustainability of critical ecosystem services and agricultural productivity. This study therefore has two objectives. First, we explored the response of NDVI to rainfall and temperature in the study area by fitting long-term trend of remotely sensed NDVI to a regression model. Second, we investigated the combined impact of climate and landuse change on vegetation dynamics in the study area from 2001 to 2017.

2. Data and Methods

2.1. Description of Study Area. Nigeria is a country in West Africa where agriculture (rainfed farming and pastoralism) is the main livelihood that closely connects people to their environment. The country is located in the middle latitudes in the Gulf of Guinea within the equatorial belt, as shown in Figure 1. The climate is characterized by extreme humid weather condition in the forest of the southern region and extreme dry conditions in the savannah and grassland region of the north. The country is bounded in the south by over 850 km long active coastline and in the north by a corresponding length of the Sahara Desert making it susceptible to coastline erosion to the south as well as desertification and drought to the north [32]. Global warming and rapid population growth also act as catalysts, exacerbating the impact of these two destructive natural forces. The pastoralists, farmers, and peasants living in villages are oftentimes heavily dependent on rainfall. Climatic calamity has had tremendous socioeconomic impacts on the areas rich in agricultural production, mounting increasing pressure on available resources despite increasing rainfall variability [33]. The years 1982-1983 and 1991-1992 have been termed especially as a period of nationwide drought conditions in the last century [18]. The dramatic rise in human population in this region in the past three decades implies a much greater pressure on forest and savanna conversion to cropland and urban use impacting negatively on vegetation, microclimate, and biodiversity in the region [34–36].

2.2. Data

2.2.1. Description of Data Used in the Study

(1) NDVI Data. These data from 2001 to 2017 were obtained from MODIS MYD13A1.005 vegetation indices. The Global MYD13A1 data are made available every 16 days at 500-meter spatial resolution as a gridded level-3 product in the sinusoidal projection. We downloaded the 16-day composite product (500m resolution) of NASA LP DAAC from Google Earth engine (GEE). Blue, red, and near-infrared reflectances, centered at 469-nanometers, 645-nanometers, and 858-nanometers, respectively, are used to estimate the

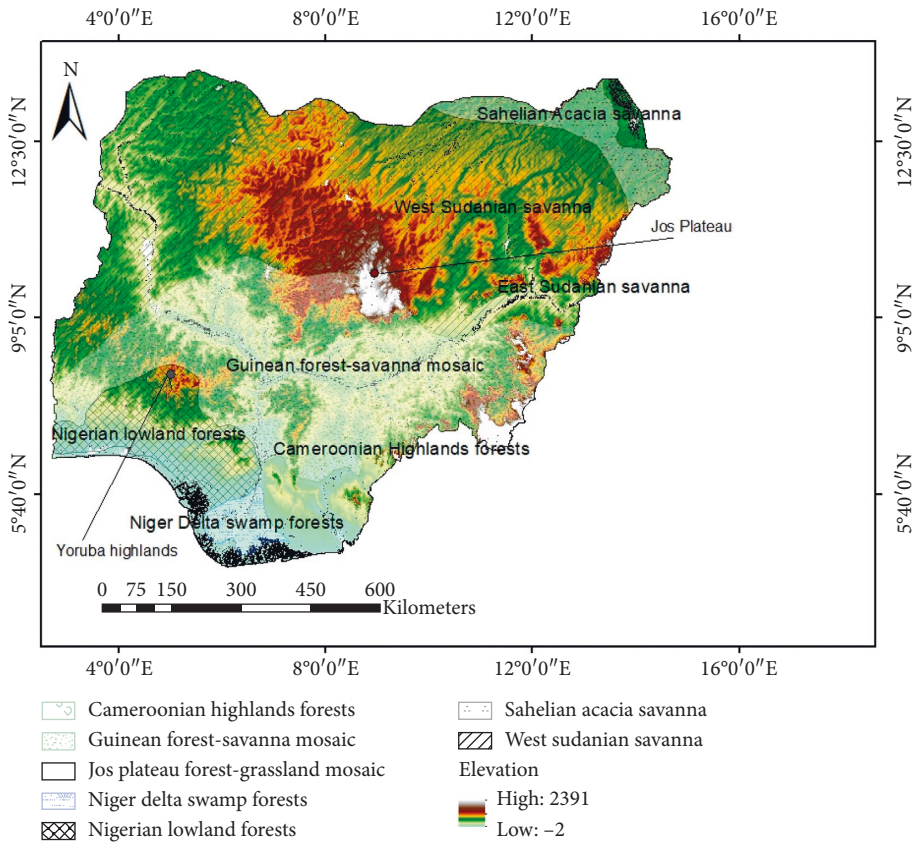

Figure 1: Location of the study area.

MODIS daily vegetation indices [37–39]. To determine the spatiotemporal patterns of precipitation-NDVI relationships, the mean monthly and annual NDVI composites over the whole study period were also generated. The maximum value compositing (MVC) procedure, as described in [40], was used to merge NDVI values into monthly and yearly aggregates. The MVC which is based on the maximum value of NDVI pixels at 250 m resolution and 10-day intervals was computed from atmospherically corrected and cloud-free gridded surface reflectance values standardized to nadir views [37]. Each grid cell of the 10-day NDVI composites is made up of 16 bytes, red, near-Infrared (NIR) and the maximum NDVI values, surface reflectances, relative azimuth, sensor, and solar zenith angles, and other quality control variables. The MVC method is widely recognized as a reliable method for monitoring global photosynthetic activity of vegetation and crops and phenological changes, and it has been used in many studies for biophysical interpretations and for the composition of vegetation indices to monthly (30-day) and annual intervals [41–43]. We excluded pixels with NDVI values that are less than 0.1 from the analysis using the method in [44] to minimize the effect of bare soil and other nonvegetated surfaces on the NDVI trends.

(2) Rainfall. Annual mean precipitation data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) for a period of 2000–2018 on GEE platform [45]. The CHIRPS dataset provides on a global basis (5 day) precipitation totals at (0.05°) which is approximately about 4.8 km resolution from 1980 to the present. CHIRPS also incorporates satellite imagery with in situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring especially in areas with limited measurements, such as in Africa [45]. The annual integrated mean rainfall values were also computed as 12-month averages and then subset to the study area boundary before they were stacked into one image using the same procedure as with the NDVI.

(3) Day Land Surface Temperature Data (MOD11A2.006). These data were obtained from the MODIS Terra Land Surface Temperature and Emissivity 8-Day Global 1 km. The (MOD11A2.006) product of NASA LP DAAC for the period between 2001 and 2017 was also downloaded from GEE platform. The MOD11A2 V6 product provides an average 8 day and night land surface temperatures in a 1200 × 1200-kilometer grid [37].

(4) Landcover. Dynamic landcover classification for the years 1975, 2000, and 2013 were obtained from [34, 35]. The landcover maps were generated from Landsat images using the visual interpretation method and additional post-processing that incorporates prior knowledge and ancillary information to further refine specific classes [34, 35]. Land cover in the region mainly comprises agriculture (42.80%), grassland (31.20%), forest (7.99%), and waterbodies (3.63%).

2.3. Methods

2.3.1. Calculation of NDVI Trends. To investigate the linear relationship between NDVI and time, and between NDVI and temperature or rainfall, we fitted linear trends in NDVI time series from 2001 to 2017 with the raster package in *R* programming software [46, 47] using the ordinary least squares regression method which is presented in the general format as follows:

$$y = \alpha + \beta * x + \sum, \tag{1}$$

where α is the intercept, β is the slope of variable x, and $\sum$ is the random error. In our model, y is the dependent variable representing NDVI and x is the independent variable representing any of time, rainfall, and temperature. The coefficient of determination R^2 measures the strength of the relationship between the dependent and the independent variable(s). In the relationship between NDVI and time for instance, the coefficient of determination also indicates the strength of interannual variation in NDVI during the study period.

To investigate the yearly temperature and precipitation, linear trends were also examined on a per pixel basis from 2001 to 2017. For each grid cell, we computed the NDVI, temperature, and precipitation trends separately, as the slope obtained from linear regression, using their stacked raster values. Here, the single regression coefficients indicate the direct response of NDVI or temperature or precipitation to unit change in time. The calculation is as follows:

$$\theta\,\text{slope} = \frac{n \times \sum_{i=1}^{n} i \times NDVI_i - \sum_{i=1}^{n} NDVI_i}{n \times \sum_{i=1}^{n} i - in \times \left(\sum_{i=1}^{n} i\right)}, \tag{2}$$

where n is the number of years under study, while NDVI_i is the maximum NDVI in the ith year. A slope value greater than zero indicates an increasing NDVI over the total number of years under study. When the slope value is however less than 0, this suggests that the trend is reducing. For the statistical significance testing, the F-test was applied at $p < 0.05$ level in this study.

2.3.2. Correlation Analysis Model. We also conducted correlation to investigate the relationships between NDVI and single climate driver at a time over the past 30 years. Before the correlation was carried out, the stacked values of NDVI, temperature, and precipitation were rescaled to those of the lowest spatial resolution among the independent variables. We assumed that there is a high possibility that NDVI variation was influenced by the correlated climatic factor despite the discrepancy between causation and correlation, as reported by previous studies [5, 30]. The correlation coefficient of temperature and rainfall with NDVI was determined in this study using the correlation equation described as follows:

$$r_{xy} = \frac{\sum (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{(x_i - \overline{x})^2 \sum (y_i - \overline{y})^2}}, \tag{3}$$

where r_{xy} is the correlation coefficient of the linear relationship between the dependent variable x and independent variable y, x_i is the value of the independent variable, $\overline{x}$ is the mean of the values of the independent variable x, and y_i is the values of the dependent variable y, while $\overline{y}$ is the mean of the values of the dependent variable y.

