IBRAHIM ABDULLAHI YABO

ANALYSIS OF LAND PRODUCTIVITY CHANGES AND RELATIVE ROLES OF THE DRIVING FACTORS IN THE SUDAN-NIGERIAN SAHEL REGION

Dissertation submitted to the Soil Science and Plant Nutrition Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae*.

Adviser: Elpídio Inácio Fernandes Filho

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Assent:

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Adviser

To my parents and family.

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First of all, all praise is due to Allah, who has given me this opportunity to carry out this study successfully. Second of all, my sincere gratitude goes to my parents, especially my mother (Khadija) and my late father (Abdullah), and then to my family, who has immensely supported me with sort of encouragement and prayers. I would also like to extend my gratitude to the Federal University of Viçosa, for this golden opportunity to successfully complete the program.

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"Do the best you can until you know better, then when you know better, do better".

(Maya Angelou, American poet, and civil rights activist)

ABSTRACT

ABDULLAHI, Ibrahim Yabo, M.Sc., Universidade Federal de Viçosa, May, 2023. **Analysis of land productivity changes and the relative roles of driving factors in the Sudan-Sahel Region of Nigeria**. Adviser: Elpídio Inácio Fernandes Filho.

Globally, about 25 percent of the total land area has been degraded, causing soil carbon and nitrous oxide released into the atmosphere, hence, land degradation is one of the most important contributors to climate change. Nigeria is listed topmost on the global land degradation danger list. Degraded land in Nigeria exceeds 238,533 square kilometers. However, Nigeria lacks a general detailed analysis of the causes of land degradation, thus hindering targeted solutions more specifically in the Sudan-Sahel Region of the country. This study analyzed the land productivity changes and driving factors in the Sudan-Sahel Region of Nigeria, between the 2001 and 2021 period. Land productivity changes were first analyzed using the NDVI-time series (2001-2021). Then, we used the Normalized Difference Vegetation Index (NDVI) trend, correlation coefficient NDVI-climate, and residual trend-climate to identify the main drivers of biomass changes. The study revealed that 30.69% of Northern Nigeria displayed a significant land productivity decrease, and 27.1% indicated an increase in the land productivity. The productivity increase could be attributed to land abandonment by the farmers due to arm banditry conflicts in the Northern Nigeria since 2009. Moreover, land productivity changed mainly due to human activities and by climate factors. Hence, the land productivity status in the Sudan-Sahel Region of Nigeria decreased mainly due to human factors.

Keywords: Land productivity changes. Driving factors. Nigeria. Sudan-Sahel region

RESUMO

ABDULLAHI, Ibrahim Yabo, M.Sc., Universidade Federal de Viçosa, maio de 2023. **Análise das mudanças na produtividade da terra e os papéis relativos de seus fatores determinantes na região Sudão-Sahel da Nigéria**. Orientador: Elpídio Inácio Fernandes Filho.

Globalmente, cerca de 25% da área total da terra foi degradada, causando a liberação de carbono e óxido nitroso do solo na atmosfera; portanto, a degradação da terra é um dos contribuintes mais importantes para as mudanças climáticas. A Nigéria está listada no topo da lista global de perigo de degradação da terra. A terra degradada na Nigéria excede 238.533 quilômetros quadrados. No entanto, a Nigéria carece de uma análise geral detalhada das causas da degradação da terra, dificultando assim soluções direcionadas mais especificamente na região Sudão-Sahel do país. Este estudo analisou as mudanças na produtividade da terra e os fatores determinantes na região Sudão-Sahel da Nigéria, entre o período de 2001 e 2021. As mudanças na produtividade da terra foram primeiro analisadas usando a série temporal NDVI (2001-2021). Em seguida, usamos a tendência do Índice de Vegetação por Diferença Normalizada (NDVI), o coeficiente de correlação NDVI-clima e a tendência-clima residual para identificar os principais impulsionadores das mudanças na biomassa. O estudo revelou que 30,69% do norte da Nigéria apresentou uma diminuição significativa da produtividade da terra e 27,1% indicaram um aumento na produtividade da terra. O aumento da produtividade pode ser atribuído ao abandono da terra pelos agricultores devido a conflitos de banditismo armado no norte da Nigéria desde 2009. Além disso, a produtividade da terra mudou principalmente devido às atividades humanas e por fatores climáticos. Assim, o status da produtividade da terra na região Sudão-Sahel da Nigéria diminuiu principalmente devido a fatores humanos.

Palavras-chave: Alterações na produtividade da terra. Fatores determinantes. Nigéria. Região do Sudão-Sahel.

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LIST OF ACRONYMS AND ABBREVIATIONS

MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index.
GIS	Geographical Information System.
SSA	Sub-Saharan Africa.
CHIRPS	Climate Hazards center InfraRed Precipitation with Station data.
RC	Rainfall Change
HF	Human Factors
TC	Temperature Change
n.s	Not significant
Ha	Hectare

SUMMARY

1. INTRODUCTION

About 25 percent of the total land area has been degraded globally - more than 20% of all cultivated areas, 30% of forests, and 10% of grasslands – and a concerned was raised about the contested causes, coverage, and severity (GEF, 2011; Bai et al., 2008). When land is degraded, soil carbon and nitrous oxide is released into the atmosphere, making land degradation one of the most important contributors to climate change. Scientists recently warned that 24 billion tons of fertile soil was being lost per year, largely due to unsustainable agriculture practices. If this trend continues, 95 percent of the Earth's land areas could become degraded by 2050 (GEF, 2011). Sub-Saharan Africa (SSA) needs to increase the production of food crops, and this need will multiply in the future. Although, part of the demand will be met by the cultivation of new land, but, it must be met by raising the productivity level of land already cultivated (FAO, 2011). Baumgartner & Cherlet 2015, identified hotspots of land degradation at a global scale by clustering countries into regions and proposed using the unique and prevailing local conditions, such as climatic variations or agro-ecological differences, as guides for understanding the complicated drivers of land degradation.

Land degradation is a serious problem in Nigeria cutting across the whole country. Nigeria is always listed topmost on the global degradation danger list (Foundation, 2020). Degraded land in Nigeria exceeds 238,533 square kilometers (World bank, 2016). However, Nigeria is among the fastest-growing population in the world, and food production increases marginally at a lower rate (Aina et al., 2019). The degradation resulting from erosion, losses of organic matter, plant nutrients, and soil compaction are the key factors threatening food security in Nigeria (Ajayi, 2015; Aina et al., 2019). Hence, despite the massive land space and fertile soil (in some parts of the country), land mismanagement constitutes a serious challenge to the attainment of sustainable food security in Nigeria (Fajobi et al., 2022). It is, therefore, essential that production and soils be managed sustainably so that the present generation is fed and soil conditions are improved to support future generations (Gandiwa & Zisadza-Gandiwa, 2015).

Nigeria faces an impending food security crisis as its rapidly growing population becomes increasingly dependent on imported foods (Jonathan & Jennifer, 2016). Nonetheless, the International Annual Review (2014), reported that Nigeria's imports of everyday goods totaled some $11 billion in 2013 (KPMG, 2014). Although net importation of food is not in itself a wrong thing, it is an unfortunate position for a nation with such vast agricultural potential—and where 70 percent of the labor force is still engaged in the agricultural sector (KPMG, 2014). Moreover, the Nigerian Demographic and Health Survey of 2018, shows that undernourishment left some 37 percent of children under age five stunted, and 2 percent underweight, with the highest rates concentrated in the Sudan-Sahel Savannah States of Nigeria (NPC/ICF, 2018). Over 50 percent of the population lives below the poverty line in northern Nigeria, where up to 70 percent of households rely primarily on agriculture (World Bank, 2016). The most glaring symptom of the slow and decline of Nigeria's agricultural sector can be spotted from the way in which the north of the country, for which agriculture was the economic lifeblood, has fallen and stayed behind on key economic indicators over the past 40 years (World Bank, 2016). Therefore, the Idea of this research was born out of the persistent complaints by the youths in the Northern part of Nigeria of the very low output of the soil in the region - making it very difficult to invest in agriculture.

