VEGETATION RESPONSE TO RAINFALL VARIABILITY IN THE SUDANO SAHELIAN ECOLOGICAL ZONE OF NIGERIA

BY

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MTech/SPS/2017/7116

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OCTOBER, 2021

~~DECLARATION~~

~~I hereby declare that this thesis titled: "**Vegetation Response to Rainfall Variability in the Sudano Sahelian Ecological Zone of Nigeria"** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.~~

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~~CERTIFICATION~~

~~The thesis titled: "**Vegetation Response to Rainfall Variability in the Sudano Sahelian Ecological Zone of Nigeria**" by: AKANDE Suleiman Kehinde (MTech/SPS/2017/7116) meets the regulation governing the award of the degree of Master of Technology of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.~~

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~~DEDICATION~~

~~This project is dedicated to Almighty Allah (S.W.T) who teaches man what he knows not and my loving, caring and industrious parents, my late father Alhaji Abdulganiyu Lawal Akande whose last word FEAR ALLAH remain my guidance and principle in life, my mother Alhaja Silifat Tayo Akande whose unrelenting effort and sacrifice has made my dream of having this degree a reality. Words would fail me to adequately express my deep gratitude to you. I pray you will live long enough to reap the fruits of your labor.~~

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~~My profound gratitude is to Almighty Allah (SWT) for making it possible for me to undergo this course. I acknowledge your great provisions, protections and support throughout the duration of this course. May the peace and blessing be upon Prophet Muhammad (S.A.W), his house hold, companions and those who follow his part till the day of reckoning, Amin.~~

~~I cannot but appreciate the constructive suggestions, criticisms and encouragement of my supervisor in person of Dr. M. T. Usman Mohammed for his valuable contribution and untiring efforts to help me realize my dreams, thank you Sir, you are really a father; may Allah reward you abundantly.~~

~~My parent are of great support in realizing this dream, my profound gratitude to my lovely Parent, Alhaji Abdulganiyu Lawal Akande (May Allah admit him into Janatul Firdaus) and Alhaja Silifat Tayo Akande for their support morally, spiritually and financially, The following for their support throughout my study:, Late Bidemi (May Allah admit him into Janatul Firdaus) , Muinat Bisola Lawal, AbdulAfis Lawal Habibat Akande (My Twinny), Abdulateef (My Lil Bro) and the entire members of Akande Family. My scholar Alhaji Yushau Saadullahi Ahmad, Thank you Sir.~~

~~My appreciation also goes to all staffs of the department for their advice all the time and unequal contribution in my life, you are all role models, if I have seen far today, it is because have stood on the shoulder of great men and women like you. I am saying thank you all, May Almighty Allah grant you all your heart desire.~~

~~To the entire class of MTech 2017 will miss you all, thank you for being there and dear throughout this journey wish you all Almighty Allah's guidance and blessing.~~

~~To my dear Wife (Khadijat) and Son (Abdulrauf), this degree is for you both, thank you for all you do, I love you both for enduring with me during this enormous task of being away from home, I am most grateful, with you both life is beautiful~~

~~Finally to all that have contribute to my life in one way or the other, when I look back I smile and appreciate those have met throughout the journey and look at the future with hope, may God reward you all abundantly.~~

Abstract

Rainfall variability is an important driver of vegetation shift or dynamics. However, the changes are symmetric and have great multiplying effects on the ecosystem and the general livelihood of man. The study examines the vegetation response to rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria (SSEZ). Rainfall data from the Climate Research Unit (CRU) and the United State Geological Survey (USGS) for satellite imageries for the study areas was acquired for the period of 1981-2018 (37 years). The Interseasonal Rainfall Monitoring Index (IRMI) was used to compute the "actual "or "real" onset and cessation date of the raining season, onset of rains was taken as the pentad within which the index is greater than or equal to 1(≥1) for the first time. The Monsoon Quality Index (MQI) was also used to determine the moisture quality in the study area and the Perpendicular Vegetation Index (PVI) for the analysis of the satellite images at the IR and the NIR. The results revealed that rainfall in the region is highly variable across the ecological zone, the lowest average rainfall is Nguru with an average rainfall of (536mm) and the highest average rainfall is Yelwa (1090.65). The Average Length of Raining Season (LRS) was between 120-140 days, Monsoon Quality Index (MQI) was calculated to determine the quality of rainfall, rainfall in the region ranged from good with value <0.005 and to extremely poor with value >0.02. Satellite imageries analysis shows a change in vegetation dynamic over the years under review. The Normalize Difference Vegetation Index (NDVI) was used to determine the vegetation index, i.e. the vegetation vigour of the region; they were ranked from areas with poor, moderate and healthy vegetation, Maiduguri, Nguru have NDVI value of around -0.2 which signify poor vegetation with average annual rainfall of less than 600mm, Kano and Gusau with NDVI value of 0.0564 which signify moderate vegetation with average annual rainfall of around 800mm and Yelwa and Bauchi has NDVI value of around 0.826whcih shows healthy vegetation with average annual rainfall of more than 1000mm. from the research it was deduced that rainfall is a function of vegetation growth, vegetation can respond positively or negatively to increase or decrease in the quality of rainfall received in a region.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Rainfall and vegetation dynamics are tightly coupled; they are physically connected to each other that cannot be easily separated from one another. Previous researches (Usman 2000, Ibrahim 2018 and Usman and Abdulkadir 2019) have shown that the amount of rainfall received by vegetation is a major factor that determines its thickness or shallowness. Studies reported that vegetation growth at high latitudes in some Northern hemisphere regions has increased from 1981 to the 1990s due to increase in amount of rainfall received but reverse is the case in the 2000's (Nayak *et al.* 2010). Large scale changes in vegetation leaf area index are also known to have led to shifts in temperature and precipitation patterns but these feedback mechanisms are complex, varying greatly from location to location and over time.

