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A GIS-based impact assessment of vegetation on rainfall patterns in cross river state, Nigeria

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Abstract

Vegetation dynamics are the phenological metrics variations and transformations in the vegetation of different land cover types over a particular region. This study investigated the spatio-temporal vegetation dynamics employing NDVI, and its response to climate variability (rainfall) between 1988-2018 with the specific objective of determining the rainfall pattern over 40years, determining land use change trend, investigating the annual NDVI trend, and analyzing the correlation between NDVI, land use and rainfall in the study area. The study utilizes annual land use land cover analysis and land use dynamics of the area from the European Sentinel Agency Climate Change Initiative (ESA CCI) at 300m resolution to analyse the vegetative response. Annual NDVI at 250m and 30m spatial resolution from very high-resolution MODIS MOD13Q1, Landsat images, and average annual rainfall for the years; 1988, 1998, 2008, and 2018 were also collected and analysed respectively. The annual Rainfall increased from 1988 to 1998 then decreased steadily from 2008 to 2018. The Av. Mean rainfall is 211.22mm, 239.64mm, 228.83mm, and 220.12mm in 1988, 1998, 2008, and 2018 respectively. Tree-covered areas had shown an increase between 1988 and 1998, then decreased from 2008 to 2018. Cropland increased from 1988 to 2008 with a sharp increase from 2008 to 2018. Grassland witnessed a swift decrease from 1988 to 1998 then steadily from 2008 to 2018. The annual NDVI for the vegetative area (tree-covered, grassland, and cropland) decreased from 1988 to 1998 but increased steadily to 2018. The NDVI of grassland, savanna, and shrubland is more sensitive to climate change than the NDVI of forest and woodland which shows that tree cover decreases while cropland increases. Comparison analysis shows that Rainfall and tree-covered areas have a direct linear relationship while Rainfall and NDVI/Vegetative areas enjoy an inverse relationship.

Keywords: Vegetation dynamics; NDVI; Cropland; LULC; Rainfall; Grassland

1. Introduction

The distribution of terrestrial ecosystems, including composition and mechanism from regional to global scales is heavily dependent on climate [1]. Thus, this infers vegetation cover to be a very delicate and unstable portion of the ecosystem [2]. The term Vegetation dynamics is the phenological metrics variations and the transformations of different land cover types over a particular region [3]. The causes attributed to vegetation dynamics largely depend on geographical conditions, including the climate constraints together with the inhabitant's daily activities. The South-eastern Nigeria economy highly depends on tourism and natural resources; which has direct effects on the abnormally changing climate [4; 5]. These changes are shown as the diversion against the normal climatology of the region, obtained by analyzing the long-term recorded data, usually over about thirty years [6]. The dry season occurs between the two

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rainy seasons from June to August. The rainfall modes are majorly influenced by the ocean's monsoonal moisture flux, regulated by the north-to-south movement of the Inter-tropical Convergence Zone (ITCZ) over the Equator.

In recent years, satellite sensors have become an important tool for vegetation dynamics and trends at regional to global scales [7]. The Normalized Difference Vegetation Index (NDVI) derived from satellite data is an important indicator that can be used to analyse live green vegetation growth conditions and reveal the response of vegetation dynamics to climate change. In the last three decades, many works have been carried out from models and statistical methods that have been used to study NDVI changes. [8] evaluated NDVI-rainfall relationships in East Africa and the Sahel, and found that the spatial patterns of annually-integrated NDVI closely reflect mean annual rainfall. [9] used NDVI imagery analysis to study changes in the vegetation over Tanzania and indicated the increase in greenness. [10] used NDVI, ENSO, and climate data to study tele-connections between ENSO with ecosystem and their work confirmed ENSO effects on climate and ecological fluctuation. Based on the anomaly of NDVI in Cross River state from 1988 to 2000, there was a reversal in NDVI linked between the precipitation traces. Recently [11], merged the NDVI data with rainfall records from the Tropical Rainfall Measuring Mission (TRMM) for 2001–2011 over East Africa; the results showed the deteriorating yields as a consequence of both the vegetation degradation and anthropogenic alterations of the land. [12], applied the FAO Land-cover Classification System (LCCS) in Tanzania of East Africa.

Thus, considering the existing literature review in this region of interest, this present research work aims to give a more detailed and updated analysis of the changes in vegetation to climate over a state in South-South Nigeria for 1988, 1998, 2008, and 2018. Most of the analyses over the region resulted from regionally averaged and short-term recorded NDVI. Also, studies over the region did not pay close attention to spatial persistence of vegetation trends. Trends can influence data records and appear to be persistent when there is not a real relationship between the data records. Higher temperatures and declining rainfall patterns, as well as increasing frequency of extreme climate events (such as droughts and floods), are the expected future climate in the tropics [13].

In southern Nigeria, for example, rainfall patterns show a declining trend of summer rainfall (about 20%) from 1950-1999, and a high frequency of rainfall frequency was predicted to intensify in the 21st century [14]. In another journal, daily rainfall in Calabar shows a negative trend when compared to 7 other stations across the southern belt of Nigeria where positive trends were noticed though statistically significant at 0.01 levels respectively (R^2=0.7822). Early and extended rainfall is responsible for Soil Moisture, Evapotranspiration, Water Balance, Biogeochemical, Cycling of carbon, Nitrogen etc. Impacts of Land Use Land Cover dynamics determine increasing runoff and volume, decreasing groundwater recharge, base flow, floods, elevated levels of sediments, and increase in concentration of nutrients.

This study presents answers to the following questions concerning the analysis of the impact of vegetation on rainfall patterns in Cross River State. (1) Are there changes in vegetation within the study area? (2) Is any change in rainfall pattern correlated with changes in statistical variables? and (3) Is there any relationship between vegetation and rainfall patterns observed between 1988-2018?

This study aims to investigate the spatio-temporal vegetation dynamics (Normalized Difference Vegetation Index (NDVI)) and its response to climate variability (rainfall) between 1988 -2018 with the specific objective to determine the rainfall pattern over 40years across the study area, determine land use change trend over the study area, investigate the annual NDVI trend over the study area, and analyse the correlation between NDVI, Land use and rainfall in the study area.

1.1. Study Area

This study was conducted in Cross River State, Nigeria (Figure 1.1). Cross River State lies between latitude 4ºN and 7ºN, longitude 7ºE and 10ºE. occupies about 20,156km². The ecological zones present in Cross River State include: lowland rainforest, freshwater swamp forest, mangrove vegetation, coastal vegetation, montane vegetation, savanna-like vegetation, and wetlands. The lowland rain forest covers extensive areas in the center, north and east of Cross River State, and is contiguous with the forests of South West Cameroon. Although significant areas have been converted into agricultural farmlands and natural forests have been disturbed by indiscriminate felling and wood removal, the State is still home to the largest contiguous and well-preserved fragments of natural forest in Nigeria. The topography of the area is undulating with gradual rise and fall. The area is well drained such that run-off water disappears 30 minutes after a typical rainstorm. The soils in Cross River State are generally deep, porous, weakly structured, well drained with low to moderate status, and where vegetation cover is removed due to human activities, the soil is vulnerable to active sheet and gully erosion. The area is currently undergoing rapid development and changes in vegetation cover as a result of the influx of people into the state and the increasing need for housing [15].

