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ROLE OF RAINFALL ON THE SPATIO – TEMPORAL DENSITY OF VEGETATION IN SUDANO – SAHELIAN ECOLOGICAL ZONE OF NIGERIA

Abdullahi, A.H. Kano State Secondary Schools Management Board, Nigeria

Mallam, I. Department of Environmental Management and toxicology, Federal University, Dutse, Nigeria

Usman A. K Department of Geography Ahmadu Bello University, Zaria, Nigeria

Abstract

Vegetation density in Sudano - Sahelian Ecological Zones (SSEZ) undergoes several changes both in space and time due to the influence of certain factors. This study analyses the role of rainfall on vegetation density in Sudano – Sahelian zone of Nigeria using Remote Sensing (RS) and metrological data. The study covers a period from 1998 to 2014. Data were analyzed using Normalized Difference Vegetation Index (NDVI) and Interpolation technique in ArcGIS environment. The results revealed that areas cover by high vegetation density in the study area decreases from 61.74% in 1998 to 52.23% in 2014 while moderate vegetation density is rising from 21.13% in 1998 to 27.82% in 2014. The study also shows that in 1998 about 86.41% of the study area received high rainfall (above 800mm), this was followed by moderate (between 600mm and 800mm) covering an area of 11.94%. The intensity reduce in 2014 where about 65.47% received low rainfall (below 600mm), 18.62% moderate while 15.91% with high intensity. It is also revealed that there is weak relationship between rainfall intensity and density of vegetation in the study area. Therefore, it is concluded that our limited vegetation resource need to be further protected against overgrazing, bush burning and other human activities.

Keywords: - Remote Sensing, Sudano - Sahelian, vegetation density, rainfall

INTRODUCTION

Analysis of vegetation cover density in semi – arid zones and Sudano – Sahelian zone (SSZ) in particular becomes a matter of global concern due to the fact that vegetation constitutes a vital source of livestock fodder (LeHoverou, 1980) energy (Bailis et al, 2005) construction materials, food and medicine (Manning et al, 2009) and also provides for a number of indispensable ecosystem function

(Sinare and Gardon, 2015). Correlation between vegetation density through analysis of NDVI and rainfall varies by geographical region and vegetation types. It has been observed by Nicholson (1995) that no matter what the geographical region is a minimum of 200 – 300mm of rainfall per year seems to be necessary to induce NDVI sensitivity to rainfall. Woodland Forest vegetation shows a lesser correlation between NDVI and climatic factors but vegetation pattern in savanna and steppe grassland evident the highest correlations with that of rainfall and temperature (Wang et al, 2001).

The SSEZ suffered from spatial and temporal variation of vegetation density. Hermann and Hutchinson (2005) revealed that, the extensive population growth, destructive land management and strong climatic fluctuations have caused widespread and irreversible destruction of the vegetation cover. The vegetation density in the SSEZ is always reducing; peoples make use of it as a source of fuel, nomadic herders survived on the vegetation cover, desertification as well is a major threat to the development of the vegetation in the study area, this therefore resulted to negative implication to the environment. Adesina (2008) reported that, reduction in vegetation cover resulted to soil erosion which consequently leads to further drop in plant productivity.

The need to study the nature of vegetation density in the study area before it becomes difficult to tackle is necessary, especially through the use of NDVI and rainfall data; this is because, NDVI can be used as a good proxy for the study of inter-annual climate variability on regional and global scales (Evans and Geerken, 2004). Identification of the role of rainfall on the density of vegetation will help to protect agricultural land and the environment as a whole by taking measures such as shelterbelt programmed. This is because; Shelterbelts are significant tools for restoring degraded areas particularly those under threat of desertification (Igugu and Osemeoba, 1991).

It has been observed that, vegetation production has historically been a key variable to describe the state and the dynamics of the Sudano – Sahelian environment and its relation to land use (LeHourou, 1989) but eleven out of seventeen countries of the zone including Nigeria have received limited attention during the period of thirty nine (39) years back (Karlson and Ostwald, 2015) Most of the studies that deals with vegetation density in the SSEZ has to do with mapping of the vegetation biomass. A studies such as that of Nicholson (1995) and Eisenfelder et al (2012) reviewed the use of RS data for mapping of vegetation covers of SSEZ and found that large proportion of the area is bare surface with patches of vegetation. Therefore, the focus of this study is to find out the role of rainfall on the spatio – temporal density of vegetation in SSEZ of Nigeria.