Remote sensing provides a vital tool to capture the temporal dynamics of vegetation change in response to weather (rainfall) or climate shifts, at spatial resolutions fine enough to capture the spatial heterogeneity. Frequent satellite data products, for example, can provide the basis for studying time-series of ecological parameters related to vegetation dynamics (Bradley *et al.* 2007, Gu *et al.* 2009, Jacquin *et al.* 2010 & Beck *et al.* 2011). Among the many available remote-sensing data products, the Normalized Difference Vegetation Index (NDVI) has been frequently used in vegetation dynamics studies, as this index is highly correlated with the leaf area index, photosynthetic capacity, biomass, dry matter accumulation, and net primary productivity (Wang *et al.* 2010a). Therefore, NDVI data are frequently used to assess spatio-temporal changes in regional vegetation dynamics (Kang *et al.* 2011 & Zhang *et al.* 2011) in response to changes in regional climate. Normalized Difference Vegetation Index (NDVI) is one of the main characteristic descriptors of vegetation cover and is widely used to monitor the changing dynamics of vegetation cover, biomass and the ecosystem. In addition, NDVI can be used to represent the proxy vegetation responses to climate changes since it is well correlated with the fraction of photosynthetically active radiation absorbed by plant canopies and thus leaf area, leaf biomass and potential photosynam thesis (Liu *et al.* 2012).

In the last 30 years, there have been many research studies conducted on the relationship between vegetation activity and its driving factors. The global vegetation presents an obvious greening trend, especially in middle and high latitudes of the Northern Hemisphere. Despite great spatial heterogeneity, vegetation greenness in arid and semi-arid regions on average experienced an increase in both global and regional scale, for example, in Central Asia, Inner Asia, Eurasia, Sahel, and Australia (Yang *et al.* 2014). The greening trend also appears in the Tibet Plateau and the arid regions in northwest China.

Potential drivers of vegetation change can be divided into two categories: natural and human factors. Natural factors include temperature, precipitation, photosynthetically active radiation, atmospheric concentrations of CO_2, etc. Human factors mainly include cultivation, afforestation, deforestation, urbanization as well as improved agricultural management practices. Generally, large scale variations are affected by climatic factors that represent the dominant limitation to plant growth. Elevated air temperature and increased water availability are the dominant climatic factors. Shule River Basin is a typical arid region in northwest China and is strongly disturbed by human activities. Compared with related research about Shiyang River Basin and Heihe river basin in the Hexi region, research about Shule River Basin is very limited. On the basis of MODIS NDVI data with 250-m spatial resolution and daily meteorological data, their research employed panel data models to analyze the vegetation dynamic and its response to climate change from 2000 to 2015. The purpose of their research was to reveal the characteristics, trend and spatio-temporal difference of vegetation change, and to quantify impacts of climatic factors on NDVI, which might provide some scientific basis for the comprehensive basin management (Yang *et al.* 2014).

Geographic information systems (GIS) and Remote Sensing (RS) have become critical tools in agricultural research and Natural Resource Management (NRM), yet their utilization in the study area is minimal and inadequate. Utilization of GIS spatial-interpolation techniques such as Inverse Distance Weighted (IDW) and Spline and Kriging interpolation techniques are some of the ArcGIS application tools essential for data reconstruction. To aid in understanding spatiotemporal occurrence and patterns of agro-climatic variables (e.g., rainfall), accurate and inexpensive quantitative approaches such as GIS modeling and availability of long-term data are essential (Wang *et al.* 2010b).

Vegetation, the main component of the terrestrial biosphere, is a crucial element in the climate system. Its variation is an important indicator of regional changes in ecology and environment. Understanding the relationship between the greenness of vegetation and climate is an important topic in global change research. It is understood that the vegetation in the Guinea Savanah Zone of Nigeria is sensitive and fragile to the global climate change (IPCC 2007, Maiangwa *et al.* 2007). Therefore, this region is a key area worthy of study to provide information in relation to global environmental changes. This explains why this study is utilizing spatial interpolation techniques to aid in the understanding of the influence of rainfall variability on vegetation dynamics.

Vegetation dynamics is affected by lot of factors, rainfall inclusive, this research assess vegetation response to early or late rainfall, quality of rainfall or the amount of rainfall received in a location over some selected years.

Sudanano-Sahelian Ecological Zone of Nigeria is the largest ecological zone in the country because this zone occupies almost one-third of the total land area of the country. It stretches from the Sokoto plains through the northern section of the high plains down to the Chad Basins (Odekunle *et al*. 2008). The whole zone is covered by Savanna vegetation consisting of Sudan and Sahel vegetation with the density of trees and other plants decreasing as one move northwards. These two zones are together referred to as the Sudano-Sahelian Ecological Zone (SSEZ) (Abaje *et al*. 2012).

