Assessment of Drought across Kaduna State, Nigeria using MODIS Dataset

ABSTRACT

Kaduna state in Nigeria is located within the Guinea Savannah of the African Continent. The state is susceptible to desertification and the risks of drought.

Aim and Objectives: The aim of the study is to access magnitude and extent drought in Kaduna state Nigeria using MODIS dataset.

Study Design: The study examined people's perception; precipitation data and satellite remote sensing as three important ways of monitoring drought. Simple statistical tables were used to present the data.

Methodology: Statistical analysis and Idrisi remote sensing and Geographical Information (GIS) softwares were used to analyse the data to determine the aerial coverage of drought and its magnitude.

Results: The study revealed that there have been several episodes of drought in Kaduna state within the period under review. The study also revealed that there is a positive relationship (0.72) between rainfall and vegetation vigour/biomas in the state. Similarly, vegetation condition index (VCI) revealed a value 10.2% indicating a severe drought in the state based on Kogans drought classification.

Conclusion: The study concluded that both rainfall and vegetation/biomas vigour are generally decreasing suggesting a strong positive correlation value of 0.71. The study recommends that individuals and organisations be encouraged to develop the habit of tree planting in order to curtail the decrease in vegetation biomass in the state. In addition, research and extension services should be strongly promoted in order to develop particular breed of seeds that can survive the drought in this period of food insecurity.

Keywords: Drought, Rainfall Variability, NDVI and Vegetation Condition Index

1. INTRODUCTION

Drought has had a significant impact on civilization throughout history, but it is one of the most difficult phenomena to measure and even to define. Numerous drought indices and indicators have been developed in the last two centuries, based on the sector and location affected the particular application, and the availability of data, among other factors [1]. Accordingly, drought can take multiple forms, including meteorological drought (lack of precipitation), agricultural (or soil moisture) drought, and hydrological drought (runoff or streamflow) [2] [3] [4] and [5].

The complexity of drought often results in a definition that is couched in general terms, such as a marked deficiency of precipitation that results in a water shortage or hydrological imbalance that affects some activity or group (The National Aeronautics and Space Administration (NASA) [6]. It is best represented by indicators that quantitatively appraise the total environmental moisture status or imbalance between water supply and water demand [3]. Civilization has struggled to develop early warning and other response systems to address the drought problem, but the diversity of climates, range of sectors impacted, and inconsistency in available resources and data make even drought assessment on a continental scale, let alone on a global scale difficult [7] and [8].

Drought is a normal part of climate, rather than a departure from normal climate [9] and the cumulative effects according to [10] are felt in other disasters such as desertification and famine; prominent in the Sahara and Sub-Sahara. Every continent has regions and climates that are susceptible to drought, including semiarid areas that are especially vulnerable to drought [11]. However, [12] have shown that fluctuations of rainfall has no direct influence of climatic variations in Kaduna State. In Africa especially across the Sahara, drought impacts are largely economic; this is aggravated by the adverse climatic nature of the region affecting quite a number of African populations according to National Oceanic, Atmospheric Administration (NOAA) [13].

In a globally warmed world, the warming can intensify hydrological droughts and alter runoff timing from snowmelt, affecting water management decisions [14], and drought-affected areas will likely increase in extent and the vulnerability of semiarid regions to drought will also likely increase [15]. Although [16] are of the view that the use of snowpack predictions are essential tools for water resources management activities, such as hydropower energy production planning, irrigation and providing early flood warnings in changing climate conditions, these may not necessarily be applicable to the prevailing weather conditions in Kaduna state. As noted by the Intergovernmental Panel on Climate Change (IPCC) [17], [18], some countries have made efforts to adapt to the recent and projected changing climate conditions, particularly through conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for flood drought and coastal management, and disease surveillance systems

However, the effectiveness of these collaborative drought monitoring efforts is outweighed by lack of basic information, observation, and monitoring systems; lack of capacity building and appropriate political, institutional, and technological frameworks; low income; and settlements in vulnerable areas, among others [19] and [6]. These shortcomings have inhibited the development of an integrated Global Drought Early Warning. On the other hand, [20], [21], [22] have all shown that NDVI is closely related to biophysical parameters such as photosynthetical active radiation, leaf area index, biomass vegetation etc. and [12] also confirmed that seasonal and sub-seasonal signals of vegetation can be detected from NDVI data and consequently climatic variability related to ENSO.

2. LOCATION AND GEOGRAPHICAL SETTING

Kaduna state is located between latitudes 9°02′ and 11°32′ north of the equator and between longitude 6°15′ and 8°50′ east of the prime meridian. Kaduna state is bounded to the north by Katsina, Zamfara and Kano states; to the west by Niger state, to the East by Bauchi and to the south by Plateau, Nassarawa and the Federal Capital Territory, Abuja (Figure 1). The state has a land area of about 43,460 square kilometres, which makes it the largest in the northwest geopolitical zone and has about 4.7 per cent of the Nigerian land area [23], [24]. The longest distance by road from north to south is about 290 square kilometres and from East to West is about 286 square kilometres [23]. It has three major urban areas; Kaduna, Zaria and Kafanchan which are accessible by different classes of roads, railway lines and airports. Kaduna state possesses a striking variety of natural environment. The topography varies from the Kudaru ring complex hills in the East, to the wide valley plains of the River Kaduna in the West. The geology of the area consists of Precambrian rocks of the basement complex. The topography constitutes of rolling lowland plain generally below 610 meters above sea level. This is not unconnected with the prolonged denudation of the basement complex rocks, which underlie the area. The area consists of older granites, schist, and quartzite in different compositions. The land gradually slopes down towards the west and the southwest and is drained by two dominant rivers i.e. Rivers Kaduna and Gurara [25].