MATERIALS AND METHODS

Study Area

The Sudano – Sahelian Ecological Zone of Nigeria lies between Latitude 9.695123^{o}N to 13.891551^{o}N and Longitude 3.536308^{o}E to 14.643450^{o}E (Figure 1). The area is the largest ecological zone in the country and occupied almost one – third of the Nigerian total land mass (Ifabiyi and Ojoye, 2013). The vegetation of the area is dominated with grasses and few tree covers which give rooms for agricultural activities where cowpeas, millet and cotton are grown in the region (Odekunle et al, 2008). Furthermore, almost all the donkeys, camels, horses and 75% of the goats and sheep found in Nigeria are from SSEZ (Ifabiyi and Ojoye, 2013)

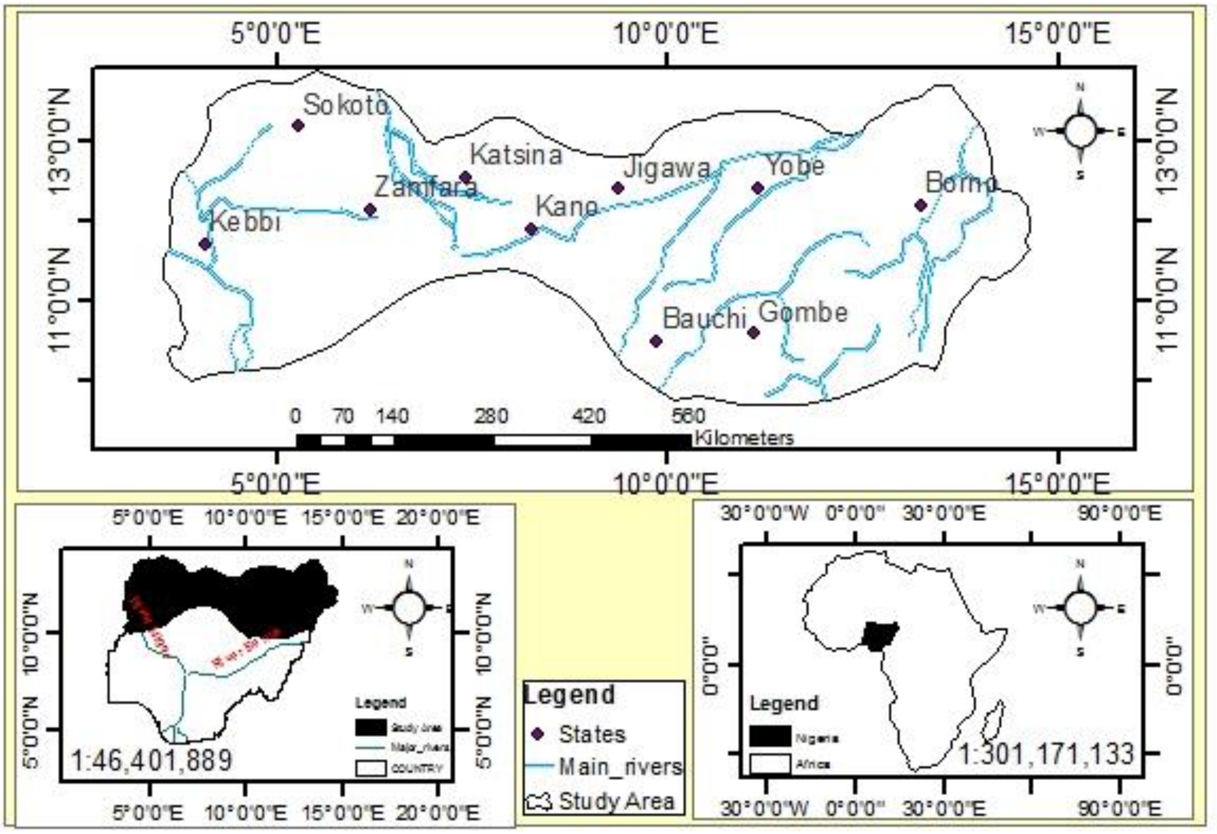

Figure 1: The study location

Source: Depicted from Administrative map of Nigeria

The nature of the vegetation has been associated with the characteristics of the climate in the zone where by temperature is high throughout the year with a mean maximum of about 34^{o}c (Ojoye, 2008). The zone has an average annual rainfall of about 500mm in the extreme northeastern part to 1000mm in the southern sub region (Abaje et al, 2012).