1.2 Statement of the Research Problem

In a typical tropical country like Nigeria, rainfall varies spatially as the rain-belt follows the relative northward and southward movements of the sun. In this tropical situation of a marked seasonal rainfall regime, variability of the onset and cessation of rain is highly significant, and its estimation and prediction are necessary. A delay of 1 or 2 weeks in the onset is sufficient to destroy the hopes of a normal harvest (Odekunle, 2004a) and in return have adverse effects on vegetation dynamics. A false start of planting, encouraged by a false start of rainfall, may be followed by prolonged dry spells whose duration of 2 weeks or more may be critical to plant germination and/or growth. For instance, in 1973, the onset was earlier in Nigeria, which encouraged early planting and animal migration. However, this was a false onset, resulting in both crop and animal loss (Odekunle, *et al.* 2008). Although, some studies exist (Amekudzi *et al*., 2015; Hachigonta, *et al.*, 2008; Ibrahim, *et al.*, 2017; Jiang, *et al.*, 2011; Oladipo and Kyari, 1993; Tadross *et al*., 2005) on the onset and cessation of rains, substantial number of them were with respect to rainfed agriculture. Similarly, while some recent studies (Alli, *et al*., 2012; Sivakumar *et al*., 2014; Sultan and Gaetani, 2016 and Ibrahim, *et al*., 2018) have shown a general rise in the rainfall of the savanna region of Nigeria, there is rarely a study that links such rise with vegetation response. In addition, while literature abounds documenting the rate of desertification in the Sudano-Sahelian regions of West Africa (e.g. Kusserow, 2017, Reshma and Roy, 2018) and the links between rainfall and crop dynamics, how vegetation responds to rainfall changes at the beginning, at the end, and throughout a given season, is yet to be fully investigated in the Sudano-Sahelian region of Nigeria. Consequently, there still exists a knowledge gap with respect to vegetation dynamics in relation to onset and cessation of rainfall. There is also the need to establish whether, like in the case of crop production, vegetation response is influenced any differently by the quality of seasonal rainfall as it is by annual rainfall receipt.

1.3 Justification for the Study

Rainfall gives life to vegetation and other species that exist in the ecosystem. The Sudanano-Sahelian Ecological Zone of Nigeria over the years has been threatened with the effects of climate change and global warming as seen in the loss of vegetation and surface water resources through desertification. It is important to note that the change in vegetation dynamics has a great effect on climate change and global warming through land-atmosphere coupling mechanisms that influence convection processes on a large scale (Omotosho *et al.* 2000). This present research try to examine how rainfall variability, onset and cessation impacts the vegetation response. The study is important in such a way that it will allow researchers, scientists, farmers and pastoralists to know how the changes in vegetation affect their decision making. It is also important to note that the study was carried out with the use of remote sensing techniques, allowing the researcher to collect adequate data, simulate and model future scenarios and contribute to the efforts for identifying climate change adaptation options to guide sustainable livelihoods decisions. The research could also contribute important insights into the causative factors of security challenges as they affect the North East and help reduce the farmers-herdsmen clashes in the country.

1.4 Scope of the Study

The study covers the entire Sudanano-Sahelian Ecological Zone of Nigeria, with rainfall data collected from the following meteorological stations; Sokoto, Gusau, Yelwa, Katsina, Kano, Nguru, Bauchi and Maiduguri. The years under study is from 1981 to 2018 (37 years). Satellite images covering the entire Sudano Sahelian Ecological Zone was acquired for the entire years under study. The research was carried out using integrated Remote Sensing (RS) and Geographic Information System (GIS) Techniques. The factors considered in the study include, land-use/land-cover changes, rainfall intensity, rainfall spread throughout the year, onset and cessation of rainfall, temperature, and other factors as it affects vegetation response to rainfall variability.

1.5 Aim and Objectives of the Study

The aim of the study was to examine vegetation response to rainfall variability in the Sudano-Sahelian Ecological Zone of Nigeria. The specific objectives for the study are to:

i. Examine vegetation response to early or late onset of rainfall in the study area
ii. Capture the spatiotemporal patterns of vegetation response to quality of rainfall across the study area.
iii. Examine the patterns in lag relationships between vegetation response and interannual rainfall variability.

1.6 Research Questions

In order to achieve the objective of the study, the following guiding questions or lines of inquiry were proposed:

1. How does the vegetation in the Sudano-Sahelian Ecological zone respond to early and late onset of rainfall?
2. What is the spatiotemporal pattern of vegetation response to quality of rainfall across the study area?
3. What are the lag relationships between vegetation and inter-annual rainfall variability?

1.7 The Study Area

1.7.1 Location of the study area

The Sudano-Sahelian Ecological Zone (SSEZ) is located in northern Nigeria between latitude 10^0N and 14^0N and longitude 4^0E and 14^0E. This is the largest ecological zone in the country because this zone occupies almost one-third of the total land area of the country. It stretches from the Sokoto plains through the northern section of the high plains down to the Chad Basins (Odekunle *et al.* 2008). The average annual rainfall in this zone varies from less than 500mm in the extreme northeastern part to 1000mm in the southern sub-region in only about five months in the year, especially between May and September (Abaje, *et al.* 2012). The rainfall intensity is very high between the months of July and August. The pattern of rainfall in the zone is highly variable in spatial and temporal dimensions with inter-annual variability of between 15 and 20% (Oladipo, 1993).

The climate is dominated by the influence of three major meteorological features, namely: the tropical maritime (mT) air mass; the tropical continental (cT) air mass, and the equatorial easterlies. The first two air masses (mT & cT) meet along a slanting surface called the Inter-tropical Discontinuity (ITD). The equatorial easterlies are rather erratic and relatively cool air masses from the east in the upper troposphere along the ITD (Odekunle, 2006; Odekunle *et al*. 2008 and Abaje *et al*. 2012). The position of the ITD is a function of the season with considerable short-period fluctuations. Generally, however, it is situated well to the north of SSEZ in July and August, thereby allowing the area to be totally under the influence of mT air mass. It is located south of the zone from October to May, with the effect that the whole of SSEZ is covered by the cT air mass during this period (Odekunle *et al*. 2008). The whole zone is covered by Savanna vegetation consisting of Sudan and Sahel vegetation with the density of trees and other plants decreasing as one move northwards. These two zones are together referred to as the Sudano-Sahelian Ecological Zone (SSEZ) (Abaje *et al*. 2012).