Impact and changes over time dictate the trends and the current potential of any ecosystem to supply services (Cherlet et al., 2013). Studies of armed conflicts have shown widespread land use changes through displacement and land abandonment, in some cases causing a reduction of cultivated land and increases in natural vegetation (Stevens et al 2011, Gorsevski et al 2012 and Eklund et al 2015). The concept of Land productivity refers to the capacity of a given soil to produce crop yield and supports standing biomass in an ecosystem. In addition to human alteration, the state of land productivity is influenced by natural factors such as precipitation, soil chemical-biological and physical status, topography, the incidence of pests and diseases and land management (Eswaran et al., 2019). Hence, land productivity assessment is a very important step to recognize the environmental limits in sustainable agriculture (Anjana Vyas, Franz-Josef Behr, 2013). Detecting changes in total biomass trend or land productivity is a very crucial yardstick in monitoring land transformations and long-term alterations on the quality of land (De La Fuente et al., 2020). Assessing vegetative cover dynamics approximates a measure of general productivity levels of a given land or human environment system (1). GIS and earth observation can be effectively utilized to analyze the potential productivity of any given land in the world, and ably monitor biomass on a spatial-temporal scale (Bernard et al., 2022). Multi-year time series Normalized Difference Vegetation Index (NDVI) reflects the growth of vegetation for different seasons and thus indirectly reflects land productivity (Anjana Vyas, Franz-Josef

Behr, 2013). Residual NDVI that is not explained by climatic factors (Rainfall and Temperature) and its trend over time, provides information on the land degradation process, and it is assumed that areas show a negative trend are degraded, while those with a positive trend are improved or at least not degraded (Ibrahim et al., 2015).

Although much research has been carried out in Nigeria on land productivity assessment, Nigeria lacks a general detailed analysis of the causes of land degradation, thus hindering targeted solutions (Adenle et al., 2020), more specifically in the Sudan-Sahel region of the country. A recent research carried out by Adele et al. (Adenle et al., 2020), in Northern Nigeria on human-induced degradation between 2003 - 2018, could only reveal the degraded land in Guinea Savannah ecological zone. However, the Sudan-Sahel Savannah region - where 70 percent of the household rely primarily on agriculture and where 50% are below the poverty line (Chalet et al., 2013), so also forecasted to experience major changes in the future - remained as a data poor region (Sedano et al., 2020).

Therefore, it is very crucial to assess the nexus between the land productivity changes and the driving forces, to bind between wise use of soil and effective soil productivity to sustain livelihood in the region. It is on this perception, therefore, unveiling the issues could be beneficial to policymakers and consequently engage more embodied farmers to embrace the knowledge on how to make wise use of the soil. This will help in increase agricultural production in the region, and henceforth, uplift livelihood.

1.1. Aims and objectives

The overall objective of this study is to assess the land productivity trends and the driving factors in the Sudan-Sahel region of Nigeria (using NDVI as a proxy) between 2001 and 2021.

Specific objectives:

i. To assess the land productivity changes in the Sudan-Sahel region of Nigeria.

ii. To identify the various factors and their relative roles contributing to land productivity changes in the Sudan-Sahel region of Nigeria.

We hypothesized that human activities have more influence on land productivity over climatic factors.

2. MATERIALS AND METHODS

2.1. Study Area

The area of study is northern Nigeria. It lies between Latitude 10° 30' 59.99" N and Longitude 7° 25' 59.99" E. Northern Nigeria borders Niger to the north, Cameroon and Chad to the east, and Benin and Niger to the west. The region covers an area of 494,000 square kilometers and comprises the states of Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara as well as parts of Adamawa, Kaduna, Kwara, Niger, and Plateau. Northern Nigeria is part of the Sudan and Sahel Savannah agroecological zones (fig.1).

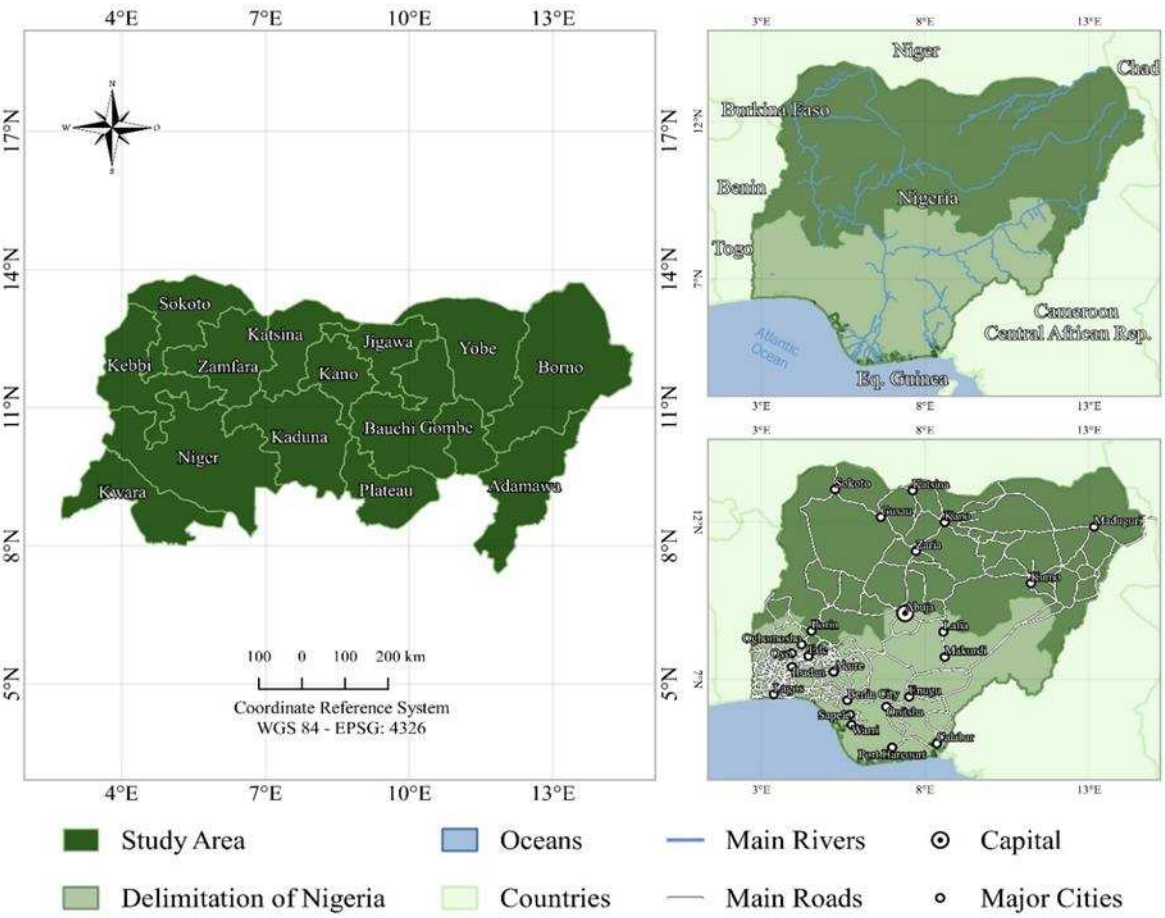

Figure 1 Study Area

2.2. Climate

Köppen climate classification is the most widely recognized and used classification in Nigeria. The location’s climate is developed due to various geographical positions on earth, height above sea level, topography, and vegetation (Mobolade & Pourvahidi, 2020). Köppen climate classifications of Sudan Sahel Region of Nigeria are warm desert climate (BWh), warm semi-arid climate (BSh), and tropical savanna climate (Aw) (Figure 2). Rain only falls from June to September in the range of 500 mm to 750 mm. The rest of the year is hot and dry. Nigerian Sudan Sahel Region areas have a high degree of annual variation in their rainfall regime, which results in flooding and droughts(Harris et al., 2020)(Figure 2).