1.1.1. Climate

Calabar falls within a tropical equatorial (Af) climate with high temperature, high relative humidity and abundant annual rainfall [16]. Two major air masses affect the climate of Calabar as well as other contiguous locations in the West African region. The Tropical Maritime (mT) and the tropical continental (cT) air masses affect the climate in two distinct seasons. The mT air prevails and influences its moisture characteristic while the cT air influences the dry season condition due to is desert source across the two air masses at the upper troposphere from east to west. This is called the Equatorial Easterlies' (EE). The two air masses meet at the pressure front called Inter Tropical discontinuity (ITD) [16]

The insolation effect is quite high caused by the sheer factors of its tropical location as well as the activities of urban development which have significantly altered the land cover. Rainfall is of the double maxima (double peak) regime with important peaks in July and September depending on the yearly weather cycles. Rainfall duration spans over 9-10 months of the year but is somewhat sporadic during the dry season. The dry season commences from November through February and is heralded by the southward moving air mass from the Saharan-high pressure belt. The dry season weather or the harmattan season produces depression due to the cool-dry temperature and moisture characteristics of the cT air. It transports Aeolian deposits (aveoli) from its source in the Sahara. This incidence produces hazy weather which reduces visibility and also cuts down insolation. Presently, over-grazing and deforestation have caused the impact of harmattan wind to be felt beyond the latitude of Calabar [17].

The main areas include the Mbukpa- Edgerly complex, the Watt market axis, the central depression (in the area around the State Housing Estate) and the Calabar River Basin. According to [17], study on the peculiarity of its climatic regime. The mean annual was given as 21.60C, while the minimum was 22.70C. Also, the daily range of temperature was given as 3.80C. The highest temperature values are recorded in February and March. Relative humidity is high all year round with the lowest value of 76.8 recorded in February and the highest recorded in August with a value of 92 percent.

1.1.2. Relief

The Calabar Flank sedimentary basin extends from the southern margin of the is Oban Basement complex to the boundary with the Niger Delta. Here, sudden sediment thickening e demarcates the Niger Delta Basin that formed as the latest of a series of basins in the Benue Trough, diagonally crossing Nigeria from the southwest to the northwest. Northwest-southern trending basement structures underlie the Calabar Flank and it defines the ltu High and the lkang Trough, thus relating the Calabar Flank to the South Atlantic Cretaceous marginal basins with similar horst-and-graben structures in Angola and Gabon (Murat, et al; 1972). The sedimentary succession on the Calabar Flank is mostly of Cretaceous age, comprising an ancient river-borne sandstone, the Awi Formation; and the overlying marine Odukpani Group of Albian to Late Cretaceous age [18].

1.1.3. Patterns of rainfall

Climate variability refers to changes in climatic patterns such as rainfall, weather and climate. Water is health and life, human beings depend on water for everything and thus, water is one of the most essential resources for survival [19]. The main source of water is rain. Rain is liquid water in form of droplets that have condensed from atmosphere water vapour and then precipitated that is, become heavy enough to fall under gravity. Rain is a major component of water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable condition for many types of ecosystems [20]

In Cross River state, there has been a yearly occurrence of severe flooding and landslides within and around the metropolis with weighty costs paid in terms of lives and property caused by rainfall. Rainfall is an integral climatic factor that affects the way and manner of human life. It affects all parts of the environmental system, vegetation inclusive. Hence the study of its pattern cannot be overemphasized [21].