1.7.2 Climate of the study area

The climate is of the dry tropical type. Rains may occur from mid-June to mid-September with virtually no rain from mid-September to mid-June. The mean rainfall varies from 100 mm at the border of the desert to 600 mm at the southern limit of the Sahel, in contact with the Sudanian ecological zone (600- 1,500 mm). The peak of the rainy season is August; duration of the rainy season varies from 1% months in the north to 3% months in the south. The number of rainy days (>O. 1 mm) varies from 20 to the north to 60 to the south. Rainfall variability' goes from 40% to the north to 25% to the south. Temperatures are high: average maximum rises to 40-42°C with maximums of 45°C occurring rather regularly in April-May. Average minimum drops to 15°C in December- January with absolute minimum rarely below 10°C. Potential evapotranspiration is extremely high: 1,800-2,300 mm/yr; class A pan evaporation is 3,000 to 3,500 mm/yr. Air humidity is extremely low during the dry season when it is almost constantly below 40% for 6 to 9 months, dropping to less than 10% every afternoon from March to May. From July to September, average air humidity is above 70%. (Omotosho *et al.* 2000).

1.7.3 Geomorphology of the study area

Altitude is low, usually 200-500m above sea level, with a few exceptions such as the Jebel Marra rising to 3,000 m at the border of Sudan and Chad. To the northern fringe of the Sahel, there are a series of mountainous massifs. The whole area is a gently rolling country with a flattened dune morphology. The extension of sand on the area dates back to the late Pleistocene, where a dry period occurred between 30,000 and 12,000 BP (Ogolian) extending the Sahara some 450 km to the south of its present limit; this period with followed by a humid phase: 10,000 to 3,000 BP (Chadian, Nouakchottian). (Omotosho *et al.* 2000).

1.7.4 Soils of the study area

Soils are predominantly sandy, yellowish-red in colour and slightly acidic (5<ph<6); they are luvic arenosols according to the FAO classification. Some black clay soils (vertisols) may occur in depressions. Shallow soils on fossil iron pans occur on sizeable areas in the southern half of the zone (ferric luvisols). Soils are deficient in phosphorus and nitrogen; organic matter content in the top layers is equal to or lower than 1%; potassium is usually in sufficient supply and trace element have rarely been reported as a problem for plant nutrition. Fertilization provokes high responses to phosphorus and nitrogen when these two elements are provided in conjunction. However the cost/benefit ratio of chemical fertilization is too low to make range fertilization an economically feasible proposition. (Omotosho *et al.* 2000).

1.7.5 Hydrology of the study Area

Runoff is very limited and occurs on short distances to fill up ponds and small lakes which generally last only a few weeks after the end of the rainy season. There are neither practically no endogenous rivers nor even wadis. Some exogenous rivers play an important role: The Kuyanbena in the Sokoto Plane, Also the Rima River Nigeria: the Logone-Chari system in Chad; and the Nile and its tributaries in the Sudan. These permanent exogenous rivers are of paramount importance in the livestock industry and agriculture. Deep ground waters are scarce and boreholes yield only small quantities of discharge, with few exceptions. This is due to the geological structure of the region, i.e., thin sedimentary layers on the metamorphic (granitoid) basement complex of the African shield; water is at the contact and in a thin layer of weathered metamorphic rock. (Odekunle, *et al.* 2008).

1.7.6 Vegetation of the study area

Vegetation is a savanna dominated by annual grasses: *Ari.\tidu mrrttrbiiis*, *A. cdscensionis*, *A. junicdutu*, *Schoenejeiditr gruciiis. Cer~chms ix'jior*-U.SC. . *prieurii*, *Ductyioctenium twg~ptilrm*, *Erugrostis trrmuiu*, *Diheteropogon hugerupii*, *Lolrdetici togoerisis*, etc., are dominant over huge areas. Shrubs and trees are 100 to 400 per hectare with three layers: 1-3 m, *3*-5 m, and 5-10 m. The main species are *Butlunites ueGqyptitrctr. H~~~hue/~c thebuicu. Commiphoru ujricunu*, *Acuciu .w~~c11A.* . SCIIY~II~*A*, . *ehren* hergiunu . *A* . *tortiiis*, *Moeruu crussijoiiu. Guieru .se~lt~s~(i4~1.si.As.d unsoniu digitutu*, *Combreturn ~ligricwls*, *C. ucuietrtum. C. girrtinowm*, *C. ghuzuiense*, *C. I,iic,i.tiritliirrii. G're\~ki tentix. G. bicoior*, *Scierocuqu hirreu*, *Pteroc*clrpll.s iuce~~s. Buuhiniu rxjescens*, *Piliosrigmu reticuiutu.* The Sudano-Sahelian subzone is an area of farming and cattle raising. The main crops are millet *(Pennisetum o.phoide.s)*, and cow pea *(Vignu sinensis)*, with some sorghum in retreat flooding cultivation and some cassava. Perennial grasses are vestigial *(Aristidu puliidu, A. longij- Ioru. A . sti1wide.s. Andropo,qon guyunus. Cenchrus ciliuris, c'~~~~~..sol)c)slo)l~r~m ido.sos (= C. cucheri)* except in the most arid parts of the Northern Sahel where large areas of steppe vegetation are dominated by *Punicam~urgidum* and *Lusiunrs hirsutirs.* Since perennials are only found in the driest and the wettest places, it is believed that the present annual grass vegetation is a fire disclimax. (Odekunle, *et al.* 2008).