Methods of Data Collection

The study made use of Land sat Thematic Mapper (TM) (1998), Enhance Thematic Mapper (ETM+) (2006) and Operational Land Imager (OLI) (2014) with spatial resolution of 30m which was download from United State Geological Survey (USGS) archive and rainfall data of 1998, 2006 and 2014 obtained from metrological station located in Kano, Katsina, Sokoto, Yelwa, Gusau, Bauchi, Maiduguri and Nguru. The use of land sat data in this study is in line with observation made by Karlson and Ostwald (2015) that NOAA AVHRR and land sat series of satellites have been the dominant RS data for vegetation observation in SSEZ.

Methods of Data Analysis

Data analysis was performed through the following steps:

Image Processing and Correction

The Land sat images after download were uncompressed and imported into Arcgis 10.1 environment on band by band basis. The land sat ETM+ undergoes radiometric and geometric errors correction. The radiometric correction was performed using con sub menu of conditional tool using ETM+ of 2003 before scan line off while the imagery was geo-rectify using land sat OLI of 2014. A color composite imagery was produce for seven bands that is band 1 to 7 in such a way that, the RGB bands of TM and ETM+ used are 3-2-1 which mean 3(red), 2(green) and 1(blue) while for OLI bands 4-3-2 were set as 4(red), 3(green) and 2(blue).

Image Classification

The NDVI method of image analysis was performed in this study because correlation between NDVI and above ground biomass is well established (Justice et al, 1985; Tucker and Sellers, 1986). Image Analysis tool were used for the generation of NDVI using the composite imagery as input raster. During the process the Digital Number (DN) of the imageries were set in the option menu of the image analysis tool as band 3 (Red) and 4 (Infrared) for TM and ETM+ while band 4(Red) and 5(Infrared) for OLI, the generation were conducted using the formula in equation 1 as adopted from Sahebjalal and Dashtekian (2013).

$$NDVI = \frac{Nearinfrared-Red}{Nearinfrared+Red} \text{--- (equation 1)}$$

The resulted imagery of NDVI was then used to generate fractional vegetation cover of the study area using the formula in equation 2 as adopted from Brunsell and Gillies (2003).

$$Frv = \text{Square}\left(\frac{(NDVI\ imagery-NDVImin)}{(NDVImax-NDVImin)}\right) \text{-------------------------------- (equation 2)}$$

The fractional vegetation cover were finally used to create vegetation density map using reclassify tool into four classes as adapted and modify from Sahebjalal and Dashtekian (2013) that is: less than 0.1 values bare surface, 0.1 to 0.2 low density, 0.2 to 0.3 moderate and above 0.3 as high density.

Analysis of Rainfall Data

The annual rainfall values was interpolated to generate continues surface map using IDW sub menu of interpolation tool of arcgis 10.1 as adopted from Napa (2015). During the analysis rainfall data was used as input, the cell size was set to that of satellite data that is 30m, the surface rainfall generated were classified into three namely: low rainfall less than 600mm, moderate between 600mm and 800mm and high above 800mm.

Change detection Analysis

To detect the changes in vegetation density and rainfall distribution within the period of study band math was performed on the resulting maps of vegetation density and rainfall distribution by subtracted the 2014 map values from that of 1998 map values; while the rate of change were determined using the formula below; this is because differences between images were made by subtracting different time imageries (Yacouba et al, 2009).

$$\text{Rate of change} = \frac{\%\ change}{100} \text{ X study years (16yrs)-------------------------------- (equation 3)}$$

Relationship between rainfall and vegetation density

Correlation coefficient and regression statistics in Microsoft excel was performed between NDVI values and rainfall values to examined inter-annual relationship between rainfall and vegetation density. To obtain the values used 50 random points were generated on the two maps.

RESULTS AND DISCUSSION

The results of vegetation density in this study area are presented in table 1 and figure 2a – c. It shows that the extent of high vegetation density is decreasing across the period of study from 61.74% in 1998 to 58.37% in 2006 and 52.23% in 2014 this was followed by areas covered by moderate vegetation density as 21.13% in 1998 which increases to 24.77% in 2006 and 27.82% in 2014.