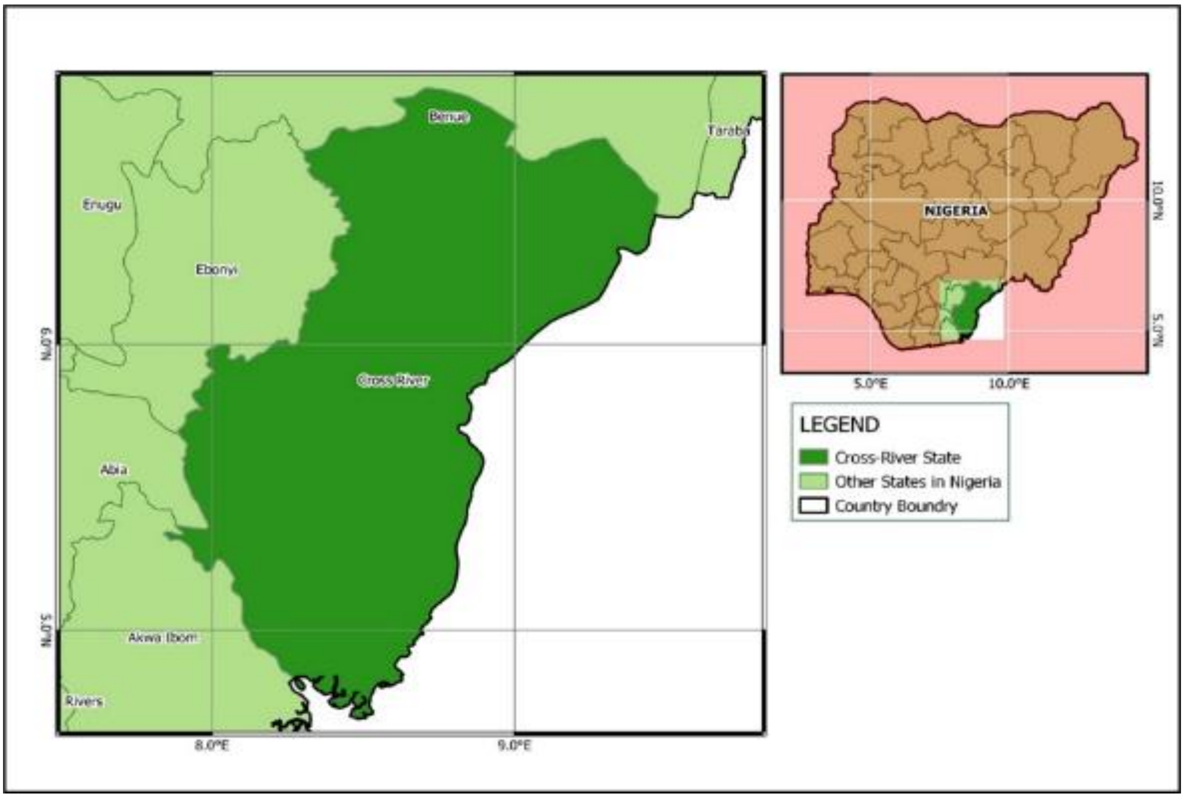

Figure 1 Study Area Map

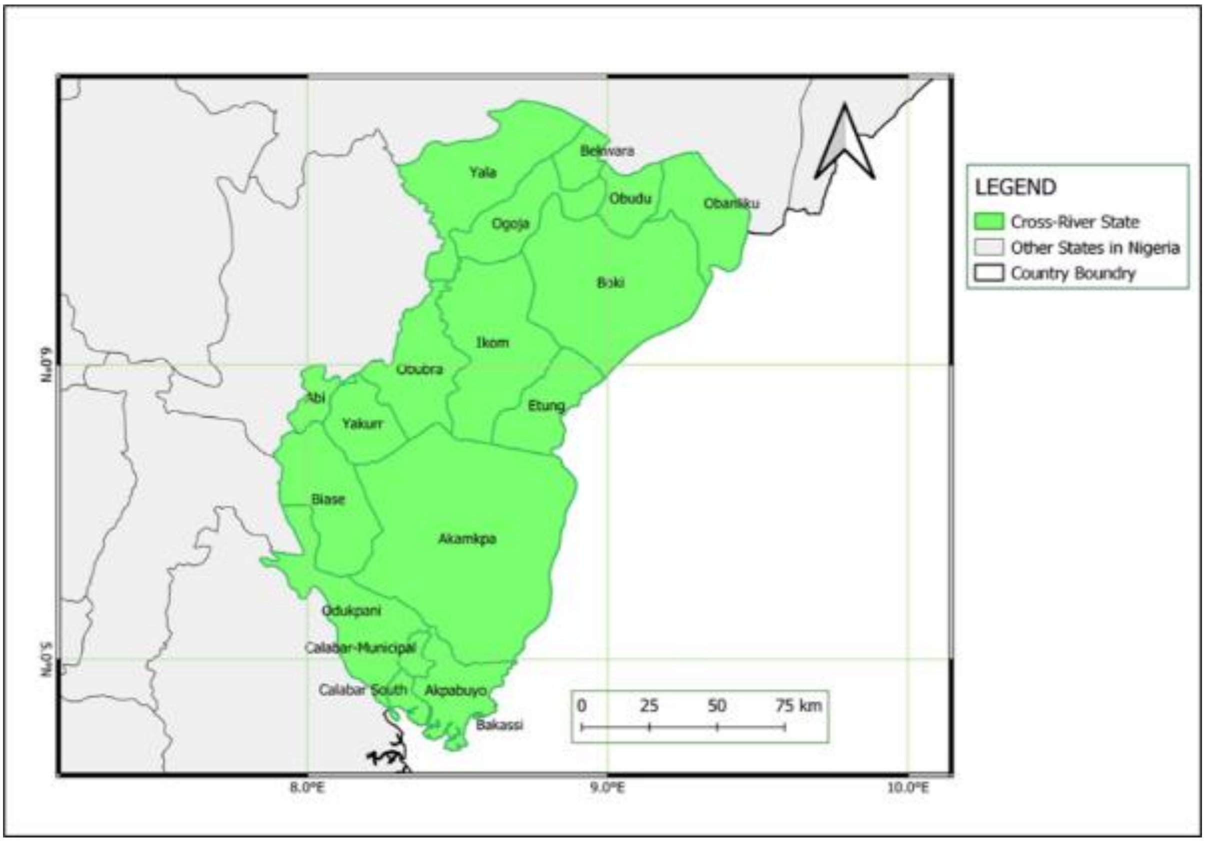

Figure 2 Study Area showing Local Government Areas

2. Materials and method

This chapter covered the research design and methodology used to address the research problem. For this research, statistical analysis was used to make inference applied to numerical evidence. Descriptive and inferential statistics were used to analyse and present the data. Descriptive statistics entails the use of tables, charts, and graphs to summarize and describe data.

Table 1 Type and Source of Data

	Data	Data Type	Resolution	
1	Land Cover	ESA CCI Land Cover	300m	1988- 2018
2	NDVI	Landsat Images	30m	1988, 1998, 2008 and 2018
3	NDVI	MODI13Q1-coll6	250m	1988- 2018
4	Precipitation	CHIRPS	5km	1988- 2018
5	Administrative Boundary	OSGOF	Vector File	

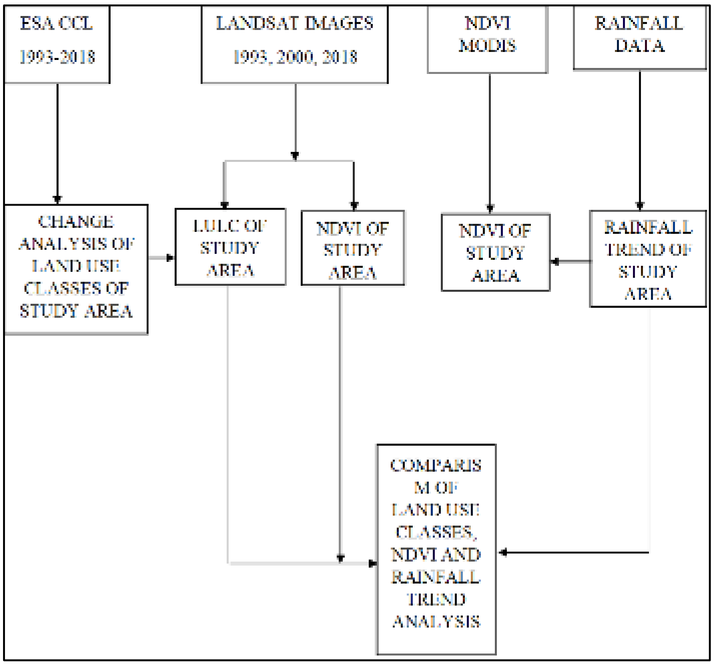

Figure 3 Methodology Workflow

2.1. Normalised Difference Vegetation Index (NDVI)

Annual integrals of NDVI were calculated from downloaded NDVI images of the study area. Positive significant trends in NDVI would indicate potential improvement in land condition, and negative significant trends potential degradation. Landsat images with spatial resolution of 30m for the years 1988, 1998, 2008 and 2018 were downloaded and the NDVI values of each of the years were calculated. The NDVI trend from 1988- 2018 were also acquired using MODI13Q1-coll6. It has a spatial resolution of 250m.

2.2. Land Use Land Cover (LULC)

ESA CCI Land Cover maps of the study area were clipped out using the boundary shapefile of the state. It was then reclassified to give land cover maps to the 7 land cover classes needed. These 7 classes being evaluated are the ideal classes for reporting to the UNCCD (forest, grassland, cropland, wetland, artificial area, bare land/other lands, and water). By comparing land cover data and maps over a while, proper documentation of land use trends and changes can be evaluated. Land cover transition analysis was performed to identify which pixels remained in the same land cover class, and which ones changed to which.

2.3. Rainfall Data

The rainfall data was collected using remotely sensed method from through Climate Hazards group InfraRed Precipitation with Stations (CHIRPS) and TAMSAT. CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring while TAMSAT has a resolution of 5km. CHIRPS data collected for the years 1988, 1998, 2008 and 2018 was used to analyse the spatial area of rainfall intensity variability while the data for rainfall indices downloaded from TAMSAT for the study area were analysed and plotted to show their trends and relationship over the period under view. The TAMSAT rainfall estimation is one of several approaches developed from the GPI application in Africa [22]. It was devised in response to the needs of some African countries for rapid identification of regions with rainfall deficits and likely shortfall in crop yields. The method uses cloud-top temperature calculated from METEOSAT TIR radiance and utilizes more frequent images (every half an hour), needed to monitor the highly variable rainfall of a region.