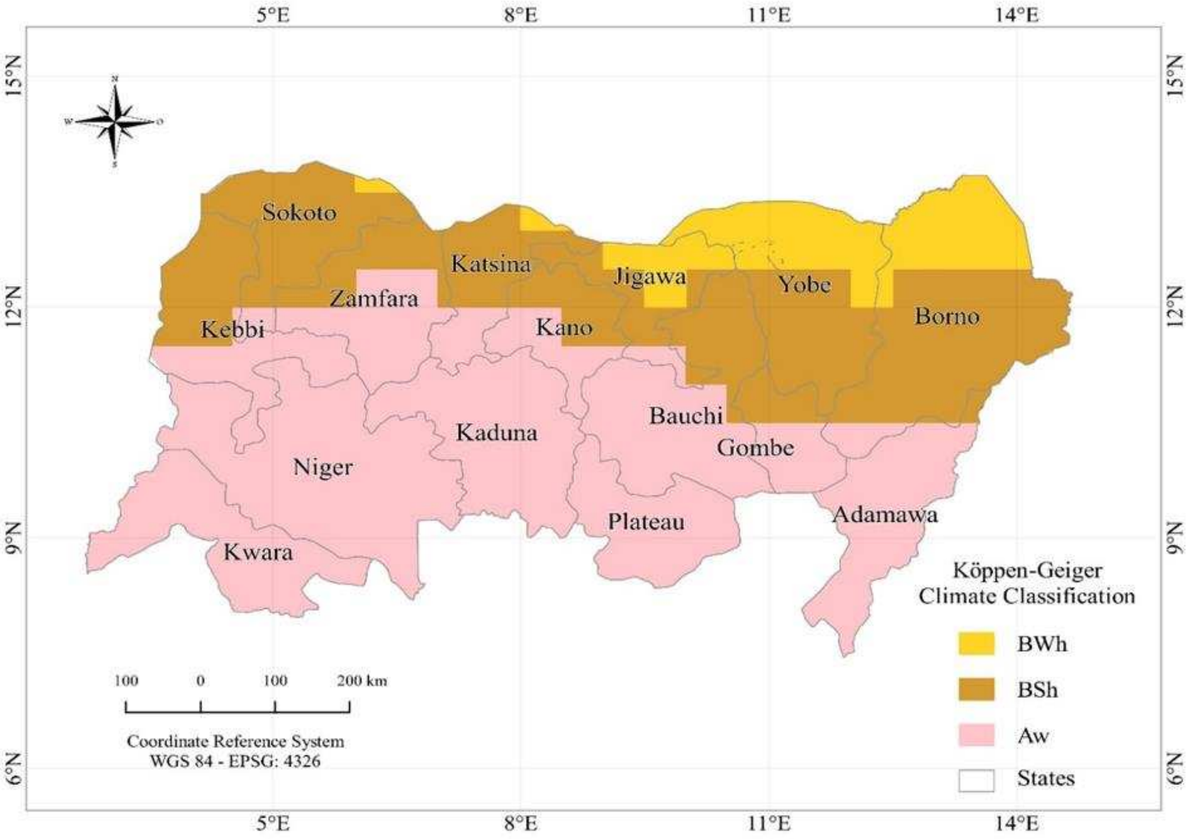

Figure 2. Koppen-Gieger Climate Classification of Nigeria 1991-2020. Source: Observed and projected climate shifts 1901–2100 depicted by world maps of the Koppen-Geiger climate classification (Rubel & Kottek, 2010).

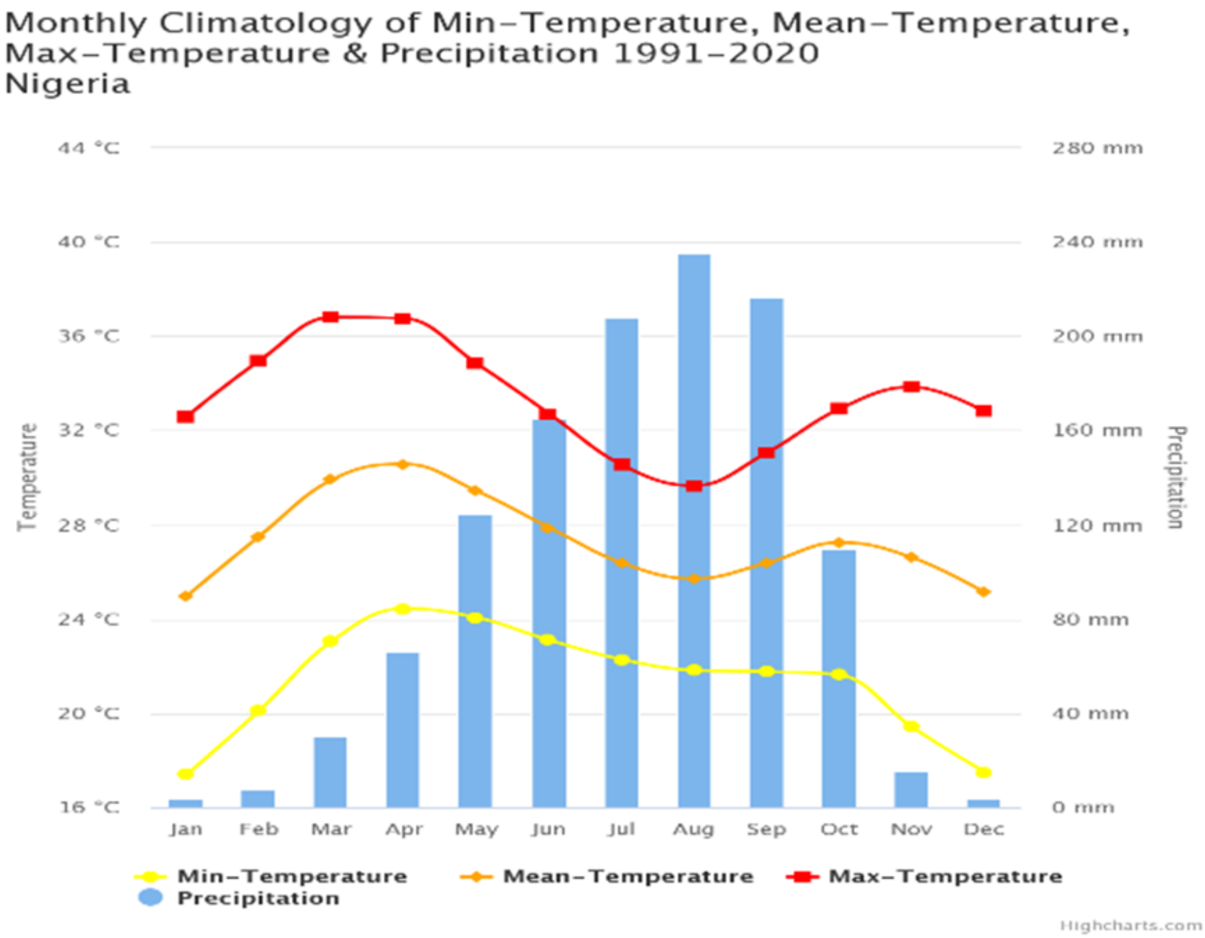

Figure 3. Monthly Climatology of Nigeria 1991-2020 (Source: Climate Change Knowledge Portal Report (2020) (Harris et al., 2020)).

2.3. Geology, elevation and soils

The geology of the study area is Precambrian Basement Complex (high-grade metamorphic rocks with gneiss and granitic intrusions) dominated in the central part of the area. While, the sedimentary rocks of the Benue Niger trough system dominated eastern and western parts of the study area (Moberg and Esu, 1991). Volcanic rocks are also found in some marginal areas, e.g. the Jos and Biu areas (FMEN, 2001, Geological Survey, 1974; Kogbe, 1976; Wright, 1976). Quaternary sandy and silty aeolian deposits, and sandy to clayey lacustrine and alluvial deposits are found in in the extreme North part of the area (Geological Survey, 1974). The landforms in the study area are highlands, plateaus, hills, plains and river valley systems (FMEN, 2001). Basins characterized by broad gently sloping plains dominated the study area, except for the Eastern Highlands in Adamawa area and the Jos Plateau (FMEN, 2001).

Generally, soil types in Nigeria, according to the FAO soil taxonomy legends are fluvisols, regosols, gleysols, acrisols, ferrasols, alisols, lixisols, cambisols, luvisols, nitosols, arenosols, and vertisols. These soil types vary in their potential for agricultural use for example, Fluvisols, Gleysols Regosols are rated good while Acrisols, Ferralsols, Alisols, Vertisols, Arenosols, Nitosols are rated low. Clearly none of these soils is rated as Class 1 with high productivity by the FAO. Indeed, over 48% of Nigerian soils fall into classes 4 and 5 (FMEN, 2001). Soil in most northern part of Nigeria are Sandy characterized by low water holding capacity, covering large areas of land with very low water-holding capacity and low organic matter, low nitrogen phosphorus content, neutral or moderately acidic in pH and also having a low cat ion exchange capacity (Usman and Suleman, 2011; Jones and Wild, 1975).

The elevation in the study area ranges between 100 and 1,300 meters above sea level. Lower elevations are found in the Benue River valley to the west and the Gongola River valley and the Lake Chad depression to the east (Figure 4). The highest elevations are found to the south in the Jos Plateau (Hennig et al., 2001).