The Sudano Sahelian receives 400 to 600 mm of annual precipitation and the rainy season lasts 3 to 4 months (rainy season is understood as the period where rain is equal to or greater than 0.5 PET or 50 mm/month). Vegetation is characterized by a *Combretuceue* savanna where trees and shrubs from this family are dominant: *Combretum glutinosum*, *C. nigricuns*, *C. uculeutum*, *C. micrunthum*, *C. ghuzulense*, *Girieru senegulensis*, etc. ; other characteristic species are: *klerocuryu birrea*, *Bombux costutum*, *Sterculiu setigeru*, *Grewiu bidor.* Characteristic dominant grasses are the annuals: *Diheteropogon hugerupii*, *Loudetia togoensis*, *Andropogon yseudupricus. Ctenium eleguns*, *Pennisetum pedicellutum*, *Schizuchyrium exile;* some perennials are found in wetter places: *Alldropogon guyunus*, *Punicum unubuptistum.* (Omotosho *et al.* 2000).

1.7.7 People and land use

The Sudano-Sahelian subzone is an area of conflict between the nomads and settled farmers. As in many arid zones in the world, the competition between rangelands and cropland results in more and more rangeland being cleared in order to meet the food requirements of a fast growing population, since population growth is of 2.5 -3.0% per annum in the settled communities and 1.5-2.0% among the pastoralists; i.e., the population of settled farmers doubles every 23-28 years whereas the nomadic population doubles in 35-46 years, in the wrong assumption that nomads do not become settled farmers. An unknown number of them obviously do, in particular consecutive to the 1970-73 drought. The people are predominantly Fulani, Kanuri and Hausa Speaking population (Omotosho, *et al.* 2000). This ecological zone house 25% of the Nigerian population and supports three-quarter of cattle population, about 75% of the goats and sheep, and almost all the donkeys, camels and horses found in the country. Major cereals such as cow peas, groundnut and cotton are the main crops grown in the region (Odekunle *et al*. 2008).

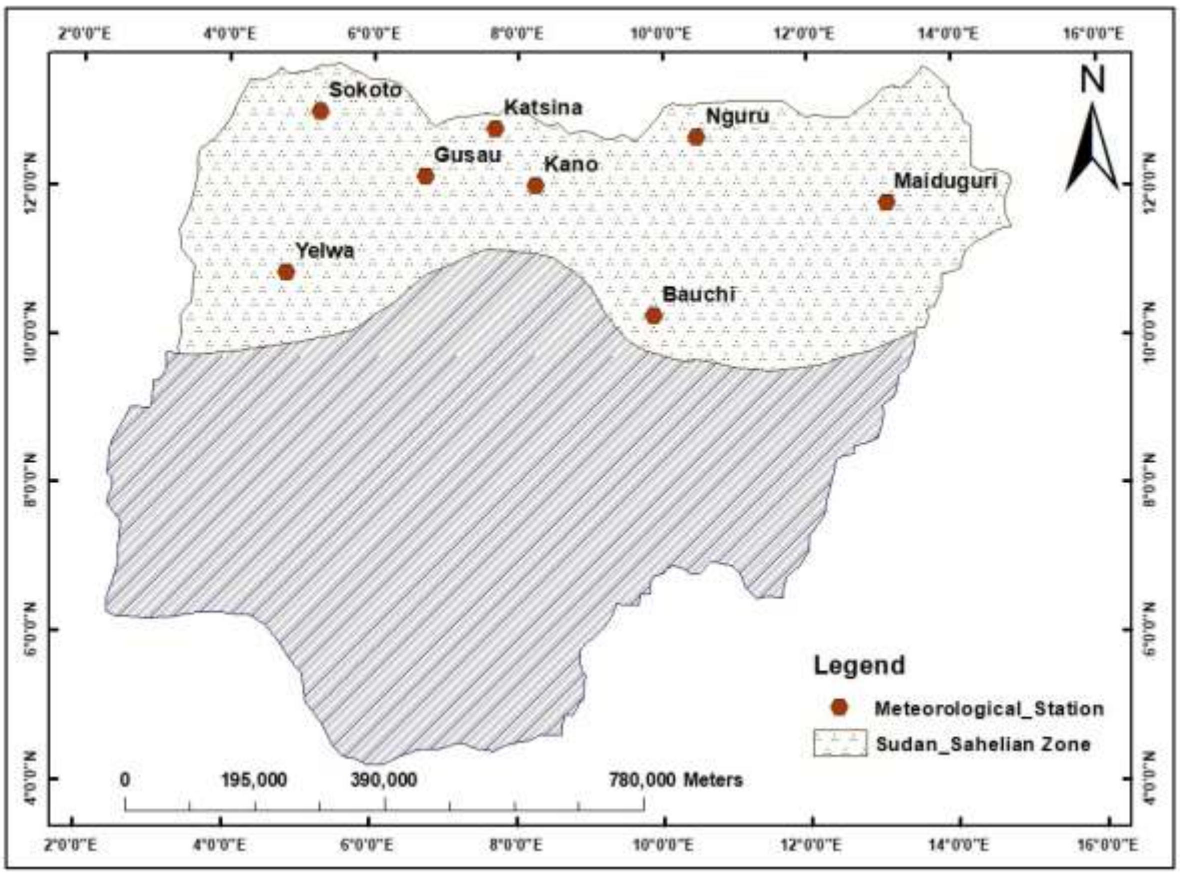

Figure 1.1: Sudano Sahelian Ecological Zone of Nigeria (Study Area)

Source: GIS Lab, FUT Minna, 2019

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Preamble

This chapter reviewed relevant literature related to the topic of study. It touches the concept of rainfall, rainfall variability, rainfall quality index (RQI) land-use/land-cover changes (LULC), vegetation dynamics, slow natural induced changes by human, deforestation, population, resource used dynamics, marginal dynamics, and livelihood sustainability in context of SDGs, security implication of vegetation loss, Remote Sensing (RS) and Geographic Information System (GIS) applications, and other factors as it affects vegetation response to rainfall variability.