The results also indicated bare surface to occupied lowest land mass of only 0.82% in 1998, 1.26% in 2006 and 0.81% in 2014; thus, the time-series analysis of vegetation density across the SSEZ is decreasing, this is attributed to how peoples considered wood as one of the major source of fuel and how rearing of animals becomes one of the major aspect of economic activities in the area. This finding is in line with that of Gadiga and Dan (2015) who reported the decreasing trends of vegetation density in Semi – arid zone of Yobe State from 65% in 1972 to 54% in 1986, 37% in 2000, 26% in 2005 as well as 16% in 2007. The results is also in agreement with that of Sahebjalal and Dashtekian (2013) in Iran where high vegetation cover density decreased from 24.73% in 1990 to 10.38% in 2006 while low density increased from 49.91% in 1990 to about 70.80% in 2006. The analysis further revealed that, the spatial distribution of vegetation cover in the study area decreased north ward throughout the study period, this is supported by Hiernaux et al (2009) who stated that the proportion of vegetation density, height and woody vegetation in SSZ decreases in south to north direction.

Table 1: Vegetation Density of SSEZ (1998, 2006, 2014)

	1998		2006		2014	
CATEGORIES	Area(Pixels)	Area (%)	Area(Pixels)	Area (%)	Area(Pixels)	Area (%)
Bare surface	3164	0.818	4869	1.259	3136	0.811
Low	63038	16.305	60312	15.6	73991	19.138
Moderate	81708	21.134	95754	24.767	107541	27.816
High	238704	61.743	225679	58.374	201946	52.235
Total	386614	100	386614	100	386614	100