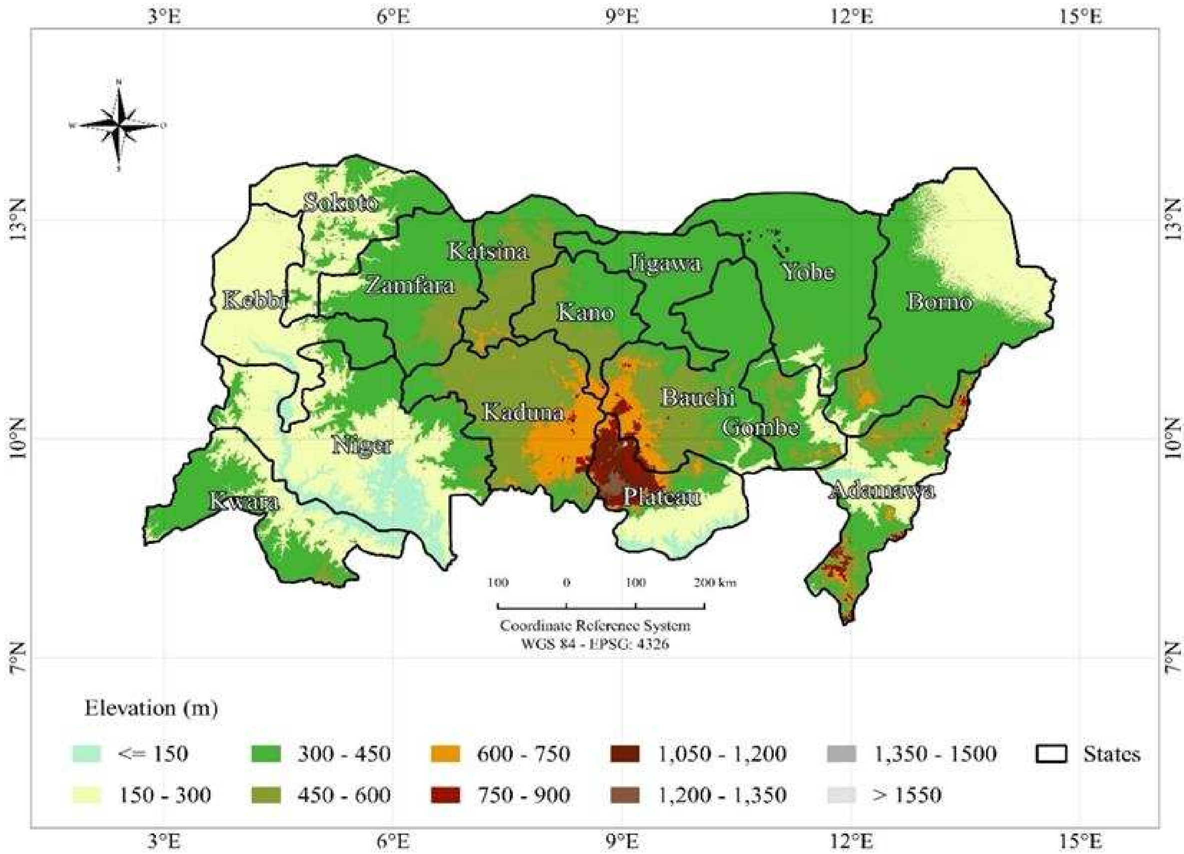

Figure 4. Digital elevation model of Sudan Sahel Nigeria.

2.4. Land use and land cover data

The MCD12Q1 Version 6.1 data LC_Type1 product was used to produce land use and land cover data of the study area (Cover, L. 2020) to ascertain some human activities responsible for the land productivity changes of the study area. The MODIS Land Cover Type Product (MCD12Q1) provides a suite of science data sets (SDSs) that map global land cover at 500-meter spatial resolution at annual time step for six different land cover legends. The maps were created from classifications of spectro-temporal features derived from the Moderate Resolution Imaging Spector diameter (MODIS) (Sulla-Menashe & Friedl, 2018). The produced map of the area is composed of 9 IGBP land cover categories (Table 1) - forest, cropland, grassland, shrub lands, savannah, urban, barren, water, and wetland (2020).

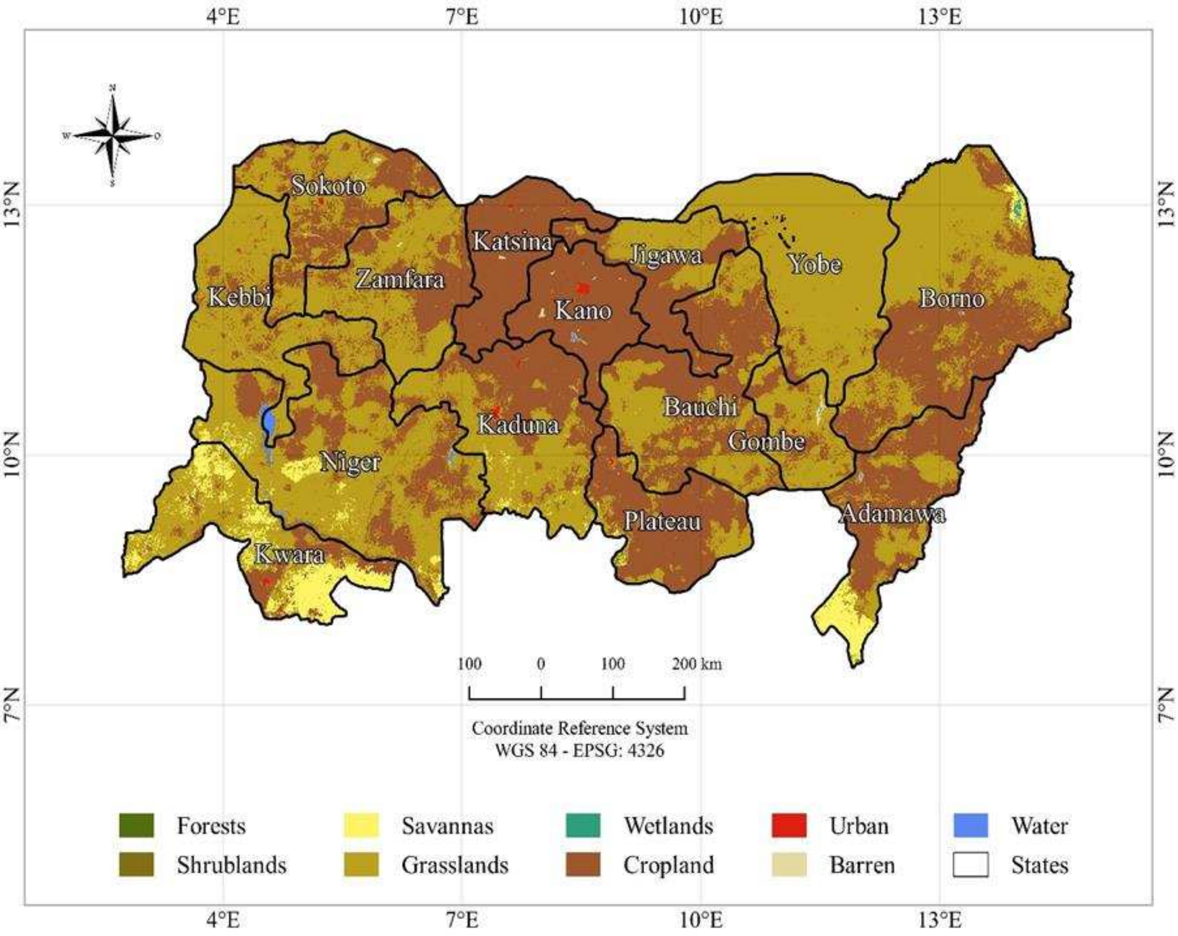

Figure 5. Land use and land cover map of Sudan Sahel Region of Nigeria (2020).

Table 1. Description of land use/land cover classes identified in the study area

Name	Value	Description
Water bodies	0	At least 60% of the area is covered by permanent water bodies.
Evergreen Needleleaf Forests	1	Dominated by evergreen conifer trees (canopy>2m). Tree cover >60%
Evergreen Broadleaf Forests	2	Dominated by evergreen broadleaf and palmate trees (canopy >2m). Tree cover >60%.
Deciduous Needleleaf Forests	3	Dominated by deciduous needle leaf (larch) trees (canopy >2m). Tree cover >60%.
Deciduous Broadleaf Forests	4	Dominated by deciduous broadleaf trees (canopy>2m). Tree cover >60%.
Mixed Forests	5	Dominated by neither deciduous nor evergreen (40-60% of each) tree type (canopy>2m). Tree cover >60%.
Closed Shrublands	6	Dominated by woody perennials (1-2m height) >60% cover.
Open Shrublands	7	Dominated by woody perennials (1-2m height) 10-60% cover.
Woody Savannas	8	Tree cover 30-60% (canopy >2m).
Savannas	9	Tree cover 10-30% (canopy >2m).
Grasslands	10	Dominated by herbaceous annuals (<2m).
Croplands	12	At least 60% of area is cultivated cropland.
Urban and Built-up Lands	13	At least 30% impervious surface area including building materials, asphalt, and vehicles.
Barren	15	At least 60% of area is non-vegetated barren (sand, rock, soil) or permanent snow and ice with less than 10% vegetation.