2.2 Conceptual Framework

2.2.1 Concept of rainfall

In a typical tropical country like Nigeria, rainfall follows the relative northward and southward movements of the sun. In this tropical situation of a marked seasonal rainfall regime, variability of the onset and retreat of rain is highly significant, and its estimation and prediction are necessary. A delay of 1 or 2 weeks in the onset is sufficient to destroy the hopes of a normal harvest or an erratic change in vegetation dynamics (Odekunle, 2004b).

According to (Tucker, 2004) rain is liquid water in the form of droplets that have condensed from atmospheric water vapor and then become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants and crop irrigation.

The primary source of water for agricultural production for most of the world is rainfall. Three main characteristics of rainfall are its amount, frequency and intensity, the values of which vary from place to place, day to day, month to month and also year to year. Precise knowledge of these three main characteristics is essential for planning its full utilization (Odekunle, 2004a).

2.3 Rainfall Variability

Rainfall variability is one of the most important factors determining variability in agricultural production. This has severe consequences for individuals and societies, causing crop failures, loss of livestock, and associated loss of income and even famine. It also results in considerable environmental degradation particularly when combined with inappropriate management strategies (Hammer 2000 and Allan 2000). Economic pressure on farmers often exacerbates the downward spiral of land degradation via irreversible trade-offs between short-term economic gains and long-term sustainability. In this context (Basher 2000, Hammer 2000, Hansen 2002 and Podestá *et al.* 2002) show that an understanding of rainfall variability is essential for appropriate agricultural risk management and (Nelson *et al.* 2002) describe how understanding of ENSO-related rainfall variability is becoming increasingly accepted in tactical risk management approaches to agriculture. However, there is also an increasing interest in understanding longer-term variability and associated strategic management and investment options (Meinke and Stone 2004)

Studies of rainfall fluctuations in West and Central Africa show a tendency towards aridification from 1970 onwards. Initially observed and studied in the Sahelian regions, this drought also appeared in wetter regions, near the Gulf of Guinea (Sircoulon, 1990; Hubert & Carbonnel, 1987; Nicholson *et al.*, 1988; Mahé *et al.*, 2001;). The rainfall deficit, observed over several consecutive years, has reduced flows of the region (Sircoulon, 1990, Odekunle 2004b).

Most studies (Leiterer 2009, Usman & Abdulkadir 2019) in West and Central Africa usually compare the rainfall levels during the 1950s and 1960s to those of the 1970s and 1980s: the former corresponding to a wet or excess period as far as rainfall and flow are concerned, whereas the latter correspond to a dry or deficit period. The drought that occurred since 1970 differs from the earlier ones in its duration, intensity and regional extent (Sircoulon, 1990). As for the 1990s, only a few regional studies of water availability have been carried out to the researcher's knowledge. Nevertheless, many people seem to agree that also during this decade a water deficit was observed.

Mahé *et al.* (2001) analyzed annual rainfall over 1951–1989 in West and Central Africa. They identified eight climatic sectors, which could be regrouped in six large geographical areas, and calculated annual pluviometric indexes (standard deviation values): Sahel ("NWSahel", "Central Sahel" and "East Sahel"), the Guinean mountains ("Guinea"), the Guinea Gulf ("North coast"), the Cameroon mountains ("East Cameroon"), the western equatorial region ("Center West") and the eastern equatorial region ("Center East"). The results obtained are confirmed by those of Servat *et al.* (1998). They focused on the existence of a deficit period since 1970, affecting the whole of West Africa. Central Africa seems to have been less affected by this phenomenon and the said climatic fluctuation does not seem to depart from the normal range of natural variability. Generally speaking, in West and Central Africa, after 1970, the mean annual rainfall was about 15–20% below the values for the reference period of 1950–1989. In the early 90s, there seems to be stability in rainfall in term or onset and cessation and with a great variability from the year 2000 and above.

2.3.1 Rainfall variability in the Sudano-Sahelian Ecological Zone of Nigeria

In Nigeria, the rainfall in recent years has witnessed significant variability leading to extreme weather events such as the 2012 flood that devastated essential components of human livelihoods most especially at the bank of River Niger and Benue with the agricultural sector worse hit with loses put at billions of naira (Nigeria Post Disaster Needs Assessment of 2012 Floods Report, 2013). An in-depth understanding of contemporary and historical rainfall trends as well as variation is of utmost importance to be able to take proactive adaptation strategies. Furthermore studies associated with the distribution and analysis of rainfall are sin qua non to the planning and management of irrigation projects, reservoir operations changes in water requirements and agricultural production.

The Sudano-Sahelian Ecological Zone is two zone mostly combined together because of their proximity to one another, The Sudan zone is found in the North West. It has an annual average rainfall of about 700-1100 mm with a prolonged dry season of about 6-9 months. While the Sahel is located in the extreme northeastern part of the country. In this zone dry season can last for as long as 9 months and the maximum annual rainfall is about 600 mm (Maiangwa 2007). The locations in this zone considered as study area include: Maiduguri, Nguru, Katsina, Gusau, Sokoto, Kano, Bauchi, and Yelwa.

2.3.2 Rainfall quality index

Rainfall Quality Index (RQI) is the estimate of the quality of all kinds of precipitation data that are generated in the data processing chain. RQI are measure either by using the Algorithm for total QI determination by the determination of quality parameter, at the outset proper parameters that most significantly characterize the quality of precipitation data should be selected. For each quality parameter individual quality index QI_1 is computed. It is assumed that the relationship between particular quality parameters and relevant individual quality indexes are linear and values $x$of each of the i $-$parameter X vary between minimal and maximal value ($X_1$and X_0). In determination of quality parameters, which are to characterize all the kinds of data, will be divided into groups, each of this is connected to measurement geometry that depends on scan strategy (Tadross, 2005).

$$RQI = \frac{x(i)}{(X_I + X_0)} \text{......... Eqn 1}$$

2.4 Vegetation Dynamics

The majority of Sudano-Sahelian Ecological Zone is characterized as semi-arid region and thus susceptible to degradation or even desertification; semi-arid regions are subject to regular seasonal dryness and large inter-annual variability in precipitation. This results in variable vegetation cover on annual and inter-annual timescales, as both natural ecosystems and non-irrigated crops rely on soil moisture derived from seasonal rains or springtime snow melt (Evans *et al.*, 2004; Weiss *et al.*, 2004).