Figure 1: The Study Area

The study area has an Aw type of Kopen's classification scheme [26] with two distinct seasons, a wet season in summer and a dry season in winter. The area is influenced by two distinct air masses that have much effect on the climate. The northeast trade winds, which are usually dry and dusty, are pronounced between November and March. This period is referred to as Harmattan. The second type is the moisture laden tropical maritime air mass that originates from the Atlantic Ocean [23]. The variations in the onset of rainfall are attributed to the fluctuations of the boundary between these two air masses. Rainfall is heavy in the southern part of the state and reaches an average of 500mm per month between April and September (www.wikiafrica/africa-nigeria/kaduna/physical/climate, 2016). In the extreme north, the monthly average is 146mm, while Kaduna metropolis receives a monthly average of 361mm. Temperature varies with season. The highest 31^{o}C temperature is recorded in April while the minimum (16^{o}C) is usually recorded during the harmattan season that is between December and January. High evaporation during the dry season, however, creates water shortage problem especially in Igabi, Giwa, Soba, Makarfi, Ikara and Zaria Local Government Areas (www.wikiafrica/africa-nigeria/kaduna/physical/climate, 2016). Kaduna state lies within the northern Guinea Savanna ecological zone. The vegetation is typically of woodland type and deciduous in character. The dominant tree species include *isoberline, doka, bridelis, terminalia, acacia, vitrex* etc. Grasses and shrubs occur in tussocks and the predominant family is the *androgenae*. The soil in most parts of Kaduna state falls under the ferruginous tropical soils. Most of the soils contain 30-40 percent clay at a reasonable depth, because of intensive leaching. The soils in the upland areas are rich in red clay and sand but poor in organic matter. The plains in Kaduna state have under gone considerable changes over the years due to combined actions of both physical and chemical weathering (www.wikiafrica/africa-nigeria/kaduna/physical/soils, 2016).

3. MATERIALS AND METHODS

Datasets utilized in this study includes a set of questionnaire, precipitation data and satellite imageries. The questionnaire was composed of well-structured open ended and close ended questions targeted towards people residing in Kaduna state particularly farmers. Perceptions of respondents on rainfall and farming activities was captured and presented in tables. Rainfall data was sourced from Nigeria meteorological stations located in National College of aviation technology Zaria and Kaduna state International Airport for 15 years (2000 – 2014). Satellite images were acquired from Aqua Modis Corporation from 2000 to 2009. The Aqua Modis 250m spatial resolution in the form of Normalized Difference Vegetation Index (NDVI) covering Kaduna state.

4. RESULTS AND DISCUSSION

4.1 Rainfall Variability in Kaduna State

Figure 2 shows the rainfall variability in Kaduna state. The trend in Kaduna metropolis and environs show a steady increase from the year 2000 to 2003 (1234mm, 1185.8mm, 1317mm, and 1642mm) from where it slide down continuously to its lowest in 2008 (752mm). From 2008 the pattern has been inconsistent with little increases and decreases until in 2013 where the highest amount of rainfall (1753mm) was recorded and then dropped again in 2014 (1623.6mm). The level of consistency in the rainfall has been very minimal with a decreasing trend from 2003 to 2008.

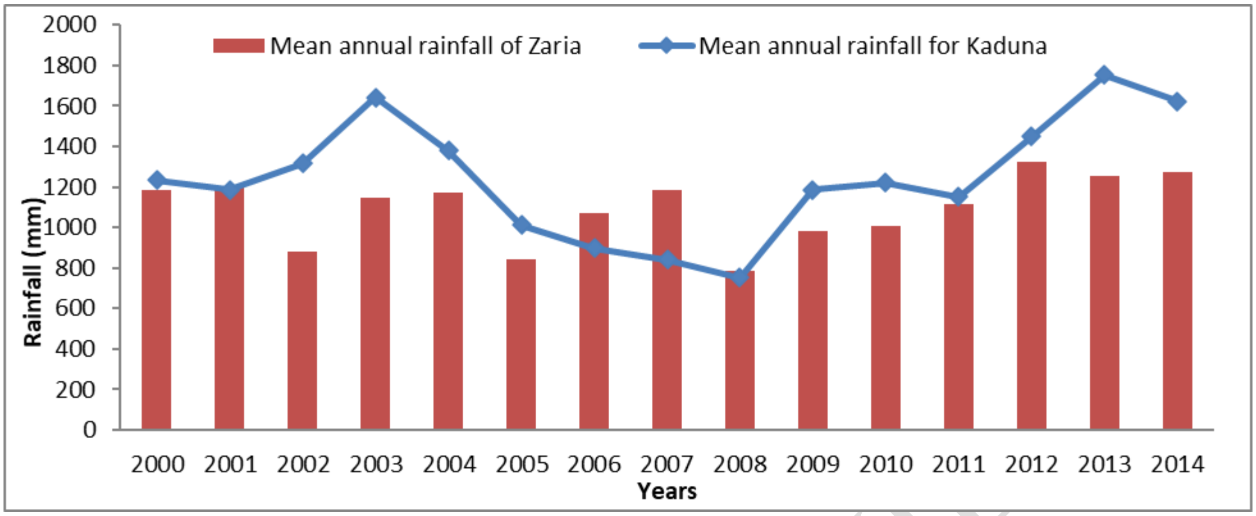

Figure 2: Comparative line and bar graphs showing annual rainfall for Zaria and Kaduna (2000-2014)