3. Results and Discussion

3.1. Spatial Trend of NDVI and Climate Drivers. The spatial distribution of the mean annual NDVI in Nigeria gradually decreased from south to north during the period of 2001–2017, suggesting high spatial variability in its distribution pattern, as shown in Figure 2(a). The mean annual NDVI is 0.41, ranging from 0.10 to 0.79, with a standard deviation of 0.12 for the whole country. Higher NDVI was observed in southwestern and southeastern parts of the country, whereas relatively lower NDVI was observed in northwestern and northeastern parts. The highest NDVI values were found along hilly slopes and forested regions of the Yoruba highlands in the west and in the southeastern parts, especially along the borders of the Cameroon highlands (Figures 1 and 3(b)). The sparse deciduous broad-leaved forests, including African walnut (Lovoa), Mansonia, mahoganies, and a host of other species that are increasingly under threat, are the most common vegetation types in the forest zone. The lowest NDVI values were also found mostly along the northern borders in the semiarid Sahel and the arid Sudan savannas where the dominant vegetation are characterized as shrub, semiarid grasses, and herbs; the main plant communities in the Sahel include the *Combretum* spp. and acacias. The Sudan savanna is also made up of similar species to those found in the Sahel, but with a greater frequency of *Tamarindus indica, Schelocarya birrea,* and *Acacia albida* [24, 25].

3.2. Spatiotemporal Variation of NDVI in the Study Area. The mean annual NDVI was found to be decreasing at a rate of 0.06 per decade (Figure 2(b)). Over the entire region, NDVI exhibited positive trend in about 5.44% of total vegetated areas, out of which only about 0.34% was significant at $p < 0.05$. Similarly, NDVI exhibited negative trend in about 58% of vegetated areas, out of which only 27.4% was significant. However, the areas accounting for significantly highly negative trend is only 2.42%, which pales in comparison with areas showing slightly significant negative trends constituting about 24.98% of the whole vegetated region, as shown in Figure 4(b). Although areas without changes in NDVI constitute about 36.56%, the areas with no significant changes in NDVI are the most widespread, constituting about 72.26% of the study area, as shown in Figure 4(b).

The areas where the NDVI showed significant increasing trends spatially from 2001 to 2017 were mainly scattered in small patches of varying sizes along the southern boundary of the far northern states from Sokoto to Yobe and in the southern portions of Kogi and Nasarawa states and along the riparian stretches of River Benue from north to south (Figures 2(c), and 4(b)). On the other hand, those places where the NDVI indicated significantly reducing trends

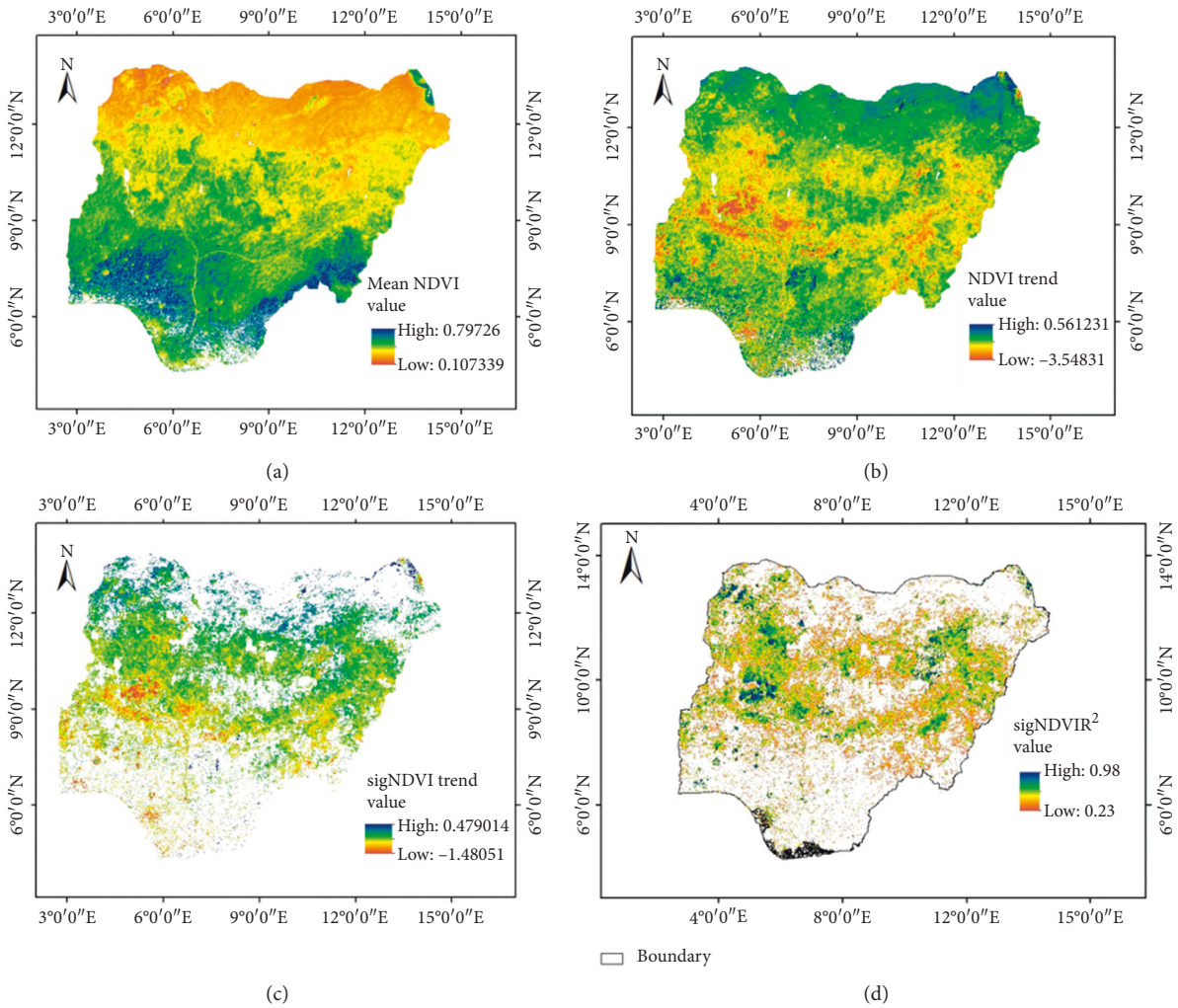

Figure 2: Pattern of NDVI in the study area from 2001 to 2017: (a) mean annual NDVI; (b) mean NDVI trends; (c) significant NDVI trends; (d) significant NDVI coefficient of determination (R^2).

were found mostly along the edges of mangrove and swamp forests dominated south-south, including Delta, Bayelsa, and Rivers states. However, the most significant decreasing trends were concentrated in the savanna dominated region of the middle belt states, including Niger, FCT, Kwara, Kogi, Nasarawa, and Taraba states. The southwest states of Oyo, Osun, Ekiti, Ogun, and Lagos states also show moderately decreasing trends. Central parts of Zamfara, Gombe, Kaduna, Bauchi, and Adamawa states located in the Sahel region which has little vegetation also show signs of moderately decreasing trends (Figures 2(b) and 2(c)).

It is evident from the values of coefficient of determination expressed by R^2 in that there was a clear dependence of the interannual variability in NDVI on the land cover types (Figures 2(d) and 4(a)). Interannual variability in NDVI is higher in savanna, agriculture, and sahelian grasslands, while it is lowest in forest, mangrove, and woodlands. There may be many reasons that could account for the observed spatiotemporal variation in interannual variability of NDVI, relating, for example, to climate variability, various resilience for vegetation types, and human influence [48, 49]. Forest vegetation and degraded forest with well-developed root systems reveal lower interannual variability in trend from 2001 to 2017 expressed through R [2]. However, savannas, especially the Sahel vegetation with much shallower root systems, on the other hand, reveal a slightly higher interannual variations in spatiotemporal NDVI trends as expressed through their lower R^2 values (Figures 3(c) and 3(d)).