2.5. Data sources and pre-processing

2.5.1. MODIS NDVI time-series

Images of the 16-day NDVI trend were collected from the MODIS NDVI products(51) available at a 500 m spatial resolution (Didan et al., 2015). The MODIS product was selected because of its capacity to provide a regular and long-term record of vegetation conditions that can be used to detect changes in vegetation over time(Montfort et al., 2021). The collected images which cover a period from 2001-2021 over the Sudan-Sahel Region of Nigeria were used to analyze NDVI trends as a proxy for biomass productivity changes (Leroux et al., 2017). The MODIS product is corrected for molecular scattering, ozone absorption, and aerosol (Didan et al., 2015). Meanwhile, residual noise may persist and disturb the NDVI signal. To reduce this noise, the NDVI time series was pre-processed using a Savitzky–Golay filter (polynomial 3 and windows 18) to smooth the data outliers without distorting the signal tendency (Chen et al., 2004). Finally, for each pixel, the annual cumulated (from 1st January to 31st December) NDVI was calculated (Montfort et al., 2021).

2.5.2. Rainfall data

Due to the sparse and irregular rain gauge network in the study area, the Climate Hazards Group Infrared Precipitation with Station data (*CHIRPS*) was used (52). CHIRPS product was evaluated over the Greater Horn of Africa and found to perform significantly better than African Rainfall Climatology version 2 (ARC2) with higher skill, low or no bias, and lower random errors. This product was also better than Tropical Applications of Meteorology using Satellite data (TAMSAT3) in terms of skill and random error(Dinku et al., 2018). The data (was obtained for 2001-2021, and resampled for comparison with MODIS NDVI data using the nearest neighbor resampling method at 500 m resolution (Montfort et al., 2021).

2.5.3. Air temperature data

Air temperature data was obtained from ERA5Land Temperature data. We selected ERA5Land Temperature product because, it generally reproduces the temperature trend very well for observations and is reliable for scientific research (Zhao & He, 2022). The average maximum temperature was calculated per climatic year for the 2001-2021 period, and it was also resampled using the nearest neighbor resampling method to the MODIS NDVI data spatial resolution of 500 m.

2.6. Land Productivity Change Analysis

2.6.1. NDVI trend analysis

Land productivity changes were analyzed using a statistical trend analysis applied to each pixel of the 21-year annual MODIS NDVI time series (2001-2021). The statistical trend analysis was based on the nonparametric Mann-Kendall test (MK), which finds trends for as few as four samples. It returns a tau coefficient that varies from -1 to 1. A positive tau coefficient indicates a productivity increase and a negative tau coefficient indicates a productivity decrease. The significance of the tau coefficient was determined using the P-value, at a 95% confidence level (P-value < .05). Each pixel was, therefore, classified into three NDVI trend types: significant increase or decrease in productivity and non-significant changes.

2.6.2. NDVI-climate correlation

The statistical trend analysis was based on the Pearson correlation coefficient (***r***) (figure 2). Pearson correlation measures the existence (given by a p-value) and strength (given by the coefficient r between -1 and +1) of a linear relationship between two variables. If the outcome is significant we conclude that a correlation exists (Boslaugh, 2012)**.** After visually verifying a linear relation among NDVI and Temperature/Precipitation, we evaluated the significance and strength of the relationships between the annual cumulated NDVI value and annual cumulated rainfall value, and annual average maximum temperature value over the 2001–2021 period for each pixel. The correlation was considered statistically significant at the 95% level (P-value < .05).

2.6.3. NDVI residual trend analysis

The RESTREND analysis method was used to examine the trend of the residual differences between the observed NDVI and the predicted NDVI (using a linear regression among NDVI, precipitation and temperature) with either rainfall or air temperature as the explanatory variable(Evans & Geerken, 2004). Although Montfort and Luerex (2020) used linear regression to examine the trend of the residual differences between the observed and predicted NDVI, we improved this approach using MK test instead of a pearson, in order to find not only a linear increasing or decreasing of residuals, but also any monotonic relationships. The residual trend is interpreted as the part of the vegetation productivity that is not explained by rainfall or temperature variable (Montfort et al., 2021). In this study, therefore, pixels with no significant vegetation productivity to rainfall or temperature correlation ($p<0.05$) were not used in the residual analysis (Leroux et al., 2017), this is because RESTREND is relevant only in cases where significant relationships between NDVI and climate (rainfall and temperature in this study) are observed(Fensholt et al., 2012).

2.6.4. Land productivity change factor analysis

In this study, we assume that changes in productivity are induced mainly by climate and human factors (which includes all factors related to land management and their environmental impacts), and this was also considered by Montfort, et al. (2020) and Leroux et al. (2017). In this analysis, we aimed to identify the productivity changes induced by rainfall or temperature trends from those changes induced by human factors. Hence, relative roles were assigned to climatic factors and other causative factors in the NDVI changes.

2.6.5. Software Packages used

Software packages used for this study are Google Earth Engine (GEE) for image analysis, image enhancement, pre-processing and statistical analysis. GEE was also used to check and validate the results. QGIS, an open-source software was used for raster visualization and map preparation. Microsoft Office, Microsoft Excel, and Microsoft PowerPoint were used to create word documents, analyze spreadsheets, do graphs, manage databases, and for presentations.

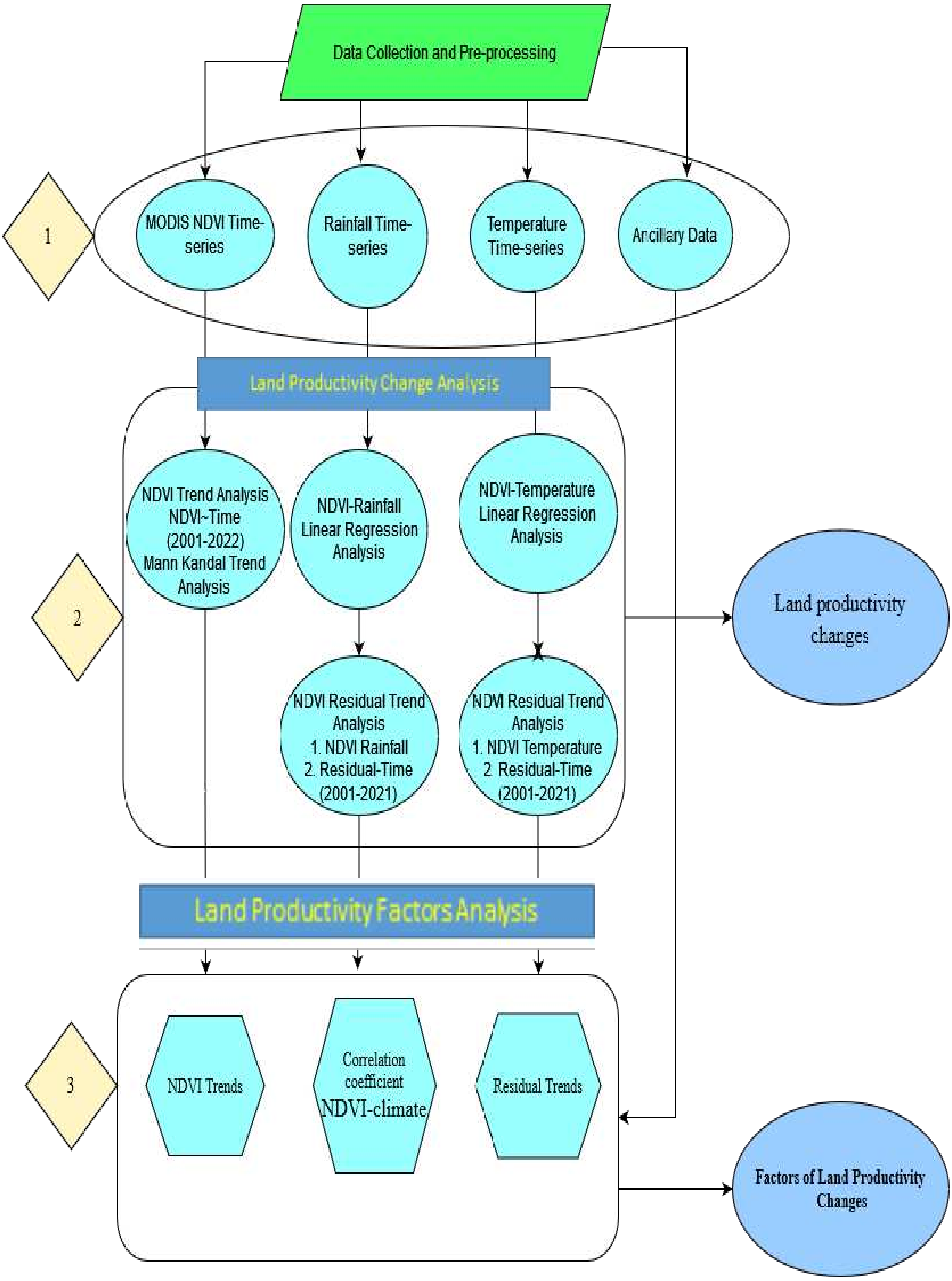

Figure 6. Flow chart of the study approach.