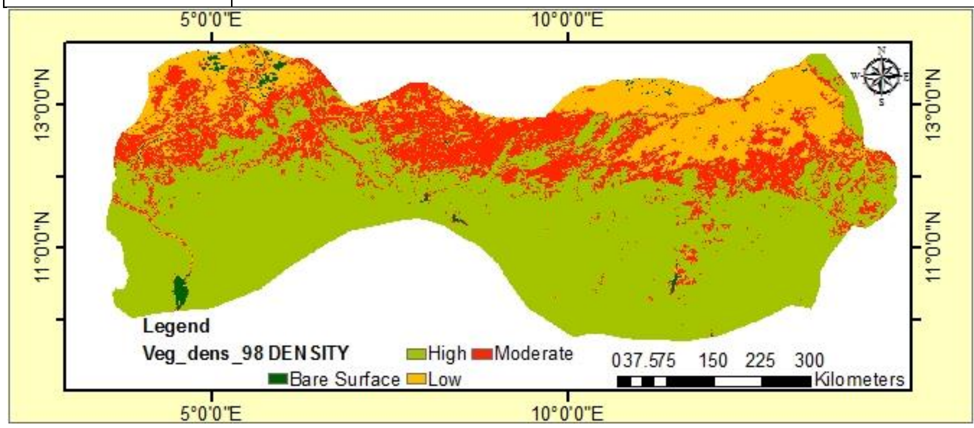

Figure 2a: Vegetation density map of 1998

Source: Data Analysis 2017

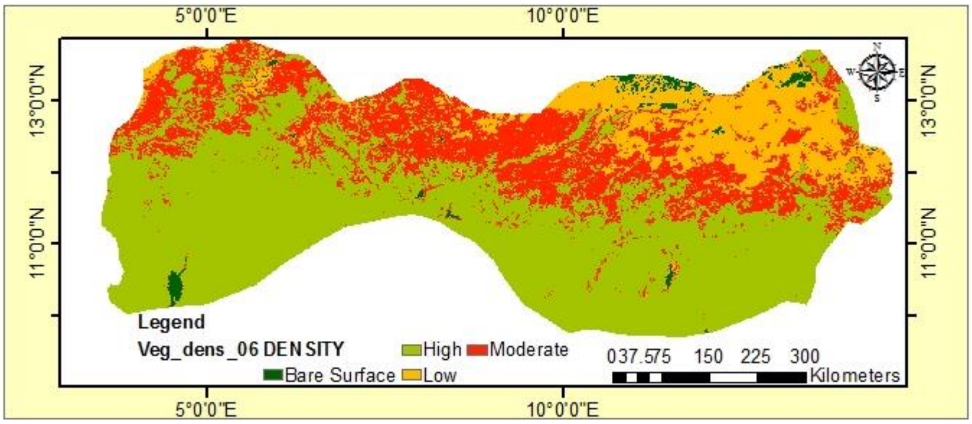

Figure 2b: Vegetation density map of 2006

Source: Data Analysis 2017

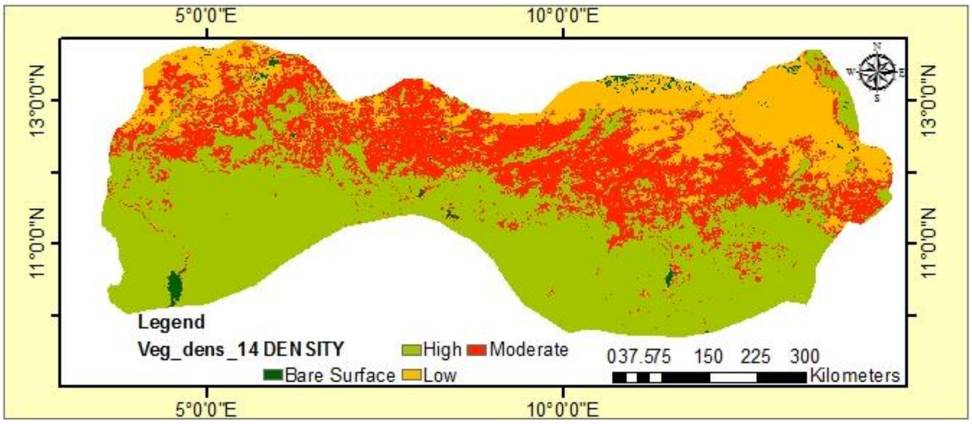

Figure 2c: Vegetation density map of 2014

Source: Data Analysis 2017

The results of rainfall intensity and distribution in this study is presented in table 2 and figure 3a – c, the results revealed that rainfall is varying in space and time, it shows that in 1998 about 86.41% of the areas received high rainfall, this was followed by moderate covering an area of 11.94% while 1.65% received low rainfall, in 2006 about 72.21% of the total land mass received high rainfall, 24.26% with moderate while only 3.53% received low rainfall, the intensity further reduce in 2014 where about 65.47% received moderate rainfall, 18.62% low while 15.91% with higher intensity, the results implies that rainfall in the zone is experiencing decreasing intensity during the study period. This is in agreement with the study made by Abaje et al (2012) who reported a decrease on annual rainfall in six out of eight areas in SSZ especially between 1998 and 2006, even though they founded an increasing wetness from the preceding years. The finding is also supported by that of Murtala et al, (2015) who reported continues decreased on the annual standardized precipitation values in Kano state from about 3.8SPI in 1998 to about 1.5SPI in 2006. The results of this study is also supported by that of Abaje et al, (2014) who found a decreased in annual rainfall of Kano state from 1998 to 2010.

Table 2: Rainfall Intensity and Distribution in SSEZ (1998, 2006, 2014)

	1998		2006		2014	
INTENSITY	Area(Pixels)	Area (%)	Area(Pixels)	Area (%)	Area(Pixels)	Area (%)
High	334075	86.41	279201	72.217	61485	15.903
Moderate	46165	11.941	93780	24.257	253126	65.473
Low	6374	1.649	13633	3.526	72003	18.624
Total	386614	100	386614	100	386614	100