3. Results and discussions

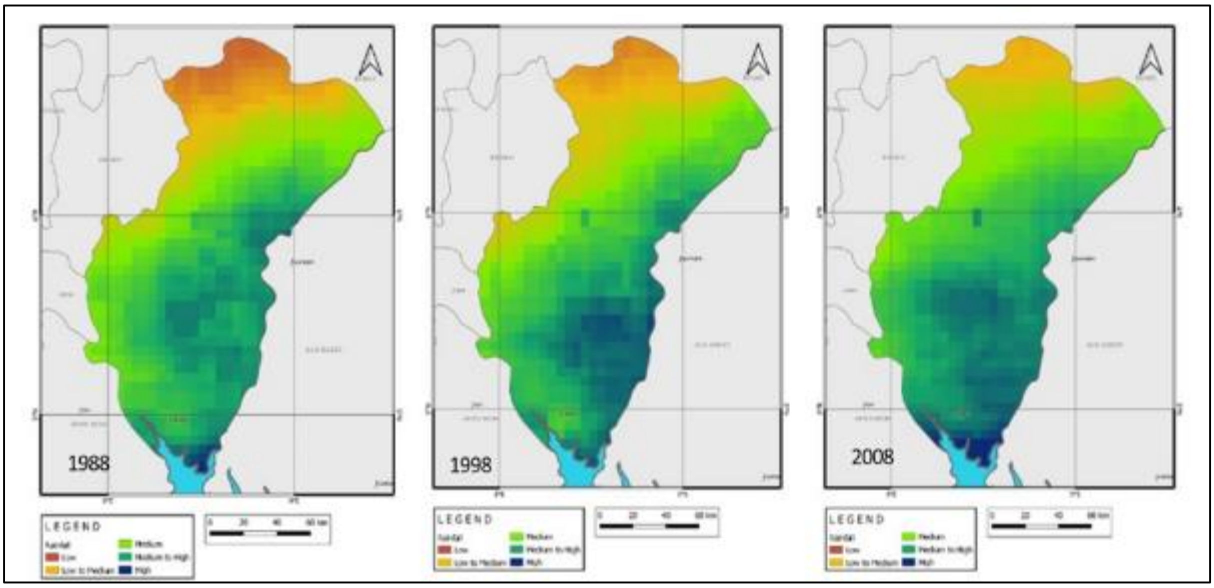

Figure 4 Rainfall Trend for 1988, 1998 and 2008

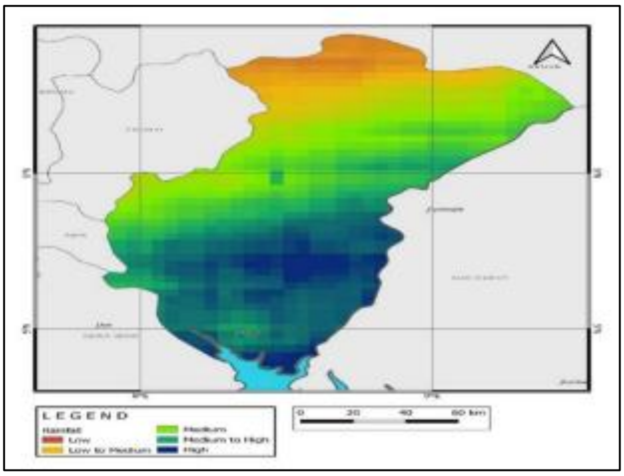

Figure 5 Rainfall Trend for 2018

Table 2 Monthly Average Rainfall quantity for 1988, 1998, 2008 and 2018 for Cross River (mm)

Months/Years	1988	1998	2008	2018
January	17.54	3.07	15.91	1.15
February	21.89	2.33	1.28	112.3
March	126.77	117.8	160.62	121.57
April	143.02	221.23	210.72	180.68
May	192.66	261.13	315.7	220.96
June	318.97	399.56	390.26	299.27
July	388.21	414.61	406.82	490.29
August	365.65	514.28	456.9	341.22
September	470.83	467.91	390.58	402.64
October	401.23	386.52	275.04	326.12
November	59.1	77.8	90.64	134.14
December	28.75	9.39	31.5	11.04
Total Rainfall	2534.62	2875.65	2745.97	2641.38
Average Rainfall	211.22	239.64	228.83	220.12