Similarly, Zaria and its environment have recorded a more inconsistent rainfall pattern making it very difficult to predict the rainfall. While the highest amount of rainfall received in Zaria was in the year 2012 (1323.1mm), Kaduna recorded it's highest in 2013 (1753mm). Similarly, the lowest amount of rainfall recorded for both Zaria and Kaduna was in the year 2008 but with dissimilar figures of (787.1mm) and (752mm) respectively; implying that Kaduna has both the highest amount of rainfall and the lowest amount of rainfall recorded within the period under review. However, the levels of variability differ_significantly. Kaduna has little variability in rainfall pattern while Zaria has very high inconsistent rainfall pattern. The total annual rainfalls received in both places also differ considerably with Kaduna having the highest (18643.4mm) and Zaria having the lowest (16412.9mm). Therefore, for the period under review (2000-2014) Kaduna state recorded a mean total annual rainfall of 17528.2mm.

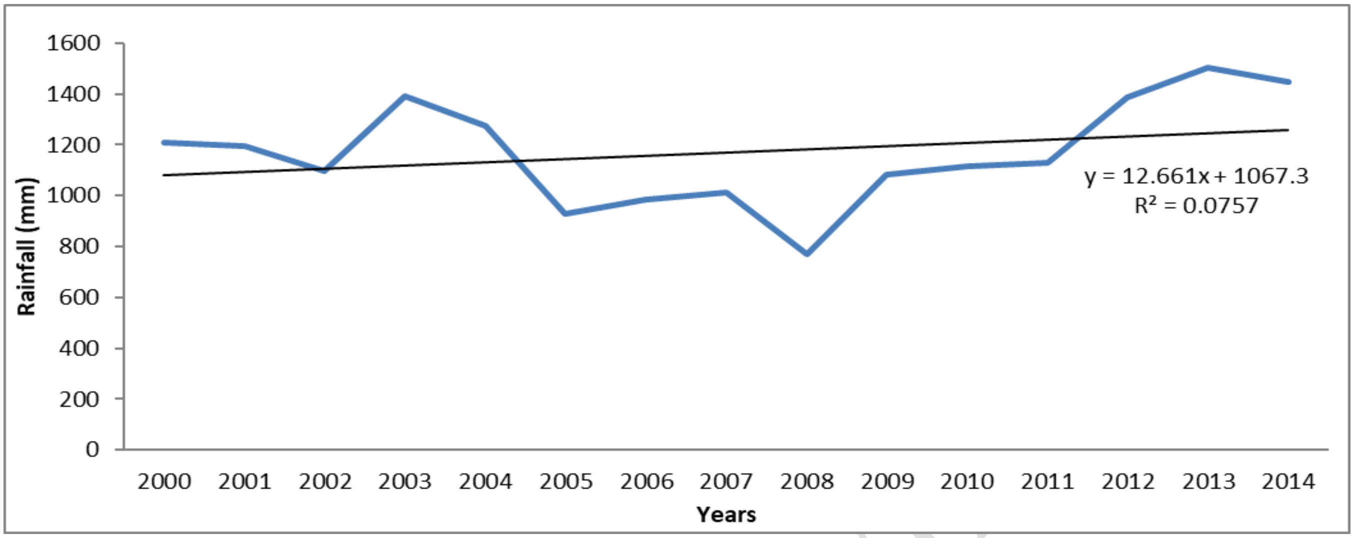

Figure 3: Annual rainfall for Kaduna State (2000 to 2014)

Figure 3 shows the derived annual rainfall pattern of Kaduna state. This was derived by computing the yearly total of Zaria and Kaduna rainfall, recorded for the period under review (2000-2014). The pattern is similar to that of Kaduna metropolis and environs. This is because Kaduna metropolis and environs receives higher rainfall recorded than Zaria. Consequently, the lowest amount of rainfall recorded in Kaduna state as whole for the period under review was 769.55mm (2008). More so, the highest amount of rainfall recorded for the same period in Kaduna state was 1502.9mm in the year (2013). Therefore, the pattern indicates that from 2003 to 2008 rainfall has decreased consistently in the state. However, from 2009 to 2013 (4 years), an inconsistent increase in rainfall was recorded followed by a decrease in 2014.