Countrywide, the average NDVI increased sharply from 2000 to 2003, after which it decreased gradually from 2004 to 2017, except with slight fluctuations when the NDVI time series was divided into two time periods. The highest annual NDVI was however recorded in the year 2003 for the entire study period. Figure 4(a) shows the interannual variation of mean NDVI and time series of NDVI for five sites from the main landcover types. This result is consistent with studies that reported a slight decrease in NDVI trend associated with reducing rainfall in the Sahel [21–24]. In the small areas where slight increase in vegetation vigour was observed, the gradual recovery of the vegetation could be attributed to spillover effects of regreening of agricultural lands in

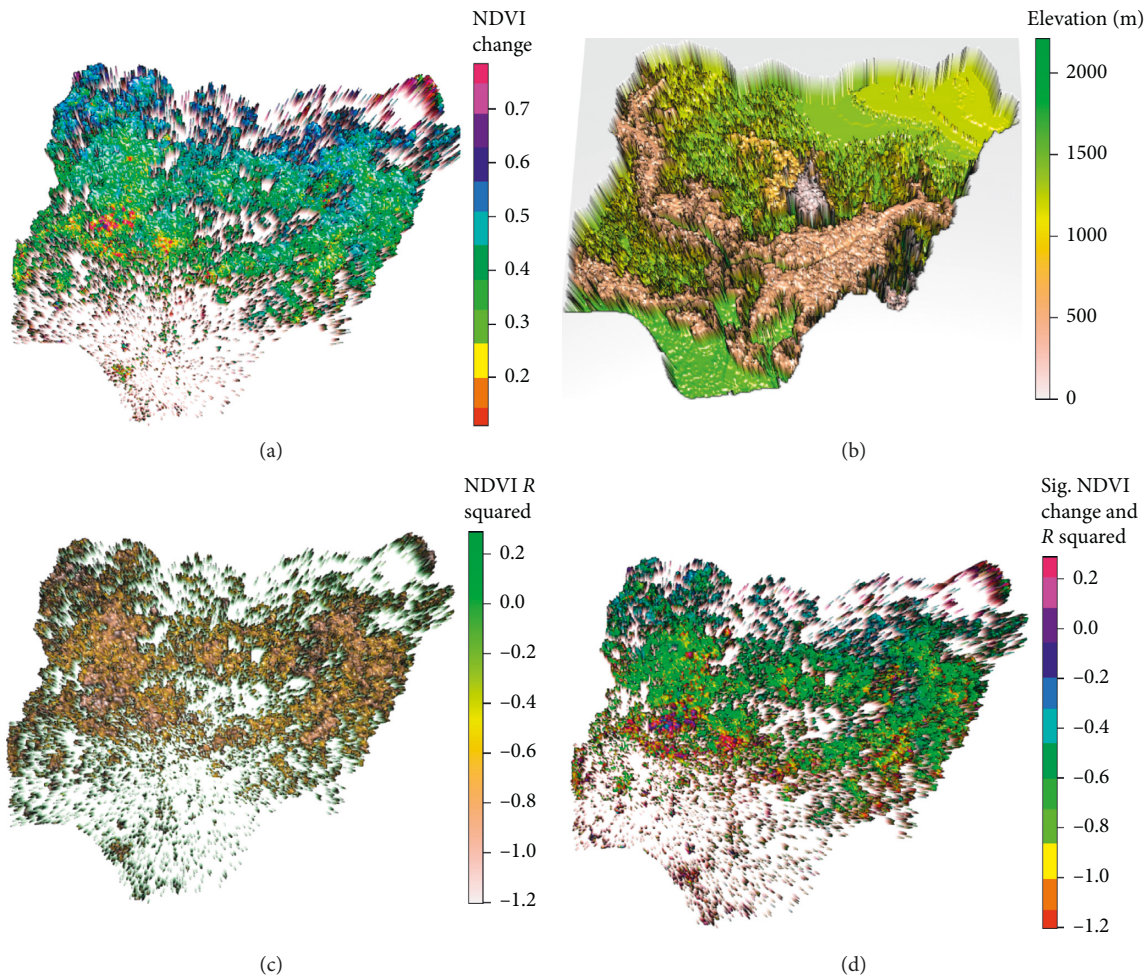

Figure 3: 3D rendering showing areas of (a) significant NDVI change; (b) elevation gradient; (c) NDVI coefficient of determination (R^2); (d) changes in significant NDVI (R^2).

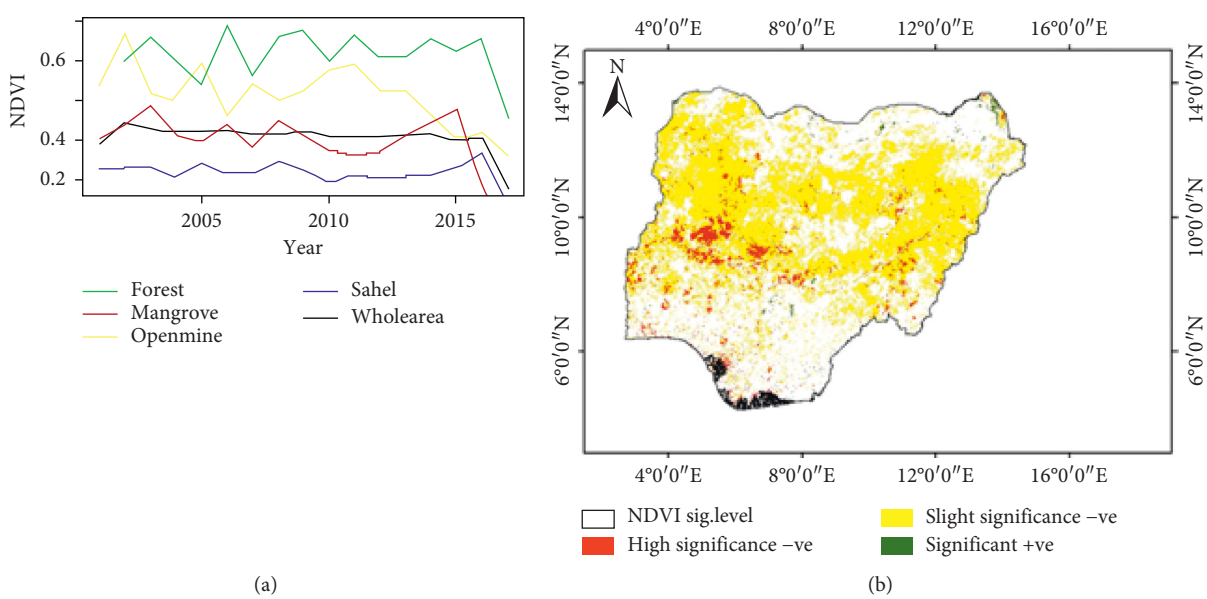

Figure 4: (a) Interannual variability in NDVI based on land cover types and (b) changes in NDVI coefficient of determination (R^2) values at ($p < 0.05$).

neighboring southern Niger by farmers who have adopted agroforestry practices that increase and maintain on-farm tree cover [34]. In more recent years, forced migration due the increased violent clashes between various groups of farmers, pastoralists, and religious extremists in northeastern Nigeria might have also been responsible for partial vegetation recovery in some areas in the northeastern part [49–51].

3.3. Relationship between NDVI and Climatic Factors

3.3.1. Annual Correlations between the NDVI and Temperature. The spatial distribution of the mean annual temperature from 2001 to 2017 with an average of 31.55°C for the entire region exhibited an upward trend at the rate of 0.75 per decade ($p < 0.05$) (Figure 5(a)). Temperature gradually increased from the south to north. The lowest temperature was recorded in the south-south region, with an annual mean of about 19°C, while the highest temperature was recorded in the northeast with an annual mean of more than 40°C. Furthermore, the land surface temperature time series increased linearly during the entire period with moderate fluctuations, as shown in Figure 6(a). The highest annual temperature was recorded in the year 2016 for the entire study period. Temperature exhibited positive trend in about 47.83% of total vegetated areas, out of which only about 9.3% was significant, as shown in Figure 6(c). Similarly, temperature exhibited negative change in about 17.09% of vegetated areas, out of which only 1.6% was significant. Although areas without any changes in temperature constitute about 35.08%, the areas with no significant changes in temperature are the most widespread, constituting about 89.1% of the study area.

On an interannual basis, the mean partial correlation coefficient of the NDVI with temperature for the entire region was −0.61 with 0.3 standard deviation (Figure 7(a)). The area in percentage of the region where the NDVI exhibited a negative correlation with temperature was 59.1%. The area in percentage of the region where the NDVI showed a positive correlation with temperature was 3.54%. These positive areas were mainly distributed as scattered patches from west to east along the northern borders and in south-south mangrove regions close to the coast. The remaining area estimated at 37.36% however does not suggest either positive or negative correlations. We found that land surface temperature increased more in agricultural land, savanna, riparian vegetation, settlements, and woodlands than in degraded forest, forest, and mangrove vegetations (Figures 8(c) and 8(d)). NDVI was negatively correlated with temperature in six landcover types including savanna, settlements, degraded forest, and sahelian grasslands providing confirmation of increases in the rate of deforestation. However, correlation analysis revealed positive but weak association between temperature and NDVI in mangrove, forest, and woodland vegetation where the mean temperature is about 19°C, suggesting that moderate ranges in temperature can enhance vegetation growth in the humid region [52–54].

Day land surface temperature has been shown not only to be sensitive to interannual variability in climate but also to density of canopy across different vegetation types and topography and therefore helpful in classifying and detecting changes in land cover types and for the rapid identification of deforestation hot spots [55, 56]. Land surface temperature is regulated by the amount of shortwave radiation absorbed by the surface (i.e., surface albedo), surface conductance, the amount of water available for evaporative cooling, wind speed, and surface roughness which regulate the strength of both sensible and latent heat fluxes. Water availability, therefore, tends to play a major role in correlation between NDVI and temperature. Areas of tree cover, which often have deeper roots and thus may access greater water resources, tend to have higher rates of evapotranspiration (and thus lower temperatures) especially during the dry season than grasses and other herbaceous cover that may senesce. Studies have found that that the diurnal temperature range can increase by over 7°C when forests are converted to bare ground [55–57]. Increasing temperature tends to accelerate the evaporation process, which can eventually result in water scarcity and prevention of vegetation growth [48, 49].