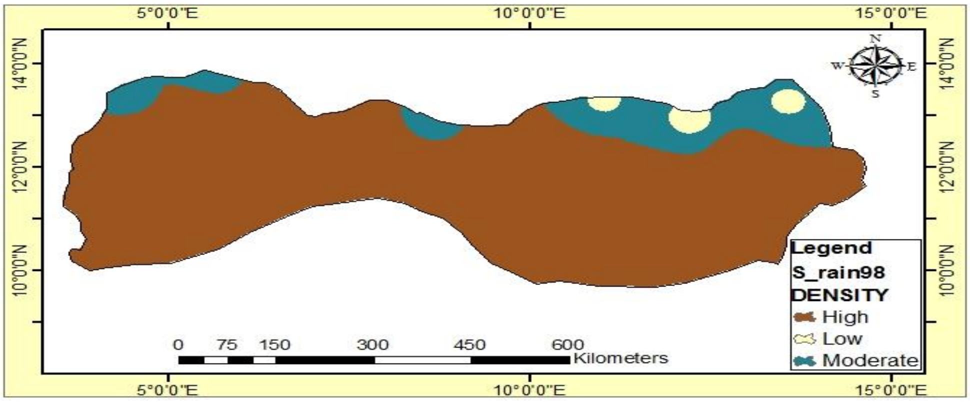

Figure 3a: Rainfall intensity and distribution map of 1998

Source: Data Analysis 2017

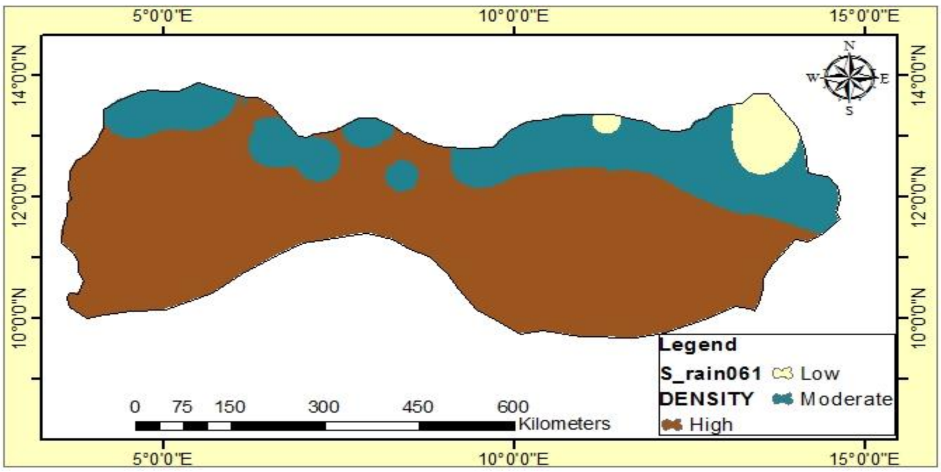

Figure 3b: Rainfall intensity and distribution map of 2006

Source: Data Analysis 2017

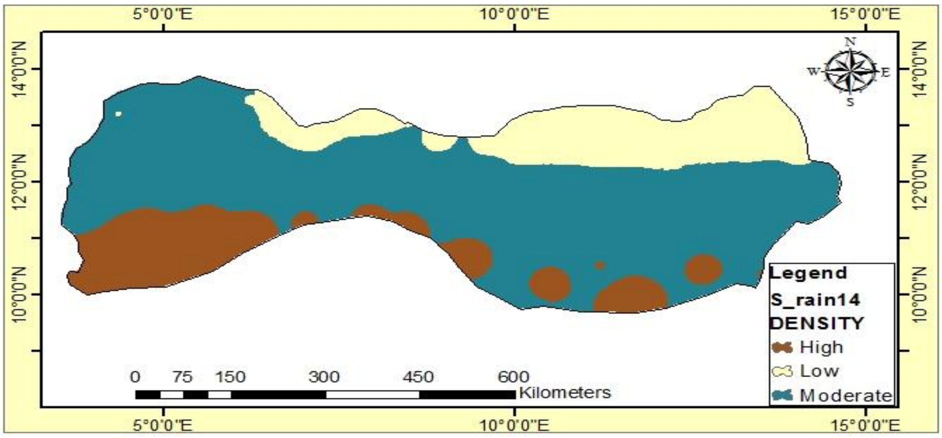

Figure 3c: Rainfall intensity and distribution map of 2014

Source: Data Analysis 2017

The pattern of the changes in vegetation density between 1998 and 2014 are presented in table 3 and figure 4a. The spatial extent of the bare surface decreases by 0.04% with an annual rate of -0.01. Low vegetation density increased by 14.89% at the rate of 2.38; the moderately density also increased by 35.11% with annual rate of 5.62 but high vegetated area decreased by 49.96% at the rate of -7.99. The result indicated how the trends of vegetation density in SSEZ fluctuate spatially and temporally. The finding is in line with that of Nicholson (1995) who revealed that, vegetation in Sahelian region of West Africa tends to grow in patches. The result is also supported by Abaje (2007) who revealed that, the density of vegetation in SSEZ decreased as one move northwards.