4.2 Assessment of surface runoff using NDVI imageries

From the NDVI images, the amount of runoff was obtained. Figure 4 shows the amount of runoff (surface overflow) in the study for the year 2000. From the image, it is indicated that the runoff for the year was between 1mm – 73mm from an annual rainfall

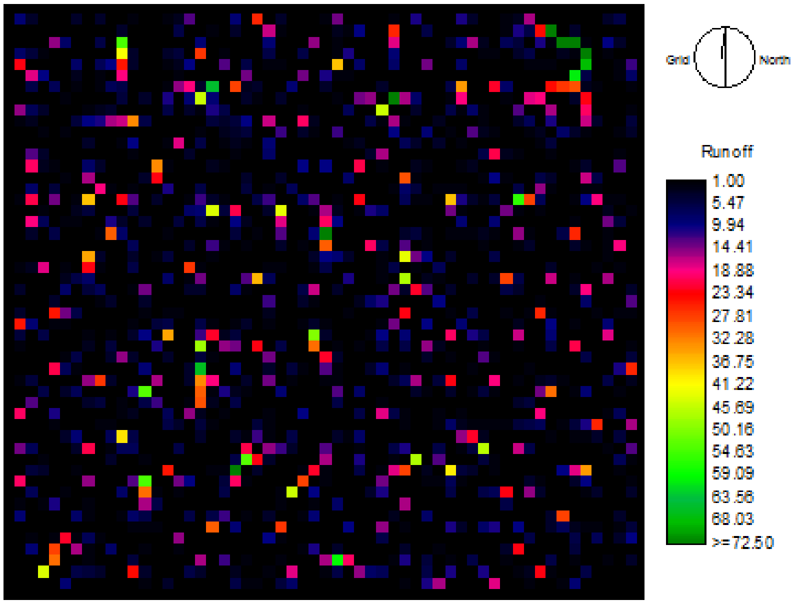

Figure 4: NDVI image showing the amount of runoff (2000)

of 1194.1mm. In the year 2004 (5 years later) runoff decreased from 72.50mm (2000) to just about 62.00mm (2004) (Figure 5) showing a decrease of 6.5mm accounting for a 9.4% change in runoff. By 2009 runoff had decreased to its lowest value of just about 48.00mm compared to 2000 and 2004.

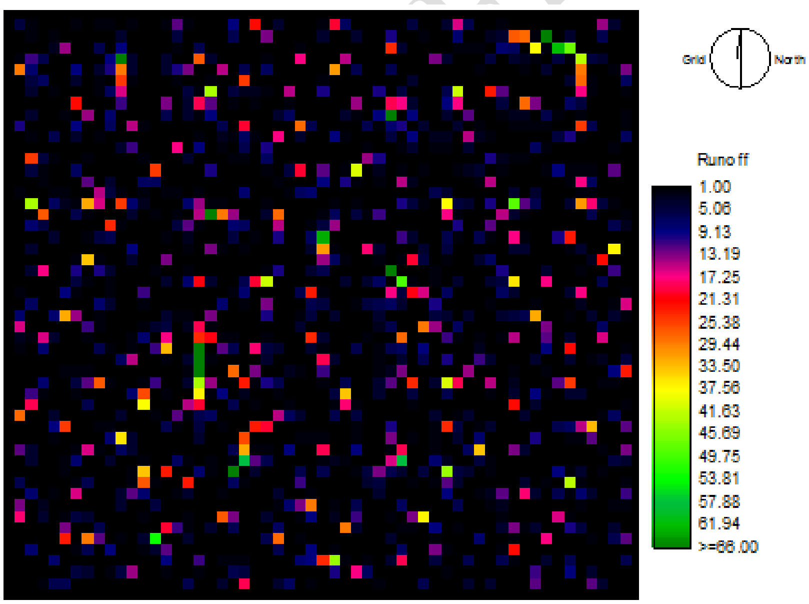

Figure 5: NDVI image showing the amount of runoff (2004)

Thus, from 2004 to 2009 runoff reduced by 18mm (i.e. from 66mm to 48mm respectively). This is higher compared to 2000 to 2004 with 6.5mm. Again from 2000 to 2009, runoff reduced from 72.50mm to 48.00mm (Figure 6); a difference of 24.5mm.

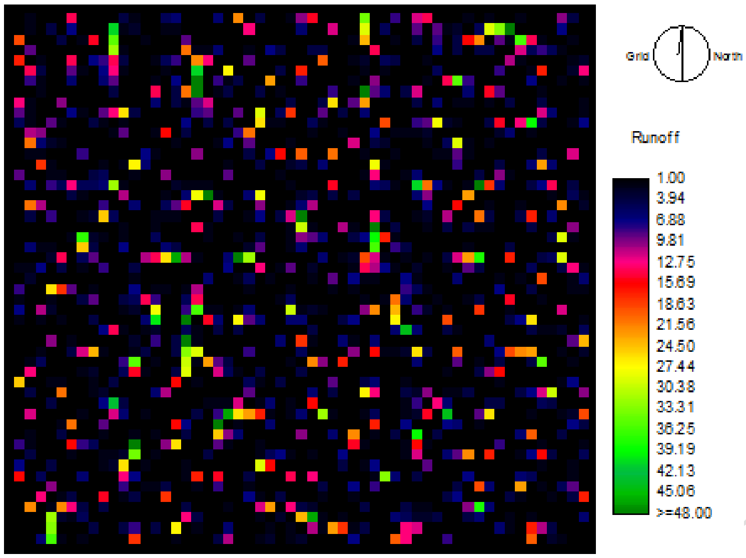

Figure 6: NDVI image showing the amount of runoff (2009)

However, of particular interest is the change from 2005 to 2009. This is more than twice the change witnessed from 2000 to 2004. This corresponds with rainfall data in Figure 3.