We postulated that if we could isolate the climatic factors from the human factors, the relative roles of both factors in NDVI trends could be assessed and mapped. This classification scheme generates a set of 15 possible decision rules based on the tau of the NDVI trend, the NDVI-climate coefficient of correlation, and the tau of the NDVI residual trend (Table 2, Figure 6). Hence, land productivity changes could be driven (i) only by rainfall, (ii) only by temperature (iii) only by human factors, (iv) by temperature + human factors, (v) by rainfall + human factors, (vi) by rainfall + temperature, and (vii) by the combinations of all the factors (rainfall + temperature + human factors). And lastly, not significant was considered no change in the land productivity. The combination case was not taken into account when considering the first two methods (Ibrahim et al., 2015). The impact of other factors is assessed using the tau of the NDVI trend corrected from the climate effect (i.e., NDVI residual trend), for which a positive trend (tau >0) means that land productivity increases more than can be explained by climate alone (rainfall or temperature), and a negative trend (tau < 0) means that land productivity decreases more than can be explained by climate alone (rainfall or temperature) (Table 2).

Thus, a positive NDVI trend (i.e., an increase in biomass productivity) associated with a significant NDVI-climate correlation (r > 0.49) and a significant positive trend in NDVI residual (tau > 0) indicates that the land productivity changes benefit both from climate (rainfall or temperature) and from human factors because—after removing the climate effect—a positive trend can still be observed in NDVI (Table 2). In contrast, if a significant NDVI-climate correlation is observed together with an NDVI residual negative (tau <0) or non-significant trend (p-value <0.05), the observed land productivity changes are due mainly to the climate factors (rainfall or temperature). Finally, when there is no NDVI-climate correlation, it means that vegetation growth benefits only from human factors (Montfort et al., 2021)(Table 2).

Table 2. Decision plan for detecting productivity change-driven factors.

NDVI trends (p-values<0.05)	Correlation Coefficient NDVI-rainfall	Residual trends Rainfall (p-value<0.05)	Correlation coefficient NDVI-temperature	Residual trends temperature (p-value<0.05)	Categories of change Factors.
Decrease (Tau < 0)	r > 0.50	Tau > 0 or n.s	r > -0.50		Rainfall change
	r < 0.50		r < -0.50	Tau > 0 or n.s	Temperature change
	r > 0.50	Tau > 0 or n.s	r < -0.50	Tau > 0 or n.s	Rainfall and temperature change
	r > 0.50	Tau < 0	r > -0.50		Rainfall + Human factors
	r < 0.50		r < -0.50	Tau < 0	Temperature change + Human factors
	r > 0.50	Tau < 0	r < -0.50	Tau < 0	Rainfall and temperature change + human factors
	r < 0.50		r > -0.50		Human factors
Increase (Tau > 0)	r > 0.50	Tau < 0 or n.s	r > -0.50		Rainfall change
	r < 0.50		r < -0.50	Tau < 0 or n.s	Temperature change
	r > 0.50	Tau < 0 or n.s	r < -0.50	Tau < 0 or n.s	Rainfall and temperature change
	r > 0.50	Tau > 0	r > -0.50		Rainfall + Human factors
	r < 0.50		r < -0.50	Tau > 0	Temperature change + Human factors
	r > 0.50	Tau > 0	r < -0.50	Tau > 0	Rainfall and temperature change + human factors
	r < 0.50		r > -0.50		Human factors

NDVI: Normalized Difference vegetation index. n.s : non-significant (p-value > 0.05)

3. RESULTS

3.1. Land productivity change

30.69% of the land in the region shows a significant decrease in the region, and this is greater in areas of Kebbi, Niger, Kaduna, Yobe, Gombe, and Adamawa and minimal in areas of Borno, Plateau, Zamfara, and Sokoto. However, 27.1% of the region's land shows an increase in land productivity, which is obviously observed in larger areas of Sokoto, Zamfara, Katsina, Jigawa, and Kwara, but very minor areas were observed in Kebbi, Niger, Kaduna, Plateau, Gombe, and Adamawa (Fig 7, Table 3). However, a heterogeneous dispersion of non-significant land productivity change (42.21%) over the Sudan-Sahel region of Nigeria was observed. This could be due to transition zones with intermediate environmental and anthropogenic changes.

Table 3. Distribution of Land Productivity changes in Sudan-Sahel Nigeria.

Residual trends	Area(ha)	%total area
Significant Decrease	174,369.44	30.69
Significant Increase	153,964.4	27.1
Not Significant	239,829.11	42.21
Total	482,298.24	100

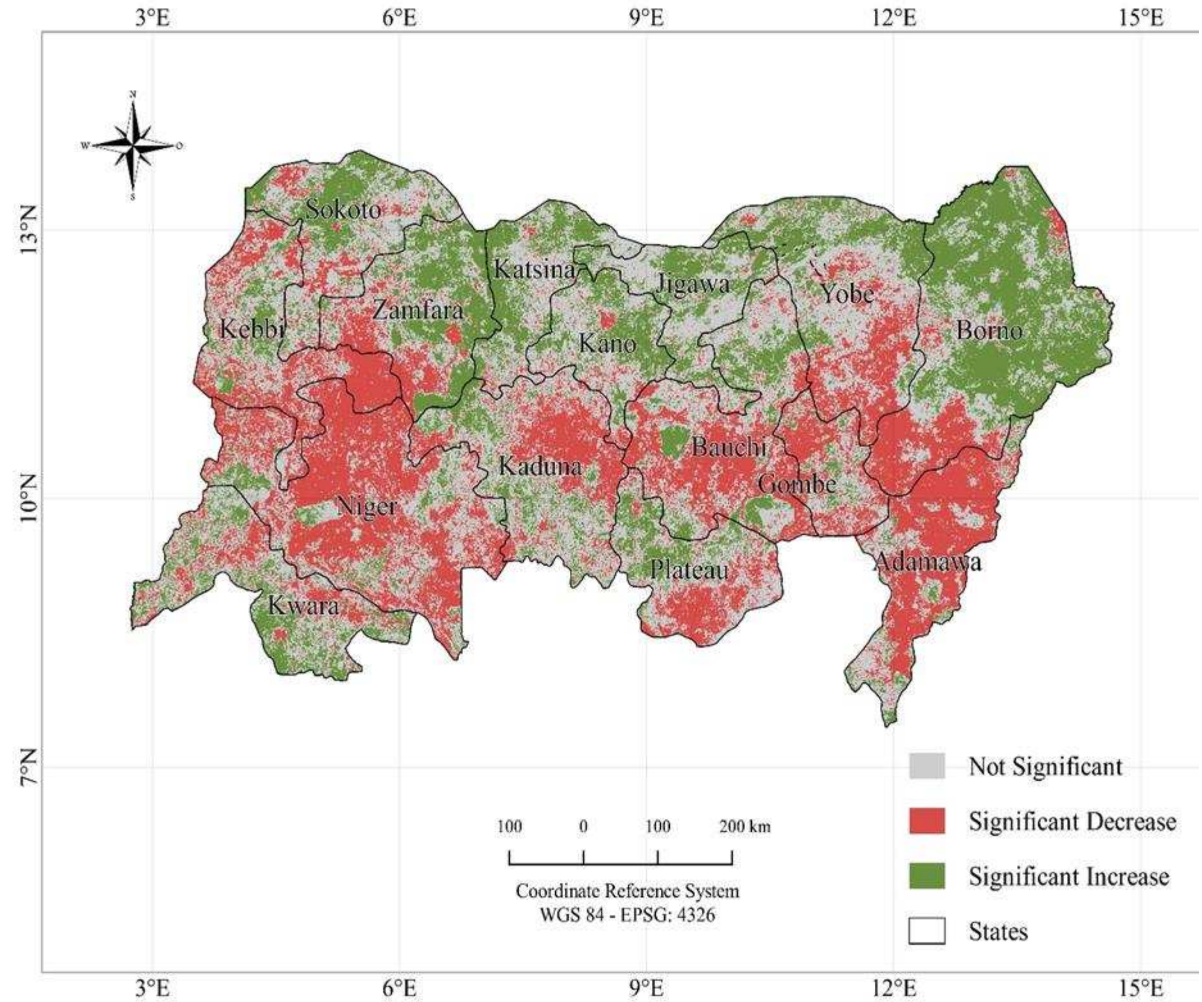

Figure 7. Distribution of land productivity status in Sudan Sahel Region Nigeria.