Acceding to (Stefanie *et al.*, 2005) they conclude that Climate-induced variability in semi-arid vegetation is a matter of both ecological interest and economic concern, as strong sensitivity to climate can result in rapid land use change and vulnerability to human-induced degradation, Also (Evans *et al.*, 2004) opined that Climate is one of the most important factors affecting vegetation condition. Therefore, evaluation of the quantitative relationship between vegetation patterns and climate is an important object of applications of remote sensing at regional and global scales. The Normalized Difference Vegetation Index (NDVI) is established to be highly correlated to green-leaf density and can be viewed as a proxy for above-ground biomass (Tucker *et al.*, 2004).

The causes of variance of relationship between NDVI and its explanatory variables are known to be spatial variations in properties such as vegetation type, soil type, soil moisture. Vegetation cover processes play a crucial role in the water balance over a wide range of spatio-temporal scales (Liu 2012). Unfortunately, vegetation dynamics and their interaction with climate are still largely unexplored. Under this framework, satellite data have proved to be very useful for collecting realistic data about land use change and vegetation trends from local to global scale (IGBP-IHDP, 1999). In particular, NOAA-AVHRR (Advanced Very High Resolution Radiometer, onboard National Oceanic and Atmospheric Administration satellites) data can provide useful information on such changes over climatic spatio-temporal scales. The long time series of observations can be very useful for studying vegetation dynamics over inter-annual scales.

Vegetation is one of the most important parameters for human environment assessment and monitoring due to their specific role in geo-sphere, biosphere and atmosphere interactions and plays an important role in global climate change. The vegetation amount controls the partitioning of incoming solar energy in the sensible and latent heat fluxes and consequently changes in vegetation amount will result in long term changes in the global and local climate, which will in turn affect the vegetation growth as a feedback. Vegetation has special characteristics due to its distinct annual and seasonal changes it is a sensitive indicator on the study of global and local environment change caused by climate or human activities. Thus it comes as no surprise that the detection and quantitative assessment of green vegetation is one of the major applications of remote sensing.

In this decade, human beings consequently realized the significance of global change monitoring, several international organizations such as IGBP, HDP and WCP, have launched very important programs, among which land cover and vegetation change monitoring is a key project. The method for studying land use and vegetation change has developed very quickly as the progress of remote sensing technique in the world.

The Normalized Difference Vegetation Index (NDVI) is the most widely used satellite-derived metric for vegetation monitoring and ecological modeling, providing a good measure of vegetation growth, or photosynthetic capacity. NDVI is the normalized ratio of red and near-infrared (NIR) reflectance, which is generally considered as a good indicator of vegetation activity (Jiang 2011). It has been used to detect the vegetation dynamics and land cover changes at the regional and global scales.

2.4.1 Vegetation index trends for african sudano-sahelian zone

Stefanie et al 2005, in their study found that contrary to assertions of widespread irreversible desertification in the African Sahel, a recent increase in seasonal greenness over large areas of the Sahel has been observed, which has been interpreted as a recovery from the great Sahelian droughts. Their research investigates temporal and spatial patterns of vegetation greenness and rainfall variability in the African Sahel and their interrelationships based on analyses of Normalized Difference Vegetation Index (NDVI) time series for the period 1982–2003 and gridded satellite rainfall estimates. While rainfall emerges as the dominant causative factor for the increase in vegetation greenness, there is evidence of another causative factor, hypothetically a human-induced change superimposed on the climate trend.

Houborg et al 2003, in their study examine the “Intraannual vegetation dynamics as potential indicator for environmental change in the West African Sahel Zone” the Studies identified desertification and land degradation as a possible cause for persistent drought in the Sahel. The specific vegetation dynamics in the Sahel are good indicators for this kind of environmental change. Due to the scattered availability of ground truth data in huge parts of the Sahel, EO data might provide the only reliable means for sound analysis and detection of long-term changes. Their study focuses on vegetation dynamic monitoring over the Iullemeden Aquifer (SAI) using ENVISAT MERIS data. The biophysical vegetation variables FAPAR and NDVI were analysed in terms of the vegetation changes within one growth period. It turned out that these information are important indicators to make reliable statements on ecological changes. They concluded that considering that in future similar products are available, it’s an outstanding tool to monitor the whole Sahel zone with a high temporal resolution to analyse vegetation dynamics in terms of climate change and human impact.

Brandt *et al.* (2014), in their study “Local Vegetation Trends in the Sahel of Mali and Senegal Using Long Time Series FAPAR Satellite Products and Field Measurement (1982–2010)” they find out that Local vegetation trends in the Sahel of Mali and Senegal from Geoland Version 1 (GEOV1) (5 km) and the third generation Global Inventory Modeling and Mapping Studies (GIMMS3g) (8 km) Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) time series were studied over 29 years. For validation and interpretation of observed greenness trends, in their study two methods were applied: (1) a qualitative approach using in-depth knowledge of the study areas and (2) a quantitative approach by time series of biomass observations and rainfall data. Significant greening trends from 1982 to 2010 were consistently observed in both GEOV1 and GIMMS3g FAPAR datasets. Annual rainfall increased significantly during the observed time period, explaining large parts of FAPAR variations at a regional scale. Locally, GEOV1 data reveals a heterogeneous pattern of vegetation change, which is confirmed by long-term ground data and site visits. The spatial variability in the observed vegetation trends in the Sahel area are mainly caused by varying tree- and land-cover, which are controlled by human impact, soil and drought resilience. A large proportion of the positive trends are caused by the increment in leaf biomass of woody species that has almost doubled since the 1980s due to a tree cover regeneration after a dry-period. This confirms the re-greening of the Sahel. However, degradation is also present and sometimes obscured by greening. GEOV1 as compared to GIMMS3g made it possible to better characterize the spatial pattern of trends and identify the degraded areas in the study region.