Table 3: Annual Rate of Change of Vegetation Density for 1998 to 2014

CATEGORIES	Area (Pixels) Change	% of Change	Annual Rate of change
Bare surface	Decreased by 28	-0.04	-0.01
Low	Increased by 10953	14.89	2.38
Moderate	Increased by 25833	35.11	5.62
High	Decreased by 36758	-49.96	-7.99

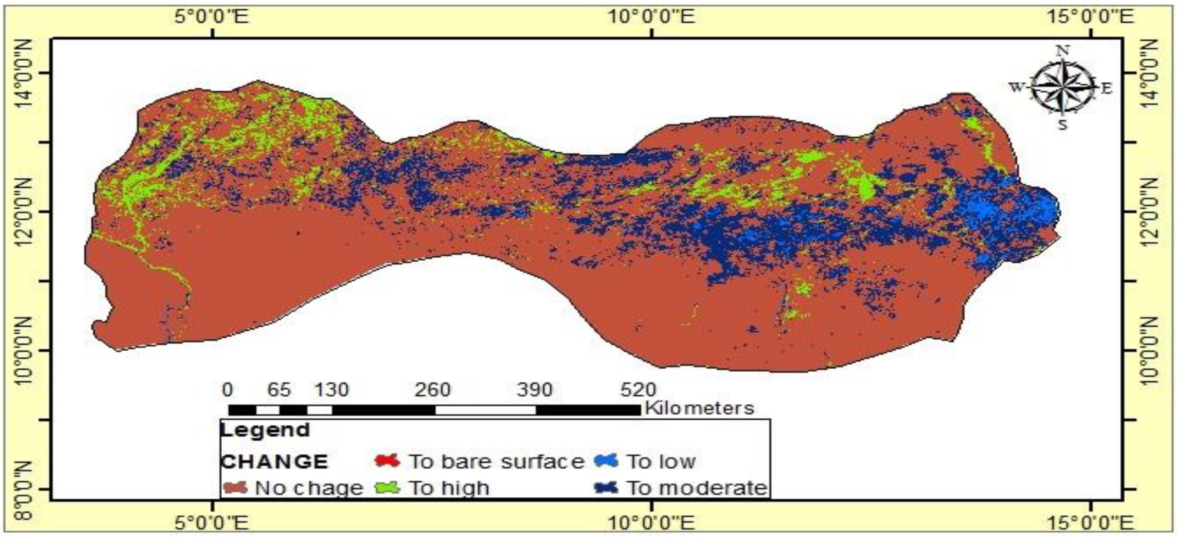

Figure 4a: Vegetation density change map (1998 – 2014)

Source: Data Analysis 2017

Change detection analysis for rainfall (table 4 and figure 4b) revealed that between 1998 and 2014, the area experiencing high rainfall (above 800mm) decreased by 50% at the rate of -8, those that received moderate rainfall (600mm to 800mm) increased by 37.96% at the rate of 6.07 while areas that received low rainfall (below 600mm) also increased by 12.04% at the rate of 1.93%. This therefore, indicated that rainfall intensity and distribution in SSEZ fluctuated with decreasing amount northward. The finding is supported by Nicholson (2013) who revealed that, a fundamental feature of the Sudano – Sahelian rainfall patterns is the strong spatio-temporal variability. The result is also in line with that of Abaje et al (2013) who revealed that, the pattern of rainfall in SSEZ is highly variable in spatial and temporal dimensions with annual variability of between 15 and 20%.

Table 4: Annual Rate of Change of Rainfall for 1998 to 2014

INTENSITY	Area (Pixels) Change	% of Change	Annual Rate of change
High	Decreased by 272590	-50	-8.00
Moderate	Increased by 206961	37.96	6.07
Low	Increased by 65629	12.04	1.93