Land degradation resulting from explosive cropland expansion into remaining natural landscapes directly affects the livelihoods of millions and erodes ecosystem services that fulfill basic needs of life [52–54, 58]. In the short grass savanna, for instance, there has been much loss of shrubs and tree cover following drought periods and from cutting trees for firewood [36]. The rapid conversion of land for agriculture and plantation can alter discharge from headwaters and temperature regimes leading to further decline or loss of important functional species in some critical ecosystems such as riparian vegetation, streams, and lakes, with implications for drought and flood further downstream [36, 59, 60]. Alternatively, the ecosystem functions of present species might be replaced by other species with less functional redundancy or resilience to environmental perturbations [59, 60]. Flood regulation and control ecosystem services from riparian vegetation and gallery forest may come under attack from invasions by nonnative species, which along with the physical and chemical pressures may affect species richness and functional redundancy of important functional species with consequent implications for the wider biodiversity within the watershed.

3.3.2. Annual Correlations between the NDVI and Precipitation. The mean annual precipitation from 1998 to 2012 was 1200.63 mm, and it showed an overall reducing trend at the rate of 58.69 mm per decade. While precipitation gradually exhibited a reducing trend from the south to north, the lowest precipitation was recorded in the northwest and northeast with an annual average of about 132 mm (Figure 5(b)). On the other hand, highest precipitation values were found in the south-south region, with an annual mean of more than 4200 mm. The average precipitation declined sharply in 2004 and increased again from 2004 to 2012, after which it decreased again with significant fluctuations during this period (Figure 5(d)). The highest annual precipitation occurred in 2012 for the entire study period which also coincided with extensive nationwide flooding

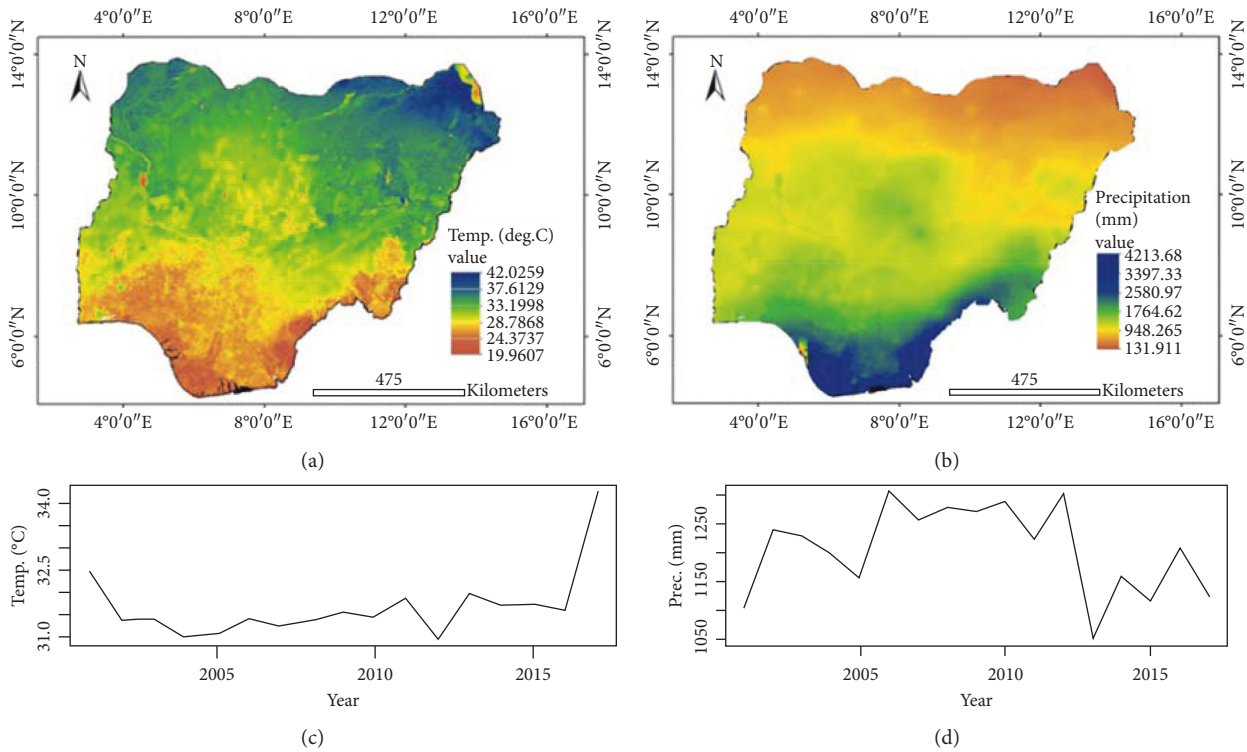

Figure 5: Pattern of rainfall and temperature in the study area from 2001 to 2017: (a) mean annual temperature; (b) mean annual precipitation; (c) interannual variability in temperature; (d) interannual variability in precipitation.

and spread of epidemics in some cases [61–63]. Generally, rainfall exhibited positive trend in about 18.36% of total vegetated areas, out of which only about 0.47% was significant (Figures 6(b) and 6(d)). Similarly, rainfall exhibited negative change in about 46.6% of vegetated areas, out of which only 6.22% was significant. Although areas without any changes in rainfall constitute about 35.04%, the areas with no significant changes in rainfall are the most widespread, representing about 93.31% of the study area. Spatially, the areas where precipitation exhibited significant increasing trends from 2001 to 2017 were located around the southeastern edge of the Jos plateau highlands, the northeastern states, and down to the southwestern regions. Areas where precipitation exhibited significant decreasing trends were primarily located along the northeast, the southeast, and the south-south regions. The mean partial correlation coefficient between NDVI and precipitation for the vegetated areas was 0.25, as shown in Figure 7(b). The area in percentage of the region where the NDVI showed a positive correlation with precipitation was 53.46% (<0.05), and the area in percentage of the region where the NDVI showed a negative correlation with precipitation was 9.26%. NDVI was found to be positively correlated with rainfall in all land covers. However, it was more positively correlated with precipitation in agricultural dominated landscapes, savanna, riparian vegetation, and sahelian grasslands than in mangrove and woodland vegetations (Figures 8(b), and 8(d)). This finding is consistent with studies that show that in arid and semiarid areas, moisture availability is a primary modulator of vegetation growth [48, 51, 53, 54, 63].

Although, rainfall is positively correlated with NDVI, however, the decreasing trend in rainfall is not a good one for vegetation growth and could be one of the major reasons for the redussscing annual NDVI trends. The result of this study conflicts with studies [14, 20, 21] that reported increasing NDVI trend due to increasing rainfall since the 1990s. Our findings, however, agrees with studies that [18, 19] reported slight but significant decline in vegetation vigour. In areas where rainfall is positively correlated with NDVI and both rainfall and NDVI trend declined overtime, this kind of relationship suggests a climate-induced desertification in arid areas [63, 64, 65]. Long-term precipitation analysis for the area revealed decreasing trend in annual rainfall amounts, and the 1968 to 2008 mean rainfall was reported to have shifted downwards by 8.8 percent from the long-term mean [52, 54]. Previous studies reported that the latter part of the last century experienced low rainfall and drought conditions and the last major drought that plagued the region towards the end of the last century occurred during the years 1982-1983 and 1991-1992, respectively [18, 52, 54]. In addition, most of the droughts that were reported in this region have been linked with a late start of the rainy season and early cessation of the rains, resulting in drastic reductions of the length of the rainy season [52–54].

3.4. Impact of Anthropogenic Activities on Vegetation Condition through Landcover Changes. Most lands in Nigeria have been converted for agricultural or pastoral uses, and agricultural encroachment poses a huge threat to the