4.2 Classifications of Annual NDVI Mean Image

The annual NDVI mean image classification is broad covering all vegetation types in the state. The classification indicates that the most dominant vegetation type in Kaduna state is scanty vegetation with total area coverage of 4977432 hectares (54.25%) spread all over the state except in the North-Northeastern part of the state (Figure 7). This vegetation type consists mainly of grasses. This is followed by the medium vegetation type covering 2984018 hectares (32.52%) found mostly in the South-Southeastern part of the state consisting of isolated pockets of trees and shrubs. Bare surfaces account for 1159816 hectares (12.64%). This vegetation type is found in the North-Northeastern (greater part of Zaria) part of the state and on isolated rocky ranges of southern part of Kaduna of Sanga Local Government Area and in Jema'a and Kaura Local Government Areas.

Table 1: Classification of Vegetation (NDVI)

Vegetation Class	Size (Hectares)	Percentage
Scanty Vegetation	4,977,432	54.25
Medium Vegetation	2,984,018	32.52
Bare Surface	1,159,816	12.64
High Vegetation	27,275	0.30
Moderate Vegetation	15,232	0.17
Water Bodies	12,146	0.13
Total	**9,175,918**	**100**

Smaller vegetation groups include the high vegetation, moderate vegetation and water bodies with 27275, 15232 and 12146 hectares with 0.30%, 0.17% and 0.13% respectively. However, the water body falls largely outside the state, which is the Gurara Water falls in Niger state, which coincides with the area of high vegetation because of the availability of water. Similarly, the moderate vegetation belts occur in southern part of Kaduna mostly in Kaura Local Government comprising of isolated pockets of forests especially along Gidan Waya and Sanga Local Government (Figure 6, Table 1).

Figure 7: Classified Vegetation Image of the study area

To show the short term and long term changes in NDVI, the 10 years image was divided into quasi 5-years and 10-years periods respectively. This is important so as to show the impacts of precipitation variability on the vegetation/biomass changes over time in Kaduna state.

The effects of climatic extremes and the likelihood of cloud contamination in the imagery are inevitable. Therefore, to reduce these contaminations, the mean NDVI of the end years of each comparison (the quasi time periods) was calculated (after [27]); this is illustrated in Table 2. Figure 8 shows the short-term change (2000-2004) in vegetation growth in Kaduna state.

Table 2: Classification of end-point years, absolute and relative changes of the annual NDVI images

Annual mean images (end-point years)	Quasi 5-year period (5-year period)	Quasi 10-year period (10-year period)
2000/2001	2004/2005 Minus 2000/2001 (2000 to 2004	2008/2009 Minus 2000/2001 (2000 to 2009)
2004/2005		
2008/2009		

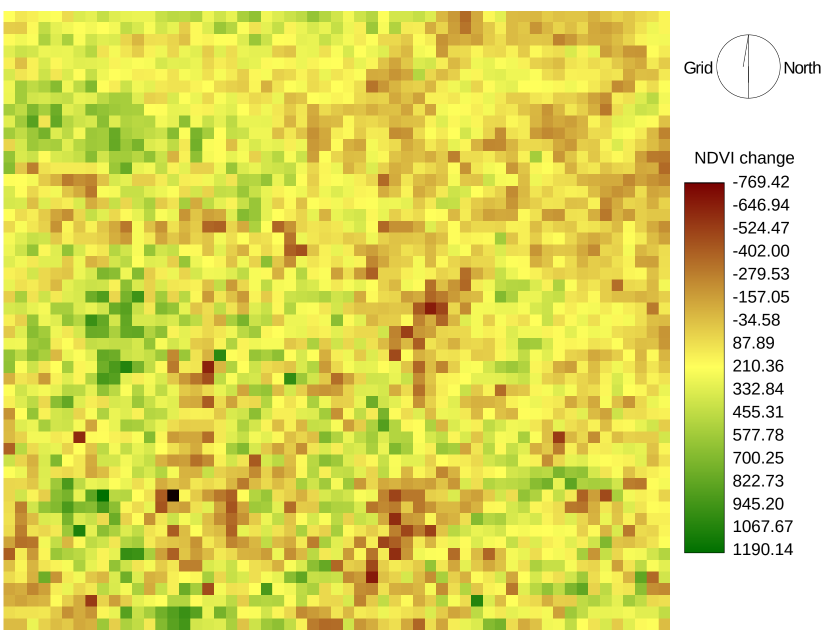

Figure 8: Quasi 5-years change image (2000/2001 to 2004/2005)

To enhance a more visual comparison of the images, the annual mean NDVI composites of the end point years were classified on an interval of three NDVI units using the information from the minimum and maximum value range (Table 2) obtained from the descriptive statistics of these images.

4.3 Relative and Absolute NDVI Changes

Figure 8 and Table 3 provide a picture of relative changes of the end point years (change of 5 years). The NDVI units in northern Kaduna area of low biomass represent a big change compared to the same NDVI units in southern Kaduna with more biomass. This can identify areas of significant changes. To derive the proportionate short term change, the original residual image for the quasi five year change (2004/2005) was divided by the 2000/2001 NDVI image to derive a 'per-pixel' (appropriate change) to show the relative changes between 2000 and 2004 (Figure 8). The same procedure was applied to the quasi 10-year period (Figure 9) to derive the proportionate long-term changes from 2000 to 2009 (10 years change image) [27].