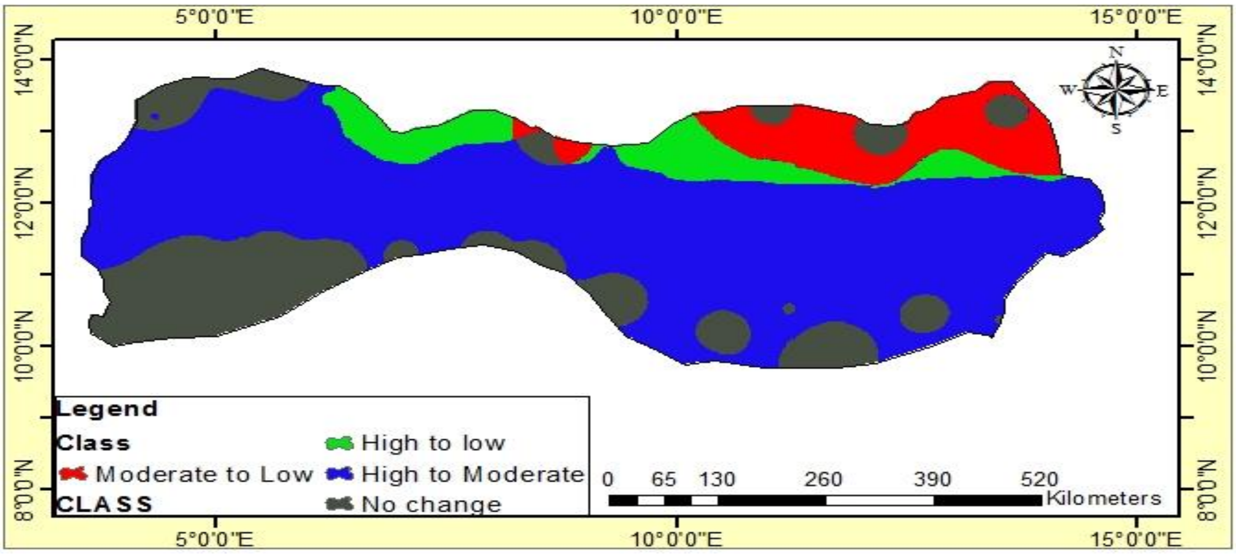

Figure 4b: Rainfall intensity and distribution change map (1998 – 2014)

Source: Data Analysis 2017

Table 5, 6 and 7 shows the correlation and regression coefficient between NDVI and rainfall in the study area for the year 1998, 2006 and 2014. It is inferred that there is weak negative correlation in 1998 and 2014 while for 2006 there is weak positive correlation. The results of coefficient of determination (R^2) for rainfall with NDVI for the three years show a poor prediction power of rainfall to the vegetation density in SSEZ. This therefore, revealed that other factors such as soil pattern, animal rearing as well as population growth plays a vital role in the determination of vegetation density. The finding is in line with the assertion of Nicholson (1995) who asserted that, the morphological structure and the floristic composition of the vegetation in the SSEZ is primarily dependent on soil properties and rainfall levels. The finding is also supported by Potts et al (2013) who revealed that low economic development, strong population increases, social unrest and climate change (such as rainfall) put pressure in the SSEZ vegetation resources.

Table 5: Relationship between NDVI and RAINFALL (1998)

Correlation Coefficient			Regression Statistics	
	NDVI	RAINFALL	Multiple R	0.003
NDVI	1		R square	8.47E-06
RAINFALL	-0.003	1	Adjusted R Square	-0.0909
			Standard Error	0.206108
			Observation	50

Table 6: Relationship between NDVI and RAINFALL (2006)

Correlation Coefficient			Regression Statistics	
	NDVI	RAINFALL	Multiple R	0.273
NDVI	1		R square	0.074728
RAINFALL	0.273	1	Adjusted R Square	-0.0094
			Standard Error	0.217334
			Observation	50

Table 7: Relationship between NDVI and RAINFALL (2014)

Correlation Coefficient			Regression Statistics	
	NDVI	RAINFALL	Multiple R	0.116
NDVI	1		R square	0.0135
RAINFALL	-0.116	1	Adjusted R Square	-0.0762
			Standard Error	0.14721
			Observation	50

CONCLUSION AND RECOMMENDATION

In conclusion, the study revealed the decreasing density of vegetation in the study area across the study periods (1998, 2006 and 2014) which serve as a means of economic development in the area through rearing of animals and protection of land against degradation. The study also examines Spatio - temporal pattern of annual rainfall in the area and found that the intensity of annual rainfall has been on continues falling especially between 2006 and 2014. It is also observed from this research that there is poor relationship between the development of vegetation density and rainfall variation in the study area, hence, the research recommended an integrated effort by government and public individual toward protected our available vegetative resource from been damage through various human activities. The study also recommends further research where other factors such as temperature and soil properties will be considered.

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