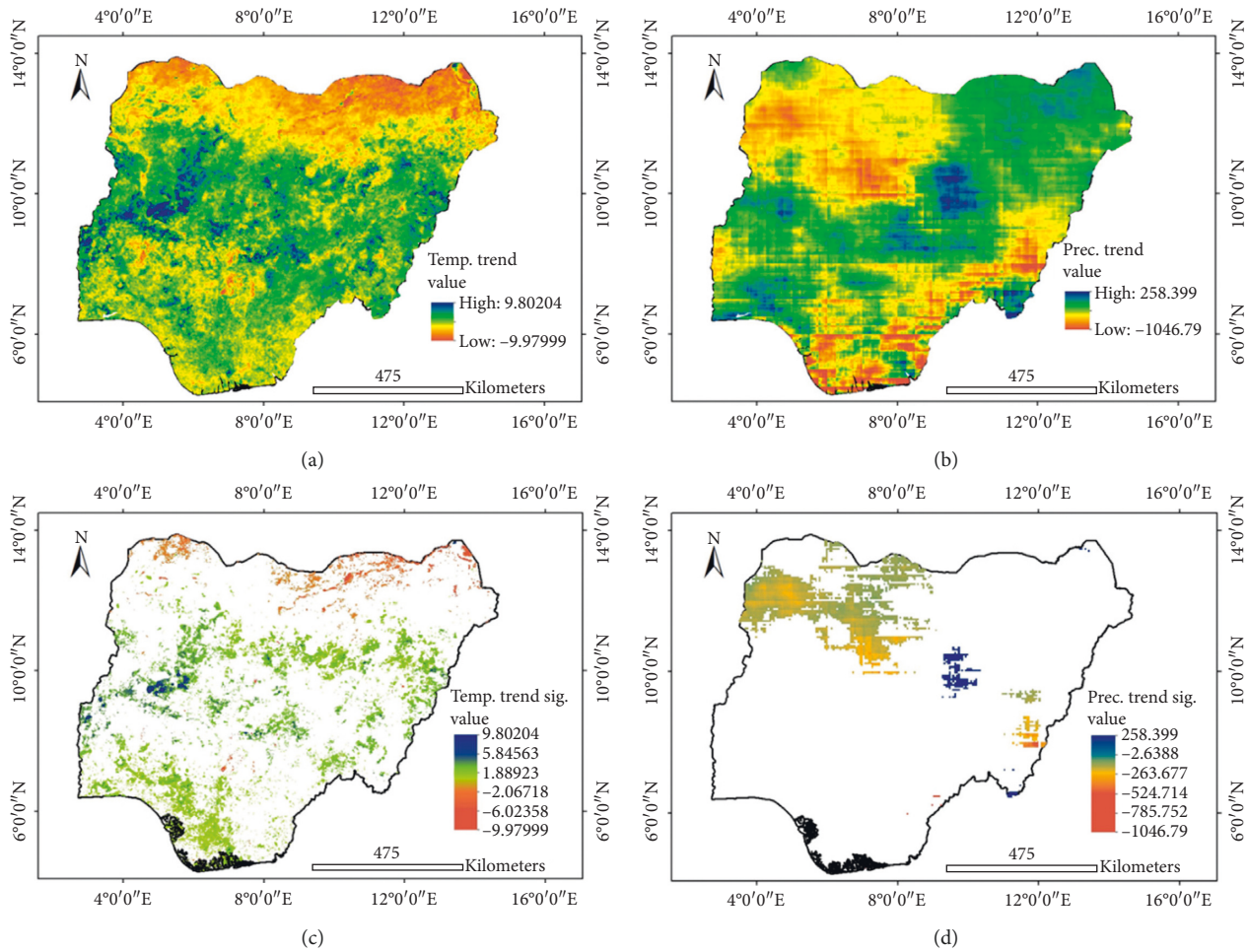

Figure 6: Pattern of rainfall and temperature trends in the study area from 2001 to 2017: (a) mean temperature trends; (b) mean precipitation trends; (c) significant temperature trends; (d) significant precipitation trends.

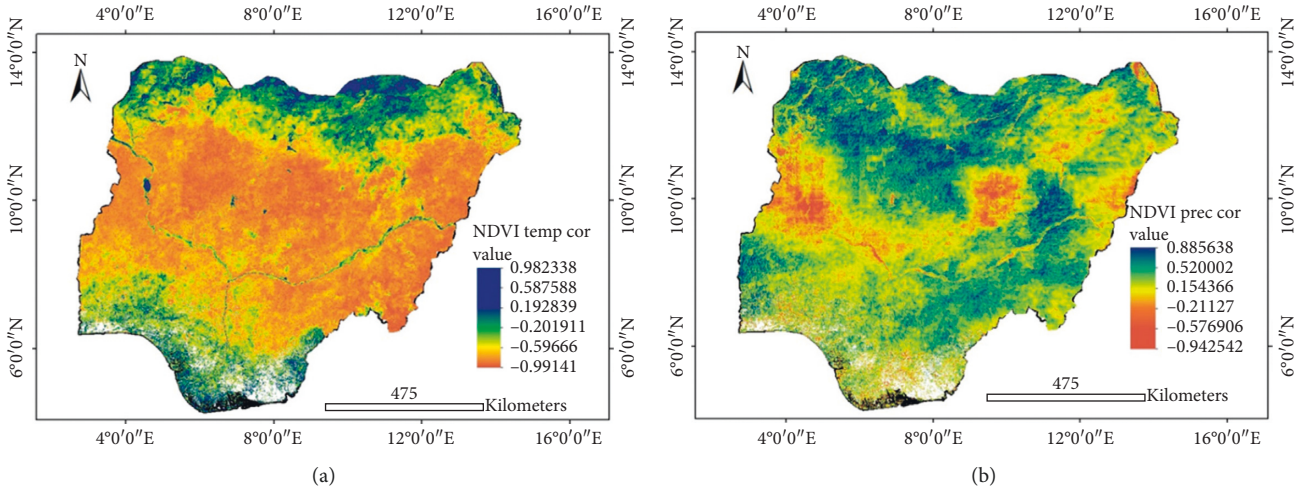

Figure 7: Correlation between NDVI and (a) mean temperature and (b) precipitation.

remaining pockets of natural landscapes [32]. Desertification, soil fertility loss, insufficient quantities and quality of water, and enormous erosion challenges have resulted in the overuse and mismanagement of the country's resources [66–68]. In areas where NDVI is positively correlated with rainfall, rainfall has not reduced significantly but long-term trend of NDVI is reducing while temperature is increasing is an inverse relationship suggesting human

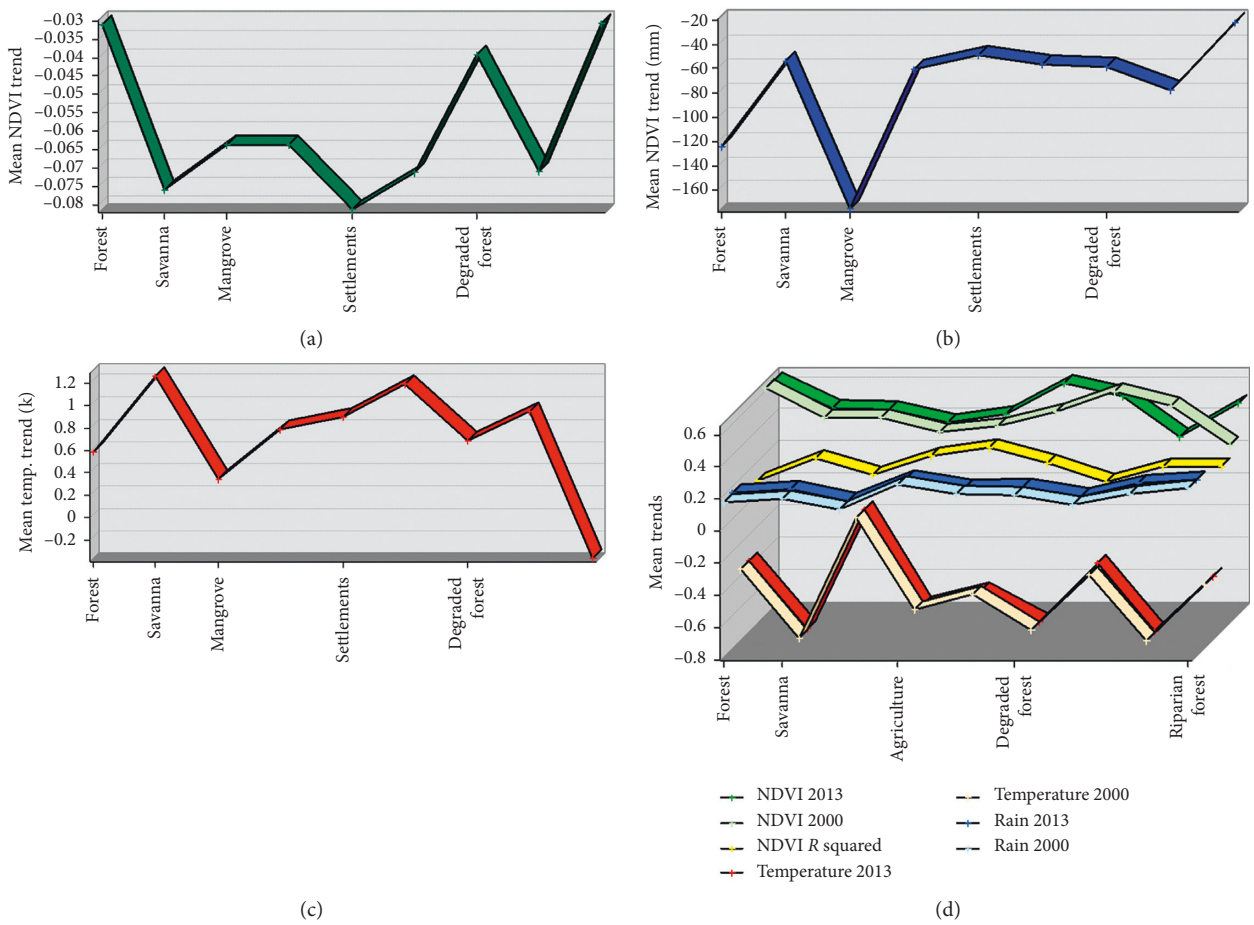

Figure 8: Spatial trend patterns across landcover types in the study area from 2001 to 2017: (a) mean NDVI; (b) precipitation; (c) temperature; (d) combination of all variables.

involvement, for example, overgrazing if it is a grassland, deforestation, and urbanization due to increasing population density [67, 69, 70]. The threat is most severe in the southeast and the north central zones. The Niger Delta region, which holds the largest remaining tract of mangrove vegetation in Africa and is the third largest in the world, is under alarming threat [32]. Much of the western end of the coastline has been degraded due to human influence, and many of the barrier islands on the outer reaches of the Niger Delta are being destroyed by erosion. In the central portion of the country, the high plateau region around Jos has been denuded for decades. The widespread mining activities have also accelerated the rate of sheet and gully erosion formation in the Jos Plateau region [32, 66–68].