Table 3: Descriptive statistics from the annual NDVI mean composite images

Annual Mean Composite images	Min. Val.	Max. Val.	Mean	SD
Quasi-5 years	-769.42	1990.14	610.36	1951.30
Per-pixel change	-1584.54	1584.55	0.005	2240.89
Proportionate long term change	-0.41	0.38	-0.015	0.56

Table 3 indicates that the short time changes (quasi-5 years) was about 610m while the change per pixel was about 0.005m. However, the longer-term change (2000-2009) indicated a negative change of -0.015 in the study area. This indicates a loss of vegetation for the period under review. This corresponds to the decrease in rainfall recorded in Figure 2.

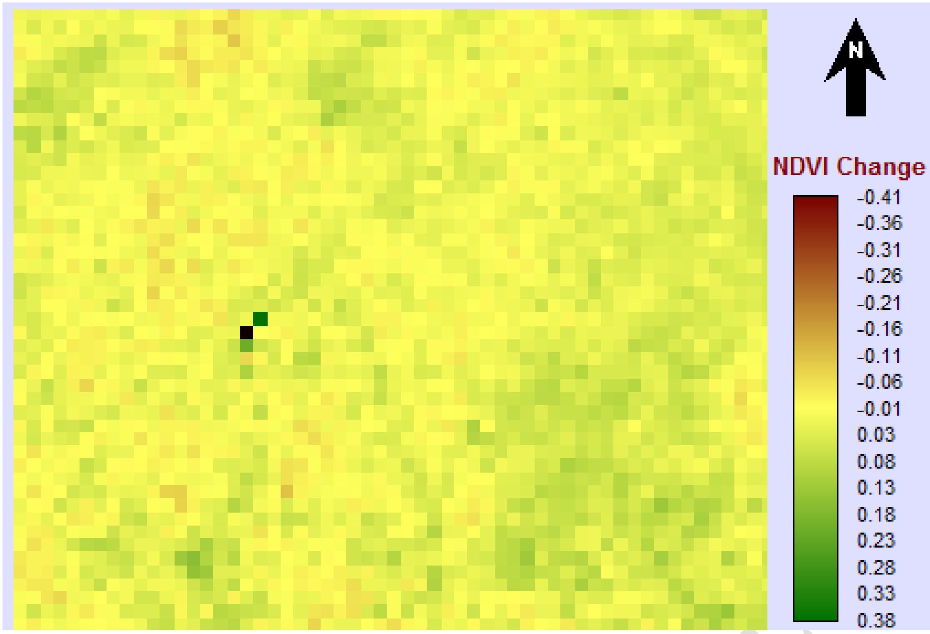

Figure 9: Proportionate long term change image

4.4 Extent of Drought in the Study Area

Table 4 indicates that 85% of the respondents agreed that they observed the decreasing rainfall in the northern part of Kaduna state (Figure 10). This is in line with the desertification problem in the northern states, which is ravaging the state. 11% of the respondents however agreed that they observed decreasing rainfall in central Kaduna (i.e. Kaduna Metropolis). However, 4% agreed that they observed decreasing rainfall in Southern Kaduna. This means that larger part of the state has witnessed some significant episodes of decreasing rainfall largely beyond dry spells. As much of this observation was made in recent years (from 2005), it suggests then that the trend is on the increase as the earliest years of the study period recorded less decreasing rainfall than the recent years.