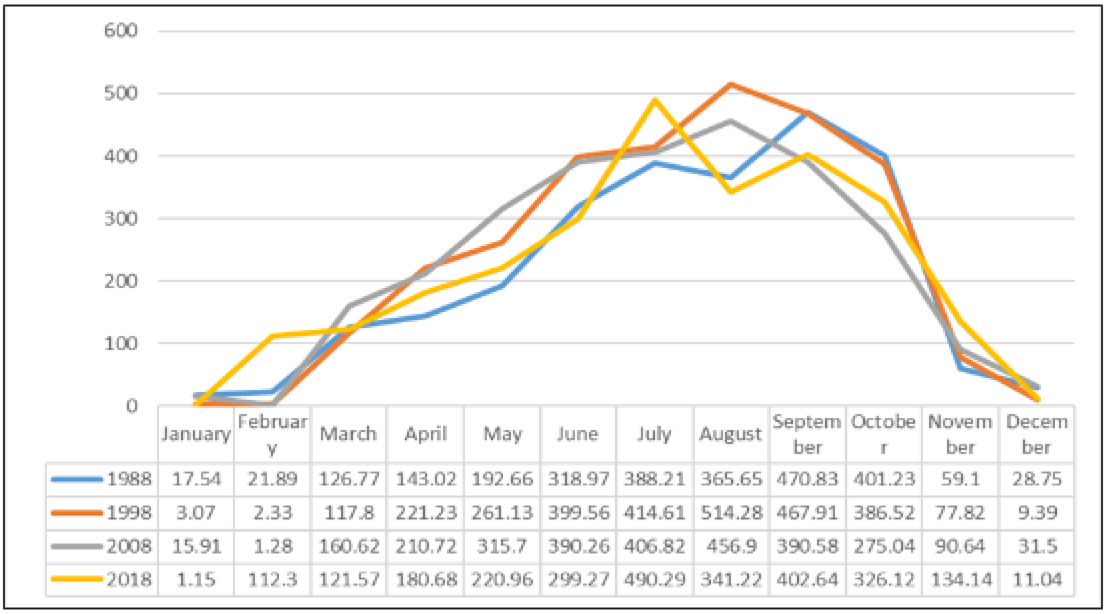

Figure 6 Rainfall Distribution in Cross River State between 1988 -2018

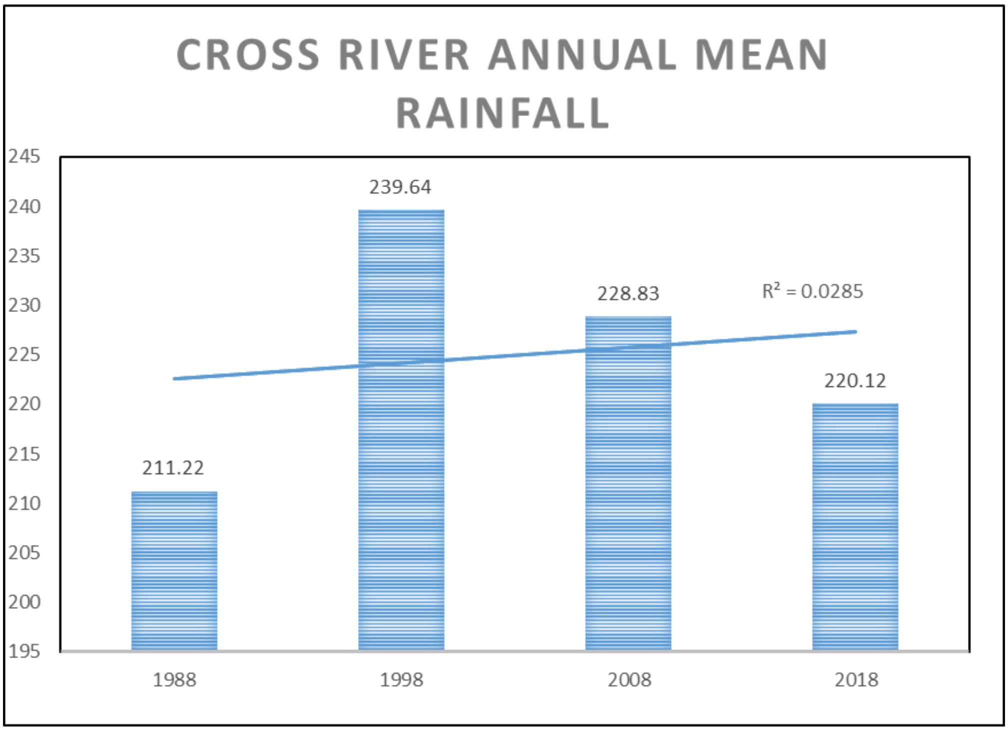

Figure 7 Average Mean Rainfall between 1988 -2018

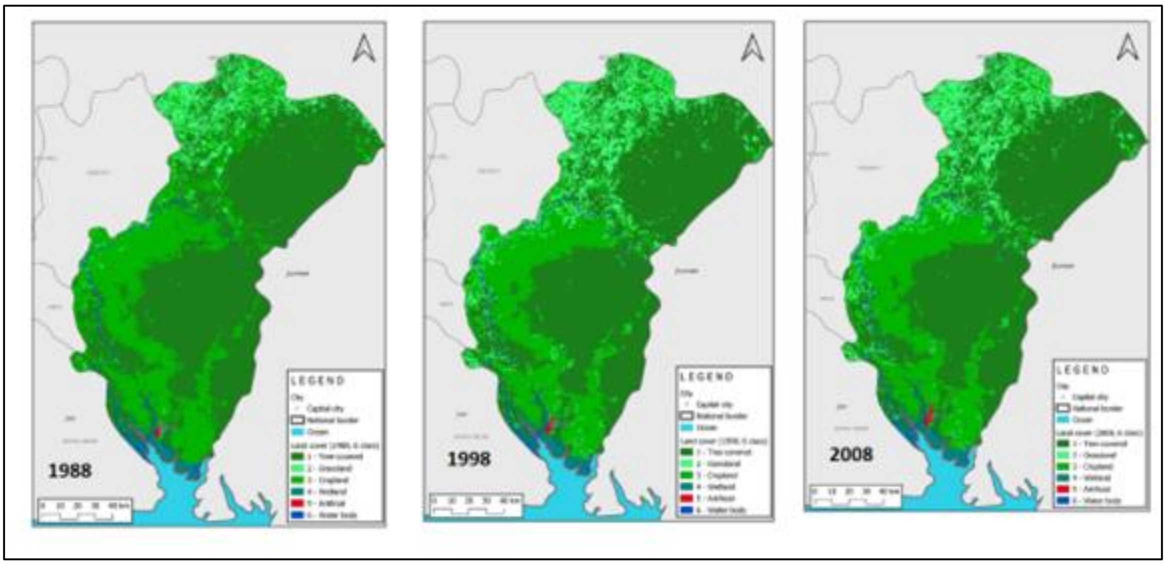

Figure 8 Land Use Land Cover Maps for 1988, 1998, and 2008

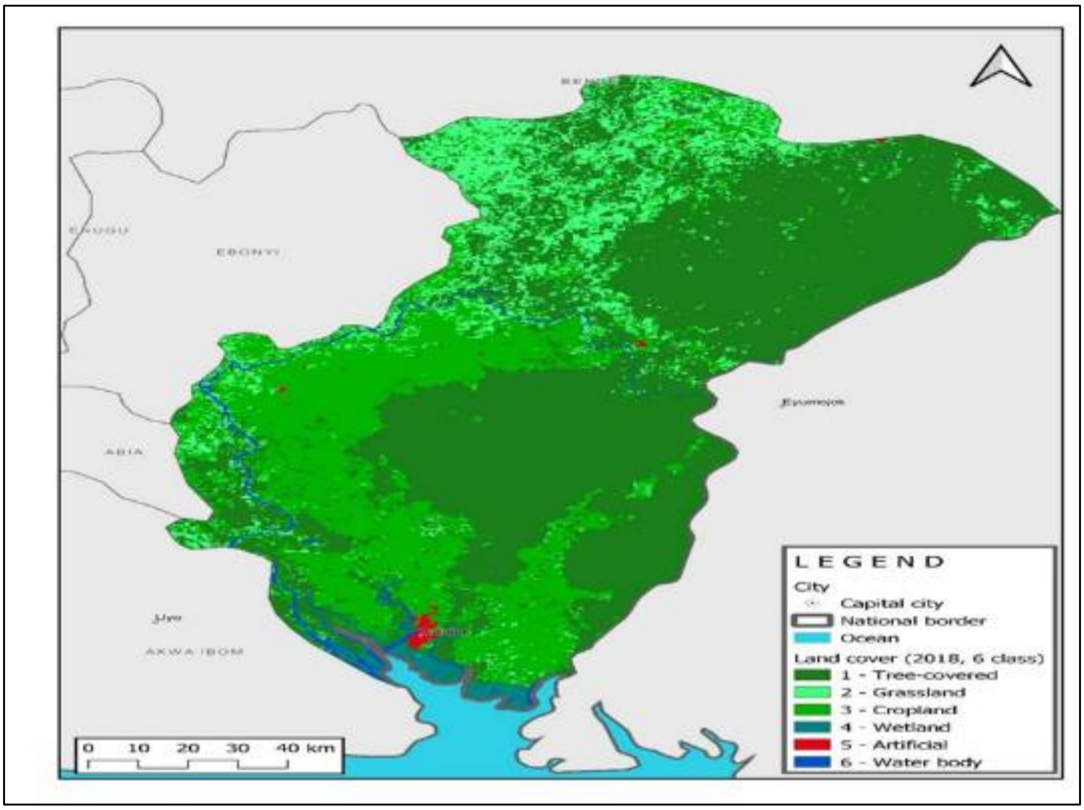

Figure 9 LULC Map for 2018

Table 3 Area of Land Use Land Cover in sq/m^2

	Tree covered areas	Grasslands	Croplands	Wetlands	Artificial surfaces	Waterbodies
1988	12,298.49	2,889.24	5,199.73	278.75	27.46	312.19
1998	12,344.86	2,774.52	5,263.57	2,77.76	33.27	312.07
2008	12,325.87	2,757.09	5,285.14	274.91	51.32	311.88
2018	12.261.90	2,635.55	5,452.19	276.45	68.75	311.88