Several studies have examined the effects of human activities on vegetation changes in Nigeria [25, 32, 57, 61]. For example, a countrywide study carried out in [71, 72] on comparative land use reported that an additional 9% of the entire country (84,073 km^2) had come under agricultural production over an 18-year period from 1978 to 1995. To show the impact of anthropogenic activities on NDVI, we investigated the dynamics of landuse change from 2001 to 2017 in the study area. The major landuse types in the study area were savanna, agriculture, sahelian grassland, woodland, swamp forest, and degraded forest, which combined to account for 76.44%, 78.23%, and 78.91% of the total area of the region in 2000 and 2017, respectively (Figure 9). While agricultural land increased significantly from 20% to more than 40% in 38 years from 1975 to 2013 to make it the largest land cover type (Figure 9), forest and savanna areas decreased significantly with loss rates increasing to over 2 percent per year during the 2000–2013 period [69]. Transition from savanna to agriculture was the largest landcover change in terms of area; some changes in the smaller land cover categories also stand out as prominent. High rates of change were recorded for plantation, open mines, irrigated agriculture, and settlements, with gains accelerating from 1 to 2 percent per year between 1975 and 2000 to 2–4 percent per year in the 2000–2013 period [69].

From 2001 to 2017, the total areas of agricultural land increased, while savanna and forest declined significantly and the annual maximum NDVI exhibited a reducing trend for these two landuse types indicating that human activities due to massive land conversion resulted in land degradation (Figure 9). Apart from the reducing rainfall trend and the increasing temperature, this negative trend can also be explained by poor soil and water conservation measures and intensive cultivation on marginal lands which led to

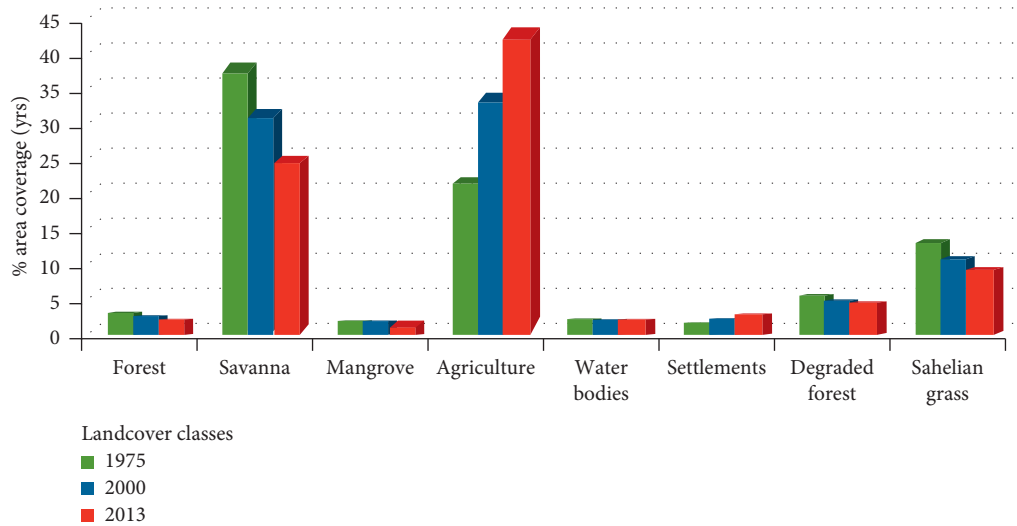

Figure 9: Changes in landcover area from 1975 to 2013 (adapted and modified from [34, 35]).

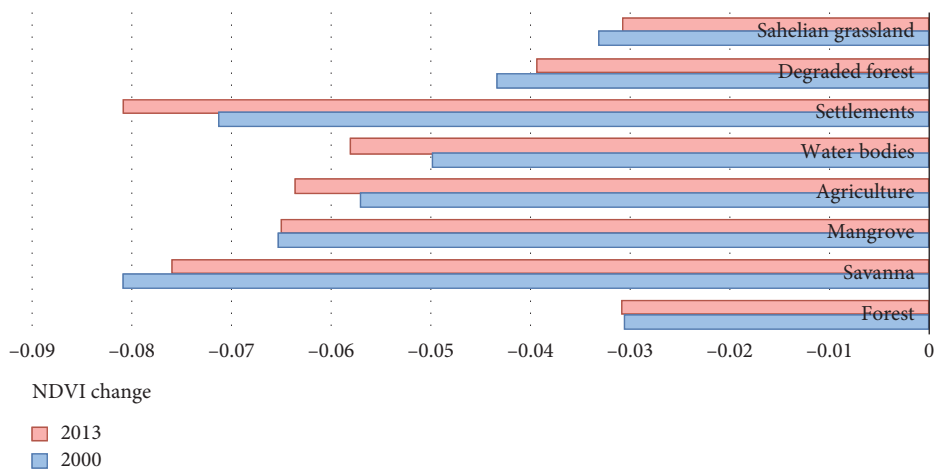

Figure 10: Changes in NDVI between 1975 and 2010 (adapted and modified from [34, 35]).

reduction in grain yields and biomass production, thus reducing the overall NDVI in these areas. This is consistent with [51], who reported that agricultural food production has been on steady decline between 1980 and 2003 in Nigeria. This situation is made worse by poverty and rapid population growth as poor people rely on fuelwood conversion and grazing to further impoverish the marginal lands leading to a vicious cycle of more severe soil erosion, desertification, and poor yields, especially in the drier regions [51, 53]. Hence, the result of this study is also in support with the well-known hypothesis that Sahelian drought is anthropogenically induced [25, 26]. Wider implications of this include the possibility for environmental degradation owing to soil fertility loss, insufficient quantities and quality of water, enormous erosion challenges, and desertification due to lack of proper management. Studies have shown that increased water demand and water consumption due to agricultural landuse conversion could impact negatively hydrological processes and ecosystem health [72–77].

Another major important impact of agricultural expansion is increasing runoff, which constitutes to atmospheric water demand since it does not allow water to percolate into underground sources, leading to a depletion of underground water resources and increased vegetation stress, eventually resulting in drought conditions. The rate of NDVI decline in 2013 which was higher than the preceding years could therefore be largely attributed to massive landcover change which occurred during this period (Figure 10). It can be concluded that increasing landuse conversion to agriculture and settlements will work in a synergistic manner with climate to increase the rate of warming and drying in the years to come. It will also exert a significance influence on the sustainability of ecosystem services with considerable change on the diversity, composition, structure, and development of native and functional plant communities in this region.

4. Conclusions

In this study, we analyzed the spatial and temporal responses of vegetation to climate and landuse factors from 2001 to

2017 in Nigeria. We also investigated the potential impacts of anthropogenic landcover change on vegetation change during this period by fitting a stack of remote sensing-based climate and landuse covariates to a regression model using the *R* software package. The annual maximum NDVI was 0.42, decreasing at a rate of 0.06 per decade. About 27.4% of the area was found to have experienced a significant negative trend in vegetation cover, while only 0.34% exhibited significant increasing vegetation vigour. Land surface temperature increased at a rate of 0.75°C/decade with higher rates in agriculture, savanna, settlements, woodlands, and riparian vegetation than in forest and mangrove vegetations. Precipitation also reduced at a rate of 58.69 mm/decade with higher rates in agriculture savanna, riparian vegetation, and sahelian grasslands than in mangrove, forest, and woodland vegetations. NDVI was negatively correlated to temperature in six landcover types including savanna, settlements, degraded forest, and sahelian grasslands providing confirmation that increases in the rate of deforestation resulted in land degradation in these landcover types. Conversely, correlation analysis revealed positive but weak association between NDVI and temperature in mangrove, forest, and woodland vegetations, suggesting that moderate temperature ranges can enhance vegetation growth in the humid regions.

Although climate has been recognized as the principal factor affecting vegetation vigour in this region, the midpart of the last century when rainfall amounts was reported to have shifted by about 8.8% below the long-term mean. We, however, found that climate has acted synergistically with human-induced landcover change to affect vegetation activities in more than half of the entire area of study. Deforestation, poor soil and water conservation measures, overgrazing, and fire disturbances are also important driving factors contributing to vegetation change and land degradation in the region. Dynamics of landuse change in the region over a period of over 38 years revealed that transition from savanna to agriculture was the largest landcover change in terms of area, increasing significantly from 20% to more than 40% in 38 years while forest and savanna areas decreased significantly with loss rates increasing to over 2 percent per year during the 2000–2013 period.

The overall warming and drying trends experienced by the country in recent decades are therefore an indicator of poor vegetation activities as evidenced by the reducing NDVI trend and are not a good sign for hydrological processes and overall ecosystem health. On this basis, we project that vegetation vigour will reduce under reducing rainfall and increasing temperature conditions especially in dryer regions. Wider implications of this include the possibility for environmental degradation due to soil fertility loss, insufficient quantities and quality of water, enormous erosion challenges, and desertification. We therefore concluded that increasing landuse conversion is not only expected to increase the rate of warming and drying in years to come but will also exert a significant influence on the sustainability of ecosystem services with considerable change on the diversity, composition, structure, and development of native and functional plant communities.

The use of land surface temperature in this study is particularly valuable in highlighting areas where changes in NDVI occurred as a result of synergistic action between climate and human-induced landcover changes which constitute more than half of the study area. Our results, therefore, underscores the importance of implementing landuse policies that account for spatial variation in synergistic relationships between the nexus of climate and land conversion processes that influence vegetation cover change in tropical humid and semiarid environments. However, the inclusion of other biophysical factors such as soil characteristics and terrain properties into the analytical framework could improve the accuracy and usefulness of the results for better ecosystem management.