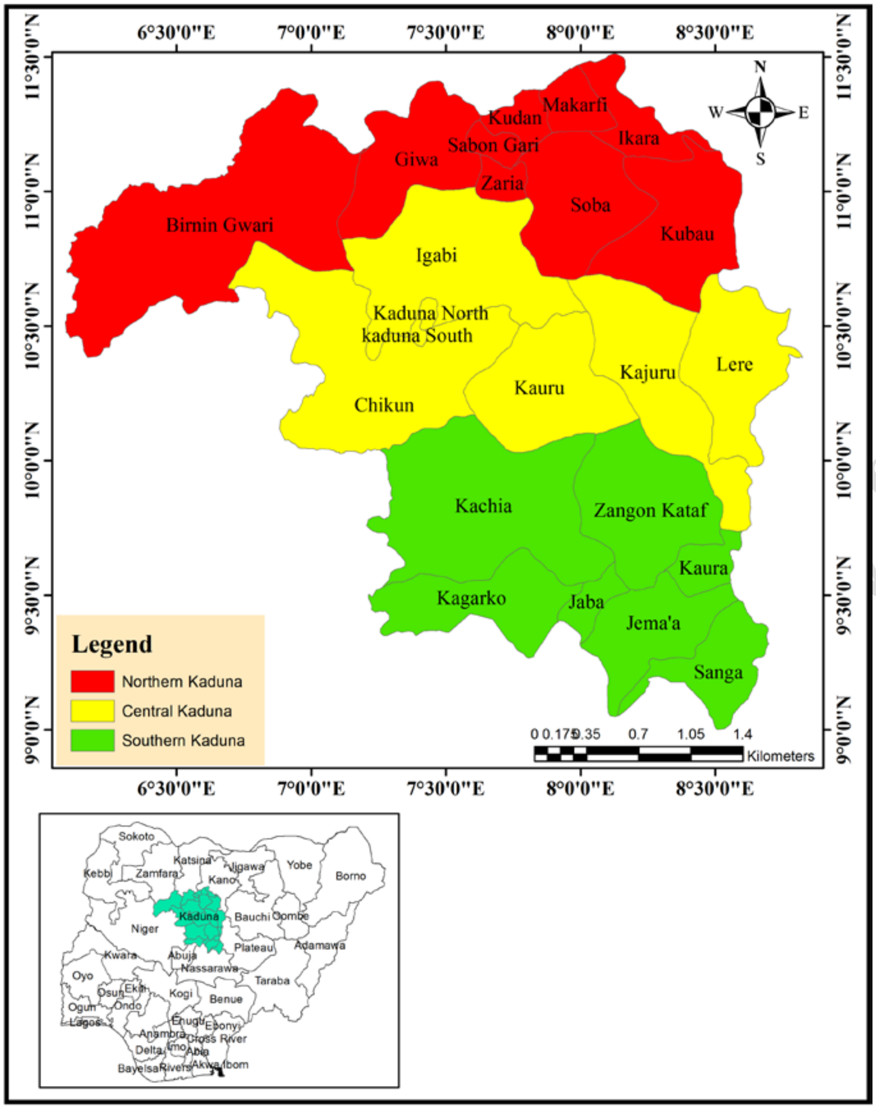

Figure 10: Study area showing the Southern, Central and Northern part of Kaduna State

Table 4: Areas and Years of Decreasing Rainfall.

Areas of decreasing rainfall	**Frequency**	**Percentage**
Northern Kaduna	341	85.25
Central Kaduna	44	11.00
Southern Kaduna	15	3.75
Total	**400**	**100**
Observed declined in rainfall		
2000-2004	54	13.50
2005-2009	241	60.25
2010-2014	105	26.25
Total	**400**	**100**

13% of the respondents observed a decrease in rainfall in the period 2000-2004 while about 26% of the respondents indicated that they observed a decreasing rainfall in the period 2010-2014. However, 60% observed decreasing rainfall between the years 2005-2009. According to them this decreasing rainfall occurred in the form of late onset, light showers and early cessation. Thus, respondents said price of food commodities in the markets skyrocketed especially in the study area and its neighboring towns. This corresponds with the period of decrease in vegetation/biomas vigour in the study area (Figure 11).

Although the effect of rainfall on NDVI seems to be inconsistent (Figure 11), this is due to other climatic variables that act in conjunction with rainfall to affect the vegetation growth in Kaduna state. These climatic elements may include one or more of humidity, winds, sunshine duration and intensity, temperature etc. Dividing the total mean absolute NDVI change by the total mean absolute rainfall change gives a constant value by which a millimeter of rainfall can produce a change in NDVI.

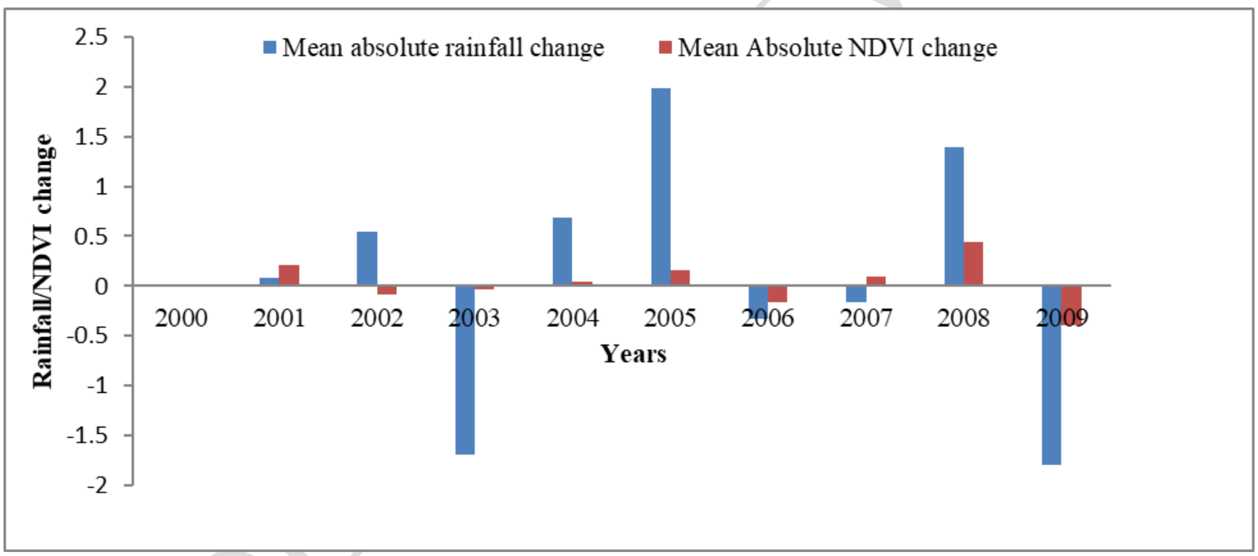

Figure 11: Mean absolute rainfall and NDVI change histogram

Thus, 1mm increase or decrease in rainfall will produce a 0.52 unit increase or decrease in NDVI respectively per annum. Of particular interest are the years 2002 and 2007 with complete negative correlations between rainfall and NDVI changes. In 2002, while rainfall increased from the previous year (2001), the following year (2003) witnessed a decrease. This did not produce a corresponding change in NDVI; the NDVI decrease in 2002 and increased in 2003 contrary to the change in the rainfall. Similarly, in 2007, a little increase in rainfall produced a higher increase in NDVI.