3.2. The NDVI-climate relationships

NDVI-climate correlation analysis revealed that 83.12% and 98.47% of the study area were not significant for precipitation and temperature, respectively. 16.75% and 1.54% of the pixels displayed significant positive NDVI-precipitation and negative NDVI-temperature relationships respectively (Figure 8, Table 3). Meanwhile, the result ascribed that climate factor has very little influence on vegetation growth in the region (2001 – 2021 period). It was also observed from the analysis that precipitation has more influence over the temperature variables. The spatial distribution of NDVI-precipitation relationship is highly concentrated in the states of Northeast and Northwest of the region while for that of NDVI-temperature relationships seen to be concentrated in some parts of Northeast and North central. The results agree with (Ichii et al., 2002), who confirmed that NDVI–precipitation correlations are higher than those of the NDVI–temperature in the semi-arid region of the world.

Table 4. NDVI-climate correlations (2001-2021)

	Precipitation		Temperature	
	% Area	Total Area(ha)	% Area	Total Area(ha)
Not Significant	83.12	47,226,292	98.47	55,946,493
Negative (P-value<0.01)	6.13	3,483,405	0.19	105,205
Negative (P-value<0.05)	10.75	6,106,914	1.35	764,912
Total	**100**	**56,816,611**	**100**	**56,816,611**

3.4. Land productivity change factor analysis

Figure 9 and table 4 present the analysis of the various productivity change factors in Sudan Sahel Region of Nigeria (2001-2021). The result revealed that 30.08% of the decreasing trend over the 2001-2021 period in the region can be explained by human factors alone. Meanwhile, only (0.29%) of the decrease can be explained by climate change factors. Whereas the climatic variability combined with human factors displayed 0.08%.

Table 5. Distribution of land productivity driving factors in the Sudan-Sahel Nigeria, calculated for the 2001-2021 period.

NDVI trend (p-value<.05)	**Hectares**	**% Area change**	**Change induced factor**
Decrease (Tau<0)	1358.15	0.24	RC
	1323.29	0.23	TC
	658	0.0	TC + RC
	280.86	0.05	RC + HF
	6.58	0.09	TC + HF
	0.0	0.0	RC + TC + HF
	170,905.91	30.08	HF
Increase (Tau<0)	28,670.83	5.05	RC
	18.93	0.00	TC
	1893	0.0	TC + RC
	1643.82	0.29	RC + HF
	6.54	0.00	TC + HF
	0.0	0.0	RC + TC + HF

	123,609.95	21.76	HF
Not Significant	**23,982,911**	**42.21**	

RC = Rainfall change, TC = Temperature change, HF = Human factor

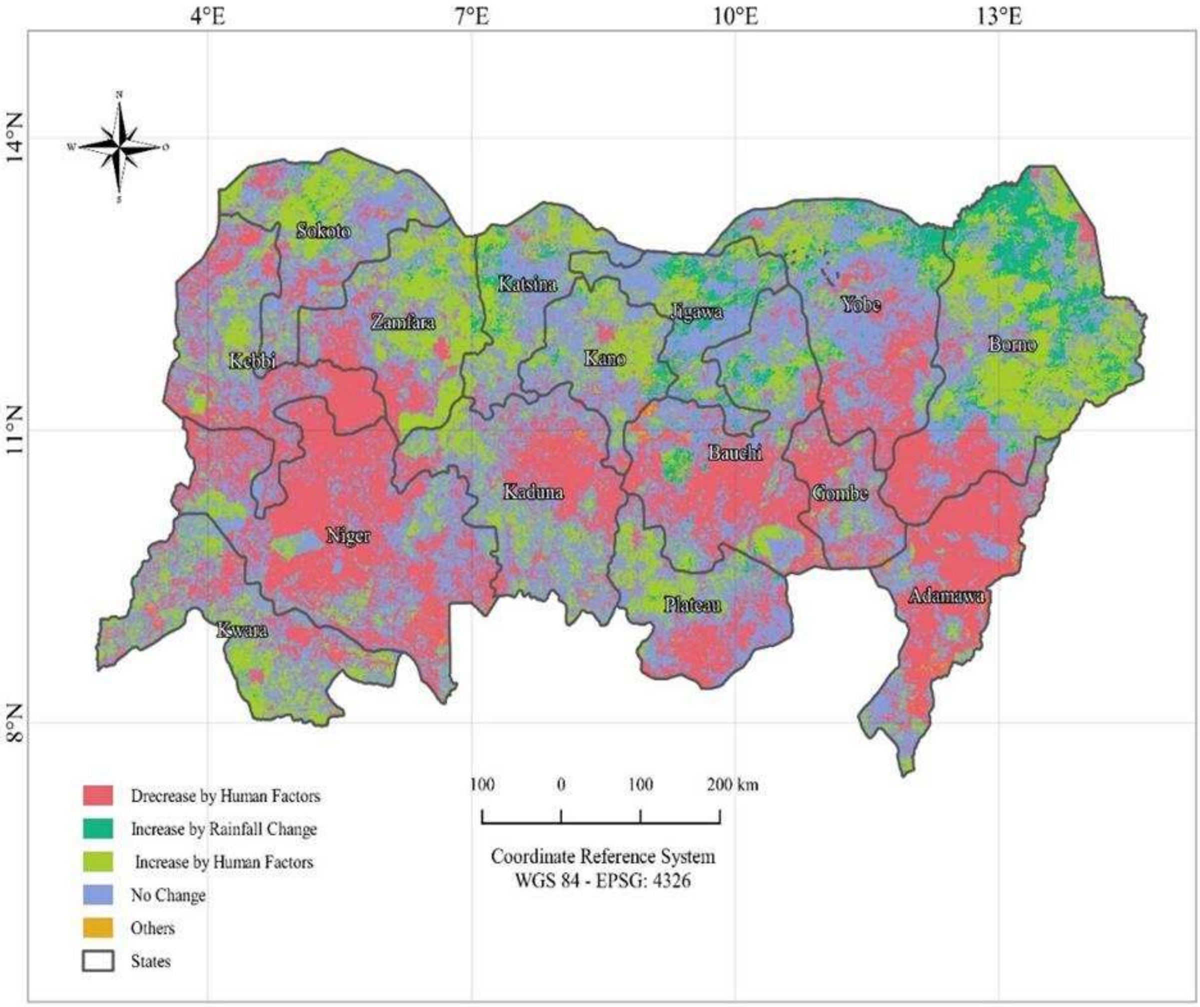

Figure 8. Distribution of land productivity change factors in Sudan Sahel Region of Nigeria (2001-2021).

With regards to positive NDVI trends, climate factors are responsible for only 5.05% of the trends over 2001-2021, Human factors for 21.76%, and climatic variability combined with human factors account 0.29% (Table 5). This shows that, in both the reduction and increase in the land productivity changes of the Region, the human factor is the dominant driven factor (Table 4, Figure 10).

3.5. Assessment of the major land use and land cover changes causing land

productivity changes in Sudan Sahel Region of Nigeria.

Our cross-matching result between land use and land cover changes and major drivers of land degradation (Figure 9) have revealed that human activity is the dominant factor that is causing land productivity changes in all the 3 climatic zones in the Sudan Sahel Region of Nigeria. Furthermore, cropland and grassland were almost 50% degraded by human activities in the tropical Savannah climate zone of the study area. In contrast, the crop and grass land productivity were also observed to be improved in arid and semi-arid climate zones of the region due to human activities, despite the less favorable climate in the zones (Figure 9).

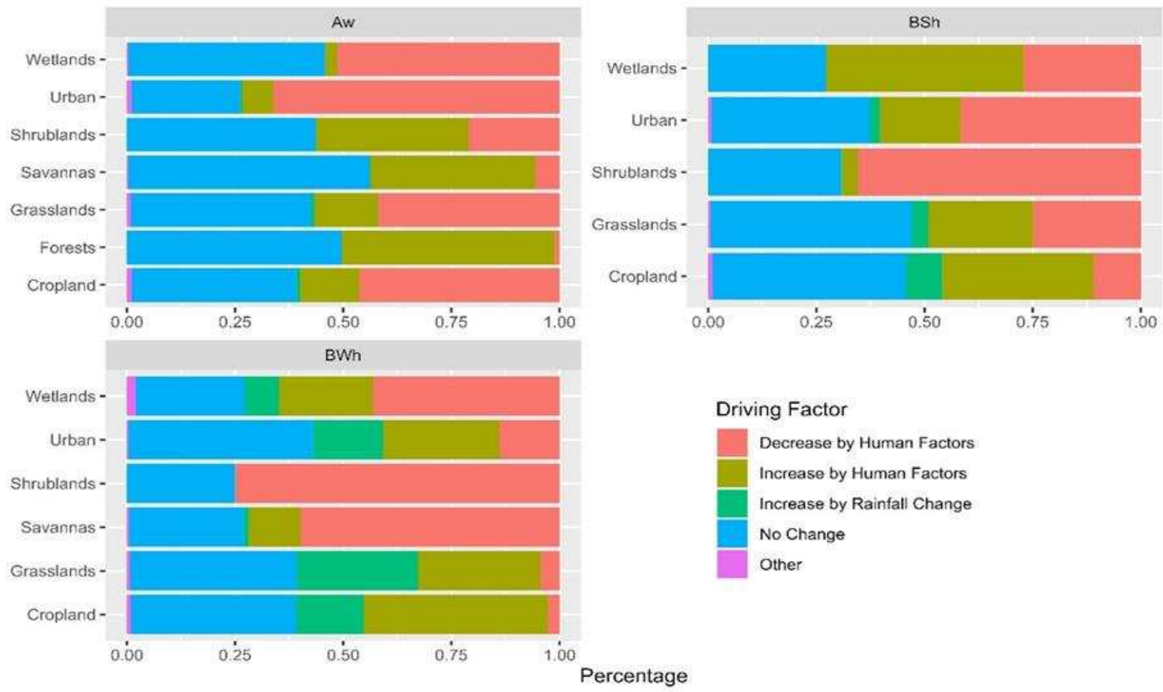

Figure 9. Percentage share of land productivity change factors by land cover and land use changes in Sudan Sahel of Nigeria.