Data Availability

The images used to support the findings of this study are available from the corresponding author upon request. Additional datasets from prior studies were also cited at relevant places within the text as references.

Disclosure

The authors declare that this manuscript has not received specific funding but was performed as part of the employment of the authors by the University of The Free State. The employer is not involved in the manuscript writing, editing, approval, or decision to publish the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Kayode Adepoju collected and organized the data and performed the analysis. All authors read, revised, and approved the final manuscript.

References

[1] R. De Jong, S. de Bruin, A. de Wit, M. E. Schaepman, and D. L. Dent, "Analysis of monotonic greening and browning trends from global NDVI time-series," *Remote Sensing of Environment*, vol. 115, no. 2, pp. 692–702, 2011.

[2] X. Wang, S. Piao, P. Ciais et al., "Spring temperature change and its implication in the change of vegetation growth in North America from 1982 to 2006," *Proceedings of the National Academy of Sciences*, vol. 108, no. 4, pp. 1240–1245, 2011.

[3] G. Qiu and Y. Feng, "Estimation of soil evaporation and plant transpiration of sparse steppes by using ground-based infrared thermal images," in *AGU Fall Meeting Abstracts*, vol. 1, p. 4, San Francisco, CA, USA, December 2011.

[4] C. J. Tucker, D. A. Slayback, J. E. Pinzon, S. O. Los, R. B. Myneni, and M. G. Taylor, "Higher northern latitude normalized difference vegetation index and growing season trends from 1982 to 1999," *International Journal of Biometeorology*, vol. 45, no. 4, pp. 184–190, 2001.

[5] G. Xu, H. Zhang, B. Chen et al., "Changes in vegetation growth dynamics and relations with climate over China's

landmass from 1982 to 2011," *Remote Sensing*, vol. 6, no. 4, pp. 3263–3283, 2014.

[6] F. Rembold and F. Maselli, "Estimation of inter-annual crop area variation by the application of spectral angle mapping to low resolution multitemporal NDVI images," *Photogrammetric Engineering & Remote Sensing*, vol. 72, no. 1, pp. 55–62, 2006.

[7] M. S. Mkhabela, P. Bullock, S. Raj, S. Wang, and Y. Yang, "Crop yield forecasting on the Canadian Prairies using MODIS NDVI data," *Agricultural and Forest Meteorology*, vol. 151, no. 3, pp. 385–393, 2011.

[8] J. Y. Zhang, W. J. Dong, C. B. Fu, and L. Wu, "The influence of vegetation cover on summer precipitation in China: a statistical analysis of NDVI and climate data," *Advances in Atmospheric Sciences*, vol. 20, no. 6, pp. 1002–1006, 2003.

[9] D.-Y. Gong and P.-J. Shi, "Northern hemispheric NDVI variations associated with large-scale climate indices in spring," *International Journal of Remote Sensing*, vol. 24, no. 12, pp. 2559–2566, 2003.

[10] D. A. Walker, H. E. Epstein, and G. J. Jiaetal, "Phytomass, LAI, and NDVI in northern Alaska: relationships to summer warmth, soil pH, plant functional types, and extrapolation to the circumpolar arctic," *Journal of Geophysical Research D: Atmospheres*, vol. 108, no. D2, pp. 10–15, 2003.

[11] H.-S. Park and B. J. Sohn, "Recent trends in changes of vegetation over East Asia coupled with temperature and rainfall variations," *Journal of Geophysical Research*, vol. 115, no. D14, Article ID D14101, 2010.

[12] T. Ning, W. Liu, W. Lin, and X. Song, "NDVI variation and its responses to climate change on the Northern Loess Plateau of China from 1998 to 2012," *Advances in Meteorology*, vol. 2015, Article ID 725427, 10 pages, 2015.

[13] N. Krakauer, T. Lakhankar, and J. Anadón, "Mapping and attributing normalized difference vegetation index trends for Nepal," *Remote Sensing*, vol. 9, no. 10, p. 986, 2017.

[14] S. M. Herrmann, A. Anyamba, and C. J. Tucker, "Recent trends in vegetation dynamics in the African Sahel and their relationship to climate," *Global Environmental Change*, vol. 15, no. 4, pp. 394–404, 2005.

[15] J. Wang, P. M. Rich, and K. P. Price, "Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA," *International Journal of Remote Sensing*, vol. 24, no. 11, pp. 2345–2364, 2003.

[16] S. A. Usman, S. A. Yelwa, S. U. Gulumbe, and A. Danbaba, "Modelling relationship between NDVI and climatic variables using geographically weighted regression," *Journal of Mathematical Sciences and Applications*, vol. 1, no. 2, pp. 24–28, 2013.

[17] J. Xiao and A. Moody, "Geographical distribution of global greening trends and their climatic correlates: 1982–1998," *International Journal of Remote Sensing*, vol. 26, no. 11, pp. 2371–2390, 2005.

[18] Z. D. Adeyewa and E. D. Aweda, "Inter annual variation of vegetation anomaly over Nigeria using satellite-derived index, Pelagia research library," *Advances in Applied Science Research*, vol. 2, no. 3, pp. 468–475, 2011.

[19] W. H. Schlesinger and S. Jasechko, "Transpiration in the global water cycle," *Agricultural and Forest Meteorology*, vol. 189-190, pp. 115–117, 2014.

[20] S. E. Nicholson and J. P. Grist, "A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales," *International Journal of Climatology*, vol. 21, no. 14, pp. 1733–1757, 2001.

[21] A. Anyamba and C. J. Tucker, "Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003," *Journal of Arid Environments*, vol. 63, no. 3, pp. 596–614, 2005.

[22] T. Hickler, L. Eklundh, J. W. Seaquist et al., "Precipitation controls Sahel greening trend," *Geophysical Research Letters*, vol. 32, no. 21, 2005.

[23] A. Bégué, E. Vintrou, D. Ruelland, M. Claden, and N. Dessay, "Can a 25-year trend in Soudano-Sahelian vegetation dynamics be interpreted in terms of land use change? A remote sensing approach," *Global Environmental Change*, vol. 21, no. 2, pp. 413–420, 2011.

[24] A. Anyamba, J. L. Small, C. J. Tucker, and E. W. Pak, "Thirty-two years of Sahelian zone growing season non-stationary NDVI3g patterns and trends," *Remote Sensing*, vol. 6, no. 4, Article ID 3101, 2014.

[25] S. E. Nicholson, "Sub-saharan rainfall 1981-1984," *Journal of Climate and Applied Meteorology*, vol. 24, no. 12, pp. 1388–1391, 1985.

[26] I. J. Ekpoh, "Climate and society in northern Nigeria: rainfall variability and farming," *The International Journal Series on Tropical Issues*, vol. 8, no. 3, pp. 157–162, 2007.

[27] H. Nouri, S. Beecham, S. Anderson, and P. Nagler, "High spatial resolution WorldView-2 imagery for mapping NDVI and its relationship to temporal urban landscape evapotranspiration factors," *Remote Sensing*, vol. 6, no. 1, pp. 580–602, 2014.

[28] Y. Y. Liu, J. P. Evans, M. F. McCabe et al., "Changing climate and overgrazing are decimating Mongolian steppes," *PLoS One*, vol. 8, no. 2, Article ID e57599, 2013.

[29] N. Pettorelli, J. O. Vik, A. Mysterud, J.-M. Gaillard, C. J. Tucker, and N. C. Stenseth, "Using the satellite-derived NDVI to assess ecological responses to environmental change," *Trends in Ecology & Evolution*, vol. 20, no. 9, pp. 503–510, 2005.

[30] J. A. Foley, R. DeFries, G. P. Asner et al., "Global consequences of land use," *Science*, vol. 309, no. 5734, pp. 570–574, 2005.

[31] R. Jong, J. Verbesselt, M. E. Schaepman, and S. Bruin, "Trend changes in global greening and browning: contribution of short-term trends to longer-term change," *Global Change Biology*, vol. 18, no. 2, pp. 642–655, 2012.

[32] USAID, *Nigeria Environmental Analysis, USAID BIOFOR IQC No. LAG-I-00-99-00013-00*, USAID, Washington, DC, USA, 2002.

[33] F. N. Kogan, "Contribution of remote sensing to drought early warning," in *Early Warning Systems for Drought Preparedness and Drought Management*, D. A. Wilhite, D. A., and D. A. Wood, Eds., pp. 75–87, World Meteorological Organization, Geneva, Switzerland, 2000.

[34] S. E. Cotillon, "West Africa land use and land cover time series: U.S," *Geological Survey Fact Sheet 2017–3004*, 2017, https://doi.org/10.3133/fs20173004.

[35] G. G. Tappan, W. M. Cushing, S. E. Cotillon, M. L. Mathis, J. A. Hutchinson, and K. J. Daland, *West Africa Land Use Land Cover Time Series: U.S. Geological Survey Data Release*, https://doi.org/10.5066/F73N21JF, 2016.

[36] K. A. Adepoju and A. T. Salami, "Geospatial assessment of forest fragmentation and its implications for ecological processes in tropical forests," *Journal of Landscape Ecology*, vol. 10, no. 1, pp. 5–21, 2017.

[37] A. Huete, K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira, "Overview of the radiometric and biophysical

performance of the MODIS vegetation indices," *Remote Sensing of Environment*, vol. 83, no. 1-2, pp. 195–213, 2002.