Table 4 Land Use Dynamics of Study Area in sq/m^2

Land cover type in baseline year 1988	Land cover type in the target year 2018							
		Tree covered areas	Grasslands	croplands	wetlands	Artificial areas	Other lands	Water bodies
	Tree covered areas	11,808.34	13.16	473.05	0.00	3.77	0.00	0.00
	Grasslands	241.71	2,621.35	10.55	1.67	13.97	0.00	0.00
	Croplands	210.81	1.05	4,967.89	1.67	18.29	0.00	0.00
	wetlands	0.56	0.00	0.68	272.75	4.70	0.00	0.00

	Artificial areas	0.00	0.00	0.00	0.00	27.46	0.00	0.00
	Other lands	0.31	0.00	0.00	0.00	0.00	3.03	0.00
	Water bodies	0.00	0.00	0.00	0.37	0.56	0.00	311.82

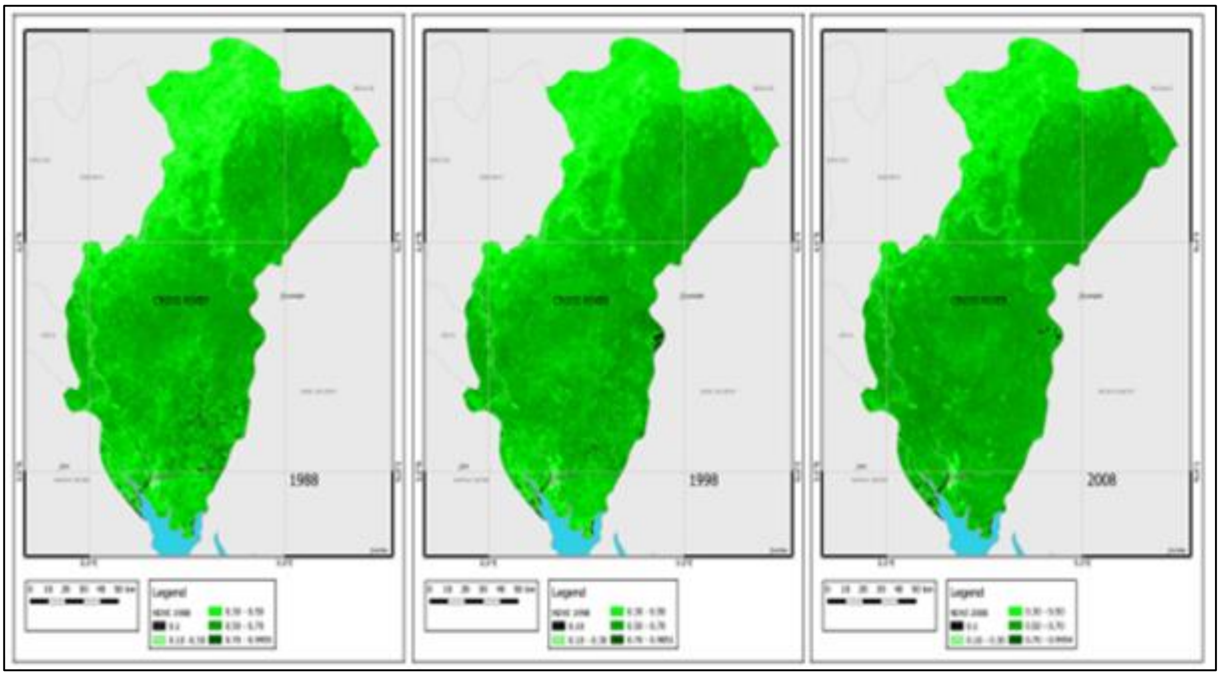

Figure 10 NDVI Maps for 1988, 1998, 2009

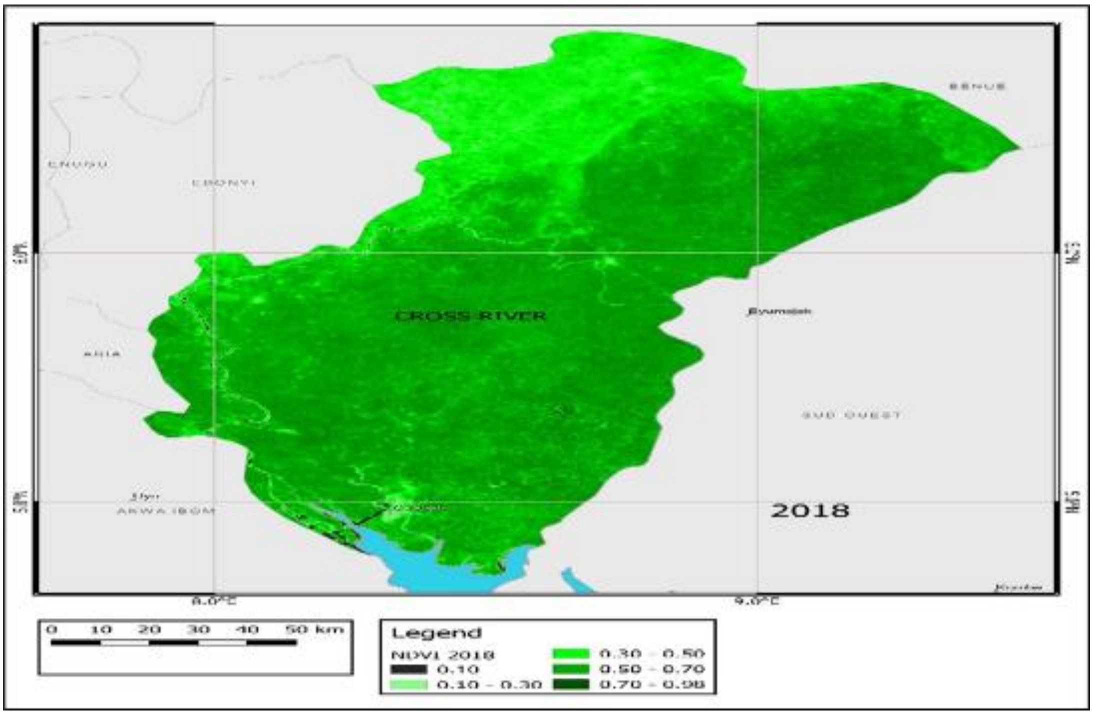

Figure 11 NDVI Map for 2018

Table 5 Average NDVI for Cross River

Average NDVI for Cross River			
1988	**1998**	**2008**	**2018**
0.61	0.57	0.61	0.63