Savannah and shrub lands were observed to be more developed (more than 40%) than decrease in the tropical climate zone of the area, however, in the semi-arid zone they were severely degraded by human activities (Figure 10). Wetlands have degraded severely in both tropical and semi-arid zones of the region, but more developed than decrease in the arid region (Figure 10).

4. DISCUSSION

The area where an improvement of land productivity (27.1%) was revealed by the result (Figure 2, 7 and 10), falls under arid and semi climate zones - characterized with erratic rain distributions ranges between 100-1000 mm and a relative humidity generally below 40%, except for the few rainy months when this can rise to 60% and above (Challinor *et al.,* 2007; Ariko *et al.,* 2019), having dry seasons ranging from 6 - 8 months (WWF, 2007), a topography mainly flat; usually between 200 – 400 meters above sea level (Dai *et al.,* 2004), and also, dominated by clayey sub soils and sandy to loamy top soils (Challinor *et al.,* 2007; Callo-Concha *et al.,* 2019), coupled with poor soil fertility being major constraint (Sanchez, 2002). However, contrary to what is expected in the climate zone, this could be attributed to rewilding of the land that was abandoned by farmers due to Boko Haram insurgencies in the region (Abdullahi, 2021), thus facilitating the resilience of natural ecosystem processes and having fewer human disturbances on the landscapes (Plieninger et al., 2014) - as farmers migrate from the conflicts affected areas of the region towards urban and then to the neighboring regions due to arm banditry ongoing in the study area since 2009. Chad L., et al. (2022), also confirmed this in their research on crop change detection in conflict-affected areas of Nigeria (2010-2020). In a another development, a paper presented in the Brazilian Army Command and General Staff School by Abdullah (2021), revealed that Boko Haram activities in the region have forced farmers to abandon their farms and markets because of the risk to their lives, which poses a serious threat to food production and economic development in the region (Abdullahi, 2021). Many rural farmers have been displaced in Nowest and Northeastern Nigeria, while others are prevented from going to their farms because of security checks and the militaristic counter-terrorism approach of the government (Adebisi et al., 2017). Research by Nunes et al. (2010) on soil erosion and hydrological response to land abandonment, has also revealed that abandonment of cereal plots leads to dense plant cover in the form of scrub communities or recovering forests. Alaigba & Adzandeh (2020) found signs of land abandonment in some parts of the Sudan-Sahel were 8% of what had been agricultural land during the study period (2002–2017) changed to fallow/ bare soil and natural vegetation. In contrast, the large land productivity decrease (30.69%) that exhibited in the region during the study period falls mostly under tropical savannah areas of Nigeria (Table 4; Figure 2; Figure 7) – where threre is higher rainfall distribution as compared to arid and semi-arid (1000 – 1500 mm), with about 6 - 8 months of rainfall (NFREL Report, 2019), soils in the zone are generally classified as Alfisols, highly weathered and fragile with low activity clays, thus making their fertility fall under continuous extensive cropping (Buba, 2015). This The States under this zone are Kebbi, Niger, Kaduna, Yobe, Gombe and Adamawa. This could be attributed to high human pressure on the savannah (B. M., 2014), which invariably reduces the savannahs' potential to provide ecosystem services because of the poor management of savannah vegetation(Zhang et al., 2016), unsustainable agricultural activities(Cover, 2020), Such human pressures have a direct effects that can lead to degradation as they place higher demands on the savannah and its resources (*Viewpoints Human Impacts in African Savannas Are Mediated by Plant Functional Traits*, 2018). This is also in line with GEIST & LAMBIN, 2004 and Sendzimir et al., 2011, who confirmed the devolution in an on-farm tree density in Nigeria in comparison to Niger, even though, Nigeria has a more favorable climate than Niger (B. M., 2014). These pressures drive the loss of biomass and ecosystem services, leading to impoverishment (B. M., 2014). Adenlele et al.(2020), found the same result in degraded areas in tropical savannah areas of Nigeria (Adenle et al., 2020). However, in all the three climatic zones of the region a heterogeneous dispersion of non-significant land productivity changes (42.21%) was observed (Figure 2, Table 3 and Figure 9). This could be due to transition zones with intermediate environmental and anthropogenic changes.

Despite the important role of climate in land productivity changes, our results (Figures 8-10, table 3 and 4) show that there is an almost complete absence of climate factors in the land productivity change, however, human activities remained the dominant factor in land productivity changes in Northern Nigeria (31.57%), impacting more decrease than the increase in the land productivity of the region (Table 3). This finding is in line with Montfort et al. (2020), who confirmed the domination of human activity in land productivity changes in the Sudan Sahel Region. This was also reported by Lanly et l. (1982) and also consistent with Leroux et al. (2017), Fenshon and Rasmussen (2011), who reported positive trends even after the removal of climatic factors in RESTREND analysis, in some Sahel Savannah Region. Moreover, our cross-matching result between land use and land cover changes and factors of land productivity change has reconfirmed human activity as the dominant land degradation factor (Figure 9) inducing land productivity changes in the Sudan-Sahel Region of Nigeria.

In Sub-Saharan Africa (SSA), reduced productivity of most agricultural crops will continue to drive land-use changes (Chinzila, 2018), West African countries have lost — and are still losing — large extents of their natural land cover classes, replaced by a heavily human-influenced landscape dominated by agriculture (Chinzila, 2018). Farming, grazing and settlements have expanded at the expense of native vegetation (Maitima et al., 2010), as native vegetation is lost, indigenous plant and animal biodiversity and plant cover are lost. So also, soil fertility and moisture drops and soils erode more easily. As plant biodiversity falls, soil erosion increases (Maitima et al., 2010). In arid, semi-arid, and dry sub-humid areas of Africa, land degradation due to erosion and salinization is exacerbated by poor agricultural practices (in particular poor management of irrigation and fertilization) (Chinzila, 2018).

However, the Nigerian government has implemented several initiatives and programs to address the recurrent land degradation situation in the country such as: the Agriculture Promotion Policy (APP); Nigeria–Africa Trade and Investment Promotion Program; Presidential Economic Diversification Initiative; Economic and Export Promotion Incentives; and the Zero Reject Initiative; Reducing Emission from Deforestation and Forest Degradation (REDD+); Nigeria Erosion and Watershed Management Project (NEWMAP); Action Against Desertification (AAD) Program - agricultural expansion, heavy reliance on firewood and charcoal for energy, unsustainable timber extraction, urbanization, grazing, bush fires, infrastructure development have continued to be the main causes of land degradation in the country (Payne, 2000).

The Nigerian government is therefore, recommended according this result to create demonstrative farms (which are lacking in all the above-mentioned programs), recruit expertise and engage farmers for practical training with effective supervision, to develop a balance between production systems, socio-economics and the biophysical and chemical cycles. The following approaches can also be considered:

1. Train how to use fertilizers appropriately.
2. Train how to use appropriate technologies in land management.
2. Developing a system of responsibility and accountability among all key players.
3. Capacity building among land users on sustainable land management.
4. Financing the farmers to continue implementing the acquired knowledge for sometimes.

5. CONCLUSION

This study mapped and assessed the changes in land productivity of Sudan-Sahel Region of Nigeria and the driving forces inducing the spatiotemporal changes in the Region, using remote sensing data. Generally, our study revealed that land productivity of the Sudan-Sahel region of Nigeria decreased and menaced over one-third of Northern Nigeria’s land. We revealed that a large part of this negative trend could be mainly related to human activities compared to climate change factors.

This study therefore, provides a logical and timely special estimation of land productivity status in (SSA), which can help decision-makers to design up-to-date suitable land degradation mitigation policies or programs to help improve the land productivity of the Region for profitable farming so that more youths could be possibly engaged not only, in subsistent farming, but also in commercial farming.

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