As an indicative of the magnitude of drought, the Vegetation Condition Index (VCI) was computed which is a ratio of the NDVI collected in a given period compared to its historical range (maximum minus minimum) derived over several years of record.

Table 5: Vegetation Condition Index of Kaduna

Group	Range of values	Price Related Differential	Coefficient of Dispersion	Coefficient of Variation
				Median Centered
2000	.000	1.000	.000	.
2001	.000	1.000	.000	.
2002	.000	1.000	.000	.
2003	.000	1.000	.000	.
2004	.000	1.000	.000	.
2005	.000	1.000	.000	.
2006	.000	1.000	.000	.
2007	.000	1.000	.000	.
2008	.000	1.000	.000	.
2009	.000	1.000	.000	.
Overall	.997	1.010	.074	10.2%

Possible VCI values range from 1 to 100. Kogan [28] stated that VCI values of 35% and under indicate drought. More so, long-term changes in NDVI data have been evaluated in several studies but results have not been conclusive, this according to [12], is as a result of differences in the tools used, data processing techniques and the length and time of the analyzed time series. Table 5 shows the vegetation condition index of Kaduna state. According to [28] VCI ranges between 1 to 100%. A vegetation condition index of 70% indicates very luxuriant vegetation while that of 10 indicates a strong drought. Similarly, a VCI of 35% and less indicates drought. Therefore, the VCI for Kaduna state shows a value of 10.2% (Table 5) showing a strong drought in the state.

4.5 Vegetation Change Vulvnerability base on Rainfall/NDVI Cross-Tabulation

Figure 12 shows the cross tabulation of rainfall and NDVI. The result was three broad major categories; little change, moderate change and high change. Three major classes 0:3, 0:4 and 0:5 classes were identified and classified as little, moderate and high/broad change respectively (Figure 13). The little change class covers about 6.5 million hectares of land. This class is predominantly grasses and shrub whose growth (size/height) remains relatively low despite positive change in rainfall. Therefore, increase in rainfall will produce little observable growth in NDVI. The moderate change class covers greater part of northern Kaduna with isolated parts to the west and eastern part of Kaduna covering about 2.1 million hectares. This class is covered by short grasses and well

Figure 12: Cross-classified image of rainfall and NDVI

dispersed trees of average sizes and heights. This vegetation class is very sensitive to even a little amount of moistures such that a little rainfall will cause grasses to sprout up covering the entire area thereby significantly increasing the spectral signature recorded by satellite sensor; this is recorded as a significant increase in vegetation. The change in these parts is sharp and recognizable because the entire area was initially dry and bare. The broad/high change class exists in clusters found mostly in southern part of the study area. This covers just about 523,286 hectares of the entire Kaduna state. This class comprises of forests with tall trees and big sizes.

Figure 13: Classification of NDVI change image

These trees are deciduous, shedding their leaves during the dry seasons to conserve water; but as soon as the rains set in and within few days, are covered with dense leaves thereby increasing the chlorophyll content as such, the spectral signature recorded by satellite sensor. During the dry season, these areas are recorded with minimum NDVI or vice versa.

Table 6: Classification of NDVI changes

Category	Hectares	Legend
1	6,513,120.0843208	Little Change
2	2,139,511.3436860	Moderate Change
3	523,286.9880192	High Change

4.6 Absolute mean rainfall and corresponding absolute mean NDVI change for ten years

Based on the degree of susceptibility of vegetation to changes resulting from rainfall change, the little change class is the part of Kaduna state is mostly hit by episodes of drought. This area covers 6.5 million hectares of the study area, covering Zaria and its environments (Figure 13 and Table 6).

5. CONCLUSIONS

There is high rainfall variability (1.4%) in Kaduna state that consistently leads to a general decrease in annual precipitation. The decrease in annual precipitation was very significant in some years especially 2002, 2005 and 2008 to the extent of inducing a significant decrease in vegetation vigour/biomass.

The decrease in rainfall is in the form of late onset and early seization of the rainy season followed by prolonged dry spells. Of all the factors contributing to drought, rainfall alone accounts for 52% making it the most important single cause of drought in Kaduna state. Kaduna state has within the period under review (2000-2014) witnessed some episodes of drought notably in the years 2002, 2005 and 2008 in the northern part of the state. However, vegetation decrease was most significant in the year 2007 (This is as a result of the interplay of other climatic elements such as temperature, Enso [12]; [21], relative humidity etc.

There is a high positive correlation (0.71) between rainfall and vegetation in Kaduna state. The study also concludes that the early signs of drought in Kaduna state are increasing temperatures, decreasing rainfall, low relative humidity, drying environments and deforestation. With a vegetation condition index of 10.2%, the study has confirmed that Kaduna state is witnessing drought. However, the area worse affected is about 6.5 million hectares covering northern part of Kaduna (Zaria and its environments).

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ACRONYMS

AVHRR: Advanced Very High Resolution Radiometer

ENSO: El-Nino Southern Oscilliations

GIS: Geographical Information Systems

IPCC: Intergovernmental Panel on Climate Change

NASA: National Aeronautics Space Administration

NDVI: Normalised Difference Vegetation Index

NIMET: Nigerian Meteorological Agency

NOAA: National Oceanic Atmospheric Administration

NPC: Nigerian Population Commission

VCI: Vegetation Condition Index