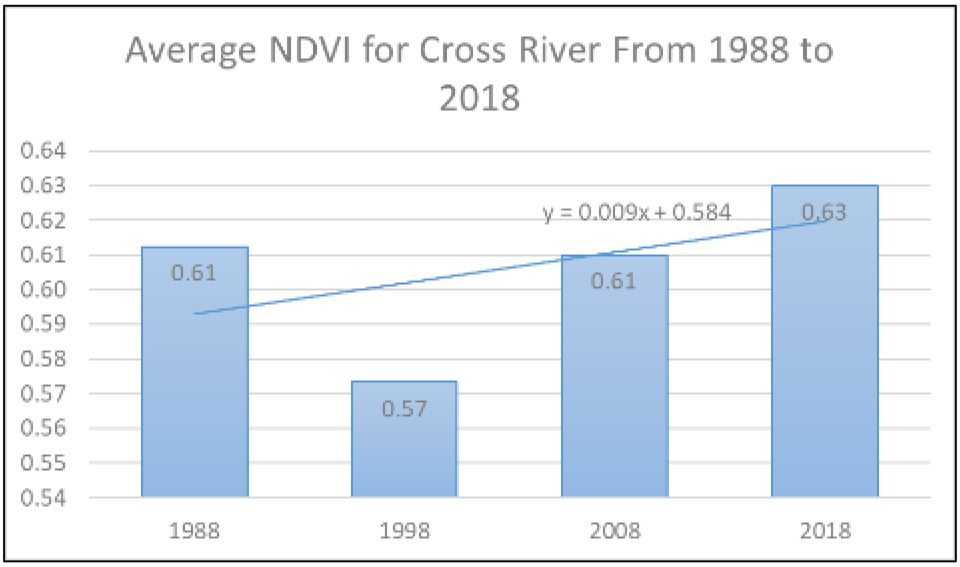

Figure 12 Average NDVI between 1988 -2018

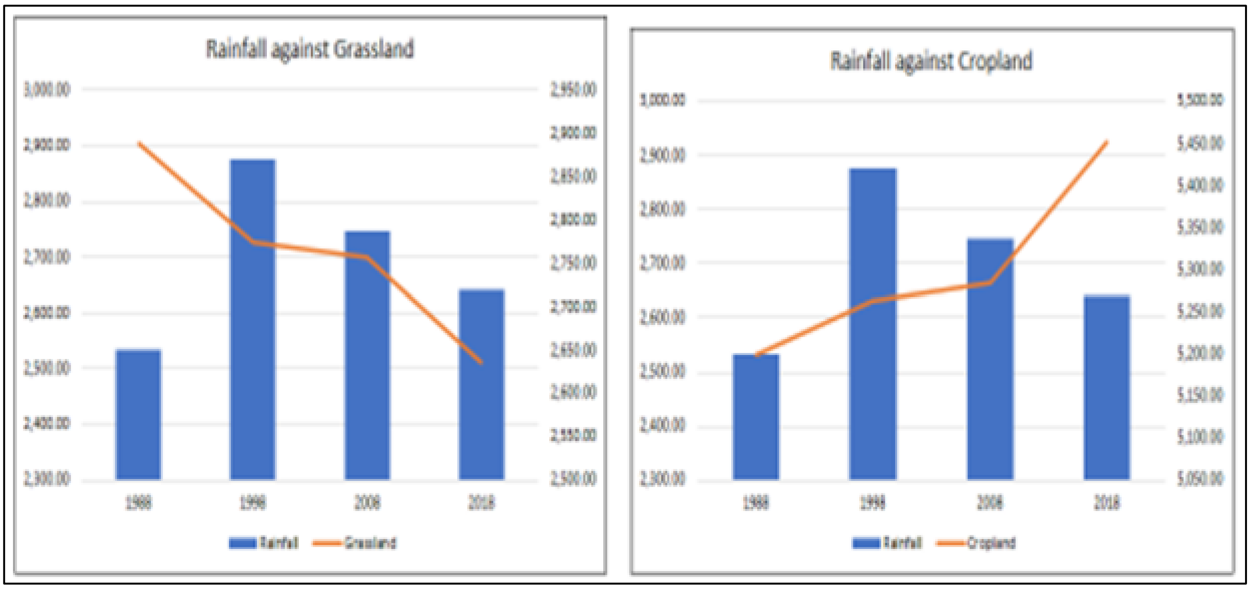

Figure 13 Rainfall against Grassland and Cropland

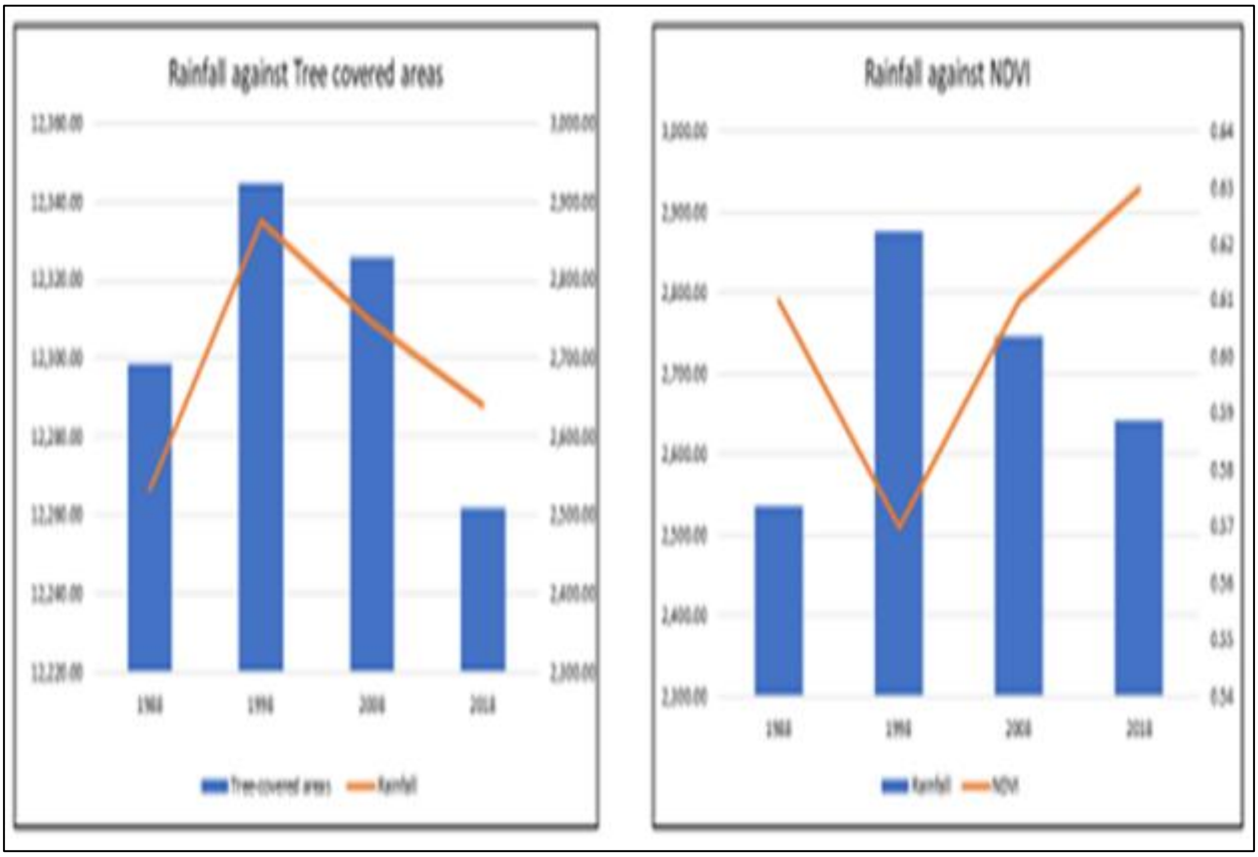

Figure 14 Rainfall against Tree-covered Areas and NDVI

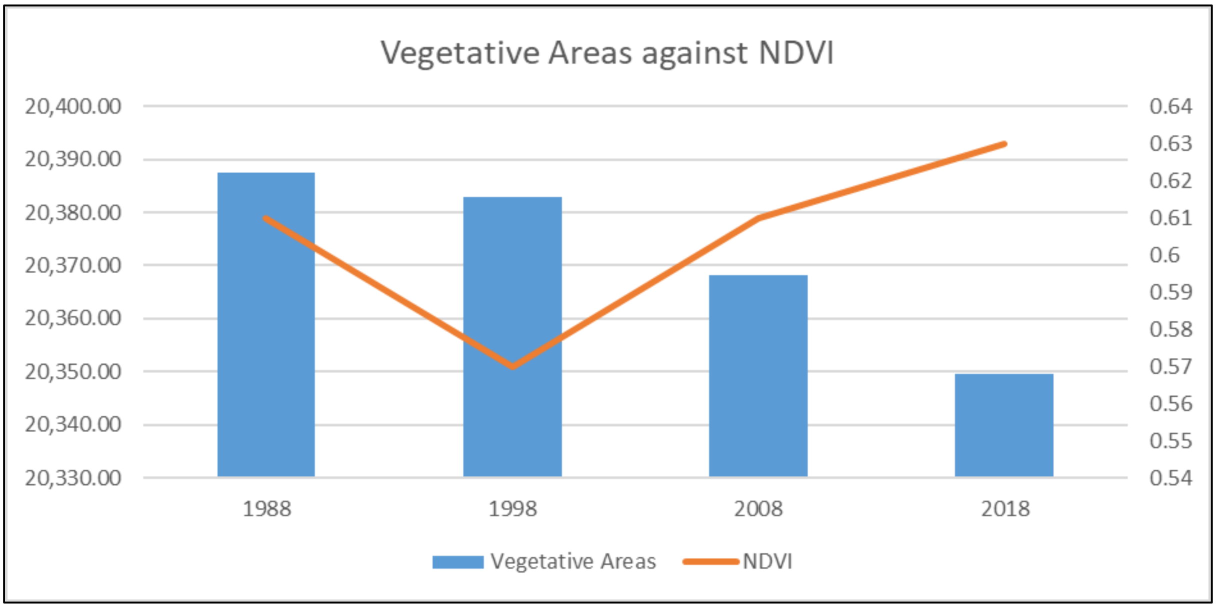

Figure 15 Vegetative Areas against NDVI

3.1. Rainfall

Rainfall is seen to be at its peak between July and August during the period under analysis, and at its lowest between December and February. The annual Rainfall for the study area increased from 2534.62mm in 1988 to 2875.65mm in

1998 then decreased steadily to 2745.97mm in 2008 and finally to 2641.38mm in 2018, (Figures 6 and 7). The Av. Mean rainfall is 211.22mm, 239.64mm, 228.83mm, and 220.12mm in 1988, 1998, 2008, and 2018 respectively.

3.2. Land Use Land Cover (LULC)

Tree-Covered Areas: displayed are the various land-use and how they have transited through the period under observation (Table 3). Tree-covered areas had shown an increase from 12,299sq./m^3 to 12,345sq./m^3 between 1988 and 1998, then decreased to 12,326sq./m^3 thereof in 2008 and then 12,262sq./m^3 in 2018. As clearly shown, most of the loss experienced during this period was to Cropland of about 473sq./m^3 (Table 4). This could be attributed to increased agricultural expansion as the state has experienced extensive farming practices.

Also, cropland was found to have steadily increased from 5199.73km2 to 5285.14km2 in 1988 to 2008 then a sharp increase to 5452.19km2 2008 to 2018 (Table 3). These gains over the years could be as a result of the population growth of farmers or governmental policies to encourage farming which further indicates that most of the loss experienced was to tree-covered areas at about 211sq./m^3 (Table 4). This might be attributed to tree planting and tree rejuvenation exercises from young to older ones as a means of afforestation.

As displayed, ggrassland lost about 242sq./m^3 to tree-covered areas (Table 4.2). It decreased swiftly over the years from 2,889.24sq./m^3 in 1988 to 2,774.2sq./m^3 in 1998 then to 2,757.09sq./m^3 in 2008 and finally 2,635.55sq./m^3 in 2018.

3.3. Normalised Difference Vegetation Index (NDVI)

As displayed, the annual NDVI for the vegetative area (tree-covered, grassland, and cropland) in the area of study was seen to decrease from 0.613 in 1988 to 0.574 in 1998 but increased steadily to 0.61 and then to 0.63 in 2018 (Tables 4, 5, Figures 10, 11). The NDVI of grassland, savanna, and shrubland is known to be more sensitive to climate change than the NDVI of forest and woodland which must have accounted for the increment even as tree cover decreases and cropland increases.

3.4. Comparison

From the trend comparison, the only two variables that seem to correlate were analysed below.

A strong linear relationship occurred between rainfall and tree covered areas is seen as the changes in the two indices seem to change at the same direction- increasing from 1988 to 1998, then decreasing swiftly through 2008 to 2018 (Figure 14).