[38] K. Didan, *MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006 [Data Set]. NASA EOSDIS Land Processes DAAC*, 2015.

[39] MODIS Land Surface Temperature Day and Night, *NASA EOSDIS Land Processes DAAC*, USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD, USA, 2017, https://lpdaac.usgs.gov.

[40] B. N. Holben, "Characteristics of maximum-value composite images from temporal AVHRR data," *International Journal of Remote Sensing*, vol. 7, no. 11, pp. 1417–1434, 1986.

[41] Y. He, X. Guo, P. Dixon, and J. F. Wilmshurst, "NDVI variation and its relation to climate in Canadian ecozones," *The Canadian Geographer/Le Géographe Canadien*, vol. 56, no. 4, pp. 492–507, 2012.

[42] M. Lanfredi, R. Lasaponara, T. Simoniello, V. Cuomo, and M. Macchiato, "Multiresolution spatial characterization of land degradation phenomena in southern Italy from 1985 to 1999 using NOAA-AVHRR NDVI data," *Geophysical Research Letters*, vol. 30, no. 2, 2003.

[43] J. Sun, G. Cheng, W. Li, Y. Sha, and Y. Yang, "On the variation of NDVI with the principal climatic elements in the Tibetan plateau," *Remote Sensing*, vol. 5, no. 4, pp. 1894–1911, 2013.

[44] W. Sun, Y. Wang, Y. H. Fu et al., "Spatial heterogeneity of changes in vegetation growth and their driving forces based on satellite observations of the Yarlung Zangbo river basin in the Tibetan plateau," *Journal of Hydrology*, vol. 574, pp. 324–332, 2019.

[45] C. Funk, P. Peterson, M. Landsfeld et al., "The climate hazards infrared precipitation with stations-a new environmental record for monitoring extremes," *Scientific Data*, vol. 2, no. 1, Article ID 150066, 2015.

[46] R Core Team, *R: A Language and Environment for Statistical Computing*, R foundation for atistical computing, Vienna, Austria, 2018, https://CRAN.R-project.org.

[47] R. J. Hijmans, "raster: geographic data analysis and modeling. R package version 2.84,," 2018, https://CRAN.R-project.org/package=raster.

[48] P. Propastin, M. Kappas, and S. Erasmi, "Application of geographically weighted regression to investigate the impact of scale on prediction uncertainty by modelling relationship between vegetation and climate," *International Journal of Spatial Data Infrastructures Research*, vol. 3, pp. 73–94, 2008.

[49] C. Fiki and B. Lee, "Conflict generation, conflict management and self-organizing capabilities in drought prone rural communities in north east Nigeria: a case study," *Journal of Social Development in Africa*, vol. 19, no. 2, pp. 25–48, 2004.

[50] A. Nyong and C. Fiki, "Drought-related conflicts, management and resolution in the West African Sahel," in *Proceedings of the Paper Presented at Human Security and Climate Change Conference in Asker*, Oslo, Norway, June 2005.

[51] E. E. Obioha, "Climate change, population drift and violent conflict over land resources in northeastern Nigeria," *Journal of Human Ecology*, vol. 23, no. 4, pp. 311–324, 2008.

[52] C. Houndenou and K. Hernandez, "Climate of the Sahel 1961–1990. Benin," *Secheresse*, vol. 9, pp. 23–34, 1998.

[53] I. J. Ekpoh, "Rainfall and peasant agriculture in northern Nigeria," *Global Journal of Pure and Applied Sciences*, vol. 5, no. 1, pp. 123–128, 1999.

[54] A. Tarhule and M. K. Woo, "Changes in rainfall characteristics in northern Nigeria," *International Journal of Climatology*, vol. 18, no. 11, pp. 1261–1271, 1998.

[55] J. C. Price, "Land surface temperature measurements from the split window channels of the NOAA 7 advanced very high resolution radiometer," *Journal of Geophysical Research*, vol. 89, no. D5, pp. 7231–7237, 1984.

[56] T. T. van Leeuwen, A. J. Frank, Y. Jin et al., "Optimal use of land surface temperature data to detect changes in tropical forest cover," *Journal of Geophysical Research*, vol. 116, no. G2, 2011.

[57] R. C. G. Smith and B. J. Choudhury, "Analysis of normalized difference and surface temperature observations over southeastern Australia," *International Journal of Remote Sensing*, vol. 12, no. 10, pp. 2021–2044, 1991.

[58] B. N. Potter and I. J. Ekpoh, "Transforming traditional agriculture," *Global Journal of Social Sciences*, vol. 6, no. 2, pp. 97–102, 2007.

[59] U. Schirpke, M. Kohler, G. Leitinger, V. Fontana, E. Tasser, and U. Tappeiner, "Future impacts of changing land-use and climate on ecosystem services of mountain grassland and their resilience," *Ecosystem Services*, vol. 26, pp. 79–94, 2017.

[60] W. D. Riley, E. C. E. Potter, J. Biggs et al., "Small water bodies in Great Britain and Ireland: ecosystem function, human-generated degradation, and options for restorative action," *Science of the Total Environment*, vol. 645, pp. 1598–1616, 2018.

[61] M. Y. Silas, S. A. Taofeek, A. K. Adewale, S. S. Adeyemi, and D. Victor, "Flood inundation and monitoring mapping in Nigeria using modis surface reflectance," *Journal of Scientific Research and Reports*, vol. 22, no. 1, pp. 1–12, 2019.

[62] O. E. Olanrewaju and K. A. Adepoju, "Geospatial assessment of cholera in a rapidly urbanizing environment 2017," *Journal of Environmental and Public Health*, vol. 2017, Article ID 6847376, 8 pages, 2017.

[63] G. E. Akpan, K. A. Adepoju, and O. R. Oladosu, "Potential distribution of dominant malaria vector species in tropical region under climate change scenarios," *PLoS One*, vol. 14, no. 6, Article ID e0218523, 2019.

[64] J. Yang, Z. Wan, S. Borjigin et al., "Changing trends of NDVI and their responses to climatic variation in different types of grassland in inner Mongolia from 1982 to 2011," *Sustainability*, vol. 11, no. 12, Article ID 3256, 2019.

[65] B. Wan, Q. Tang, Z. Huang, S. Sun, and K.-A. Techato, "Spatial and temporal variation of NDVI in response to climate change and the implication for carbon dynamics in Nepal," *Forests*, vol. 9, no. 6, p. 329, 2018.

[66] R. Jones, "Report on a soil conservation consultancy to study soil erosion problems on the Jos plateau," Land Resource Report No. 6, Central Nigeria Project, Ministry of Overseas Development, London, UK, 1975.

[67] S. R. Longtau and A. Gwaivangmin, *Rethinking Natural Resource Degradation in Semi-arid Sub-saharan Africa: Soil and Water Conservation in Northern Nigeria. CRUDAN, Jos (Nigeria) for ODI*, London, UK, 1999.

[68] A. Adediji, A. M. Tukur, and K. A. Adepoju, "Assessment of revised universal soil loss equation (RUSLE) in Kastina area, Kastina state of Nigeria using remote sensing (RS) and geographic information system (GIS)," *Iranica Journal of Energy and Environment*, vol. 1, no. 3, pp. 255–264, 2010.

[69] J. Hill, P. Hostert, G. Tsiourlis, P. Kasapidis, T. Udelhoven, and C. Diemer, "Monitoring 20 years of increased grazing impact on the Greek island of Crete with earth observation satellites," *Journal of Arid Environments*, vol. 39, no. 2, pp. 165–178, 1998.

[70] CILSS, *Landscapes of West Africa—A Window on a Changing World*, U.S. Geological Survey EROS, Garretson, SD, USA, 2016.

[71] FORMECU, "Assessment of vegetation and land use changes in Nigeria," Unpublished Report by Geomatics International Inc, and Beak International Inc, FORMECU, Abuja, Nigeria, 1998.

[72] Geomatics International Inc, Geomatics Nigeria Ltd., and Beak Consultants Ltd., *The Assessment of Vegetation and Land Use Changes in Nigeria between 1976/78 and 1993/95. Submitted to: Forest Management, Evaluation and Coordinating Unit (FORMECU)*, Nigerian Federal Department of Forestry under the World Bank Environmental Management Project (EMP), Lagos, Nigeria, 1998.

[73] Y. Chen, Y. Xu, and Y. Yin, "Impacts of land use change scenarios on storm-runoff generation in Xitiaoxi basin, China," *Quaternary International*, vol. 208, no. 1-2, pp. 121–128, 2009.

[74] N. Sajikumar and R. S. Remya, "Impact of land cover and land use change on runoff characteristics," *Journal of Environmental Management*, vol. 161, pp. 460–468, 2015.

[75] W. Tadesse, S. Whitaker, W. Crosson, and C. Wilson, "Assessing the impact of land-use land-cover change on stream water and sediment yields at a watershed level using SWAT," *Open Journal of Modern Hydrology*, vol. 05, no. 3, pp. 68–85, 2015.

[76] T. A. Woldesenbet, N. A. Elagib, L. Ribbe, and J. Heinrich, "Hydrological responses to land use/cover changes in the source region of the Upper Blue Nile basin, Ethiopia," *Science of the Total Environment*, vol. 575, pp. 724–741, 2017.

[77] G. Shao, Y. Guan, D. Zhang, B. Yu, and J. Zhu, "The impacts of climate variability and land use change on streamflow in the Hailiutu river basin," *Water*, vol. 10, no. 6, p. 814, 2018.