As further revealed, shows an inverse relationship between Rainfall and NDVI as well as rainfall and vegetative areas respectively (Figure 14 and 15). Rainfall tends to decrease while NDVI and vegetation areas tend to increase and vice versa.

4. Conclusion

From the results, significant relationships were found between Rainfall-Tree covered areas, Rainfall- NDVI, Rainfall-Cropland and Rainfall-Grassland.

It could be deduced that though there might have been policies to encourage tree planting/ afforestation over the years but extensive farming practices still surpasses the effort and has caused degradation in the tree covered area as revealed by the findings of this study. Thus, in Cross-River state, land degradation, such as deforestation, clearance, clear-cutting, or clearing as a removal of a forest or stand of trees from land which is then converted to non-forest use poses a serious environmental problem. Such deforestation can involve conversion of forest land to farms, ranches, or urban use.

Forest landscape fragmentation and decrease of land under forest cover (due to a myriad of unsustainable human land use practices), imply serious impacts on flora and fauna species depletion and extinctions in the region, agree that wherever there is a decrease in land under forest cover, the attendant effect is biodiversity loss or negative change in species evenness and richness, implying that agricultural land-clearing activities culminate in biological species extermination and scarcity. One of the DFID consultants (GIS specialist)- Stephanie Filasse involved in the second phase of a DFID-assisted Cross River State Forestry Project (1999-2002), commented in the DFID final project report that Cross River State forests under the current rate of deforestation will be exhausted by the year 2033. This will have serious implications on the region's biodiversity and the sustainability or survival of endemic primate species like the

Cross River Gorilla (Gorilla diehli), Chimpanzees (Pan troglodytes), Drills (Mandrillus leucophaeus), and other assorted monkey species that lives in it.

Recommendation

Slash and burn agricultural practices, logging, etc; which are widely practiced by the locals, have culminated in the perpetual destruction of the Tropical Rainforest in Cross River State. There are still no legal restrictions in land use plans guiding land use practices in a land with over 2500 local communities and a population of over 2.1 million people. Change in forest policy from current centralization/government monopoly of forest management to decentralized/community-based forest and other natural resources management could help put these practices in the right place. This will also assist in banning further logging activities in the remaining rainforest and pursue aggressive reforestation programs in degraded forest reserves.

The UNREDD (Reduction of Emissions from Deforestation and forest degradation) programme in Nigeria, introduced in 2009, with the Cross River State rainforest as a pilot site, should be effectively implemented.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest is to be disclosed

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