Eklundh and Olsson, (2003), in their study “Vegetation Index for the African Sahel 1982-1999” Pathfinder AVHRR NDVI data was analyzed for the African Sahel to study recent trends in vegetation greenness. A strong increase in seasonal NDVI was observed over large areas in the Sahel during the period 1982 – 1999. The increase was interpreted as a vegetation recovery from the drought periods of the 1980’s. Although strong shifts in satellite overpass times have led to shifting solar zenith angles (SZA) over the time period, only minimal influence of SZA’s on the Pathfinder NDVI was found in their data. A preliminary analysis of rainfall data indicates increasing rainfall during the period of their study. They concluded that the observed trends may have important implications to the Sahel including changes to the water cycle, energy exchange and carbon storage.

2.4.2 Land use and land cover changes

Dominant land use and land cover changes studies in the study area has been carried out by various researchers to examine the extent of land cover changes in the Sudano-Sahelian Ecological Zone. Hansen 2003 examines the Impact of land Use on Sahelian climate, he opined that this changes are adverse and has threatened the ecosystems and ecology of the region, Also Alli *et al.* (2012) Study focused on Land used land cover changes in the study area, it concluded that this change have transformed ecological balance, anthropogenic and livestock impacts. A number of General Circulation Model (GCM) experiments have shown that changes in vegetation in the Sudan Sahel Ecological Zone are majorly linked to reduction in rainfall, in some studies, the climate sensitivity is large enough to trigger drought of severity observed since the late 1960s. Tadross *et al.* 2005) in their study assessed the impact of land use change on Sahelian Climate using a GCM forced by the estimates of land use in 1961, 1996 and 2015. The decreases by 4.6% (1996) and 8.7% (2015). The decrease are closely linked to a later onset of the wet season core in July.

Satellite sensors have played an important role in the investigation of vegetation condition at regional and continental scales. Images from the Advanced Very High Resolution Radiometer (AVHRR) onboard National Oceanic and Atmospheric Administration (NOAA) satellites have had a key role in this activity because of their frequent observation (daily), large area coverage (continental) and historical record (>20 years). Vegetation condition is typically indicated using the Normalized Difference Vegetation Index (NDVI) derived from the reflectance in the visible (VIS) and near-infrared (NIR) bands i.e. $NDVI = \frac{(R_{NIR}-R_{VIS})}{(R_{NIR}-R_{VIS})}$ Where R_{NIR} and R_{VIS} are reflectance of the two bands. Numerous studies have shown that NDVI is proportional to the fraction of absorbed photosynthetically active radiation, leaf area, vegetation fraction, and net primary productivity; therefore, the index has been successfully applied to measure and monitor vegetation greenness (Tucker *et al*. 2004, Stefanie *et al*. 2005 and Yengoh *et al*. 2014).

2.4.3 Deforestation

Wide spread report of disappearing tree species and senescing savanna parklands in the Sudan Sahel have generated debate, a vigorous debate whether rainfall variability or severe human and livestock pressure is principally responsible. Many of the tree taxa are closely associated with human settlement and farming suggesting that the parkland ecosystem may not be natural vegetation assemblage. Myneni (2005) in his study assess the possibility that human activities promoted the spread of edible fruit into the Sudano-Sahelain areas during high rainfall periods. He used the methods cultivated savanna parklands and adjacent forest and transitional landscapes were inventoried at 27 sites in five countries. Result species composition and spatial distribution data indicate that the parkland ecosystem is significantly shaped by human activities. Rainfall isohyets at the northern range limits of parkland species shifted southwards in the late 20th century, crossing the critical 600-mm mean annual rainfall threshold for Sudanina flora. Sultan and Gaeteni (2016) in their study examines the sensitivity of climate to changes in vegetation over and land use in South Sudan, the cause lies on the effect of deforestation on precipitation and surface especially during the rainy season. The experiment indicates that the vegetation changes affect precipitation and surface temperature in Southern and Central Sudan Sahel significantly all through changes are imposed only in the South, the precipitation during the rainy season (June-September) was reduced in the perturbed region.

2.5 Human Induced Changes

Human induced changes is slow but with more devastating and lasting effect on the environment, it happens even sometime unnoticed and it is as a result of accumulated stress and strain on the environment, environmental changes are mostly strongly linked to human displacement and related conflicts (Omobowale, 2014). Mohamed *et al.* 2016 works on ecological zone degradation in the Sudan Sahel Ecological Zone Through Human Induced changes, it was found that majorly has population increases, there is need for human expansion and the completion for food and shelter has had great impacts on the environment, the vegetation has undergone remarkable changes, this changes occurs in most of the predominant ecological zone, particularly those which are currently affected by environmental degradation and desertification due to erratic change in onset and cessation of rainfall which can also be human induced. During the last 5 decades the environment devastating changes that have undermined food security, which is strongly linked to human displacement and related conflicts.

2.6 Livelihood Sustainability in Context of the SDGs

One of the goal of the SDG is to tackle poverty, this is in lie with the goal 1 of the SDG which is "no poverty", where as a major factor in poverty is livelihood, which include the various resources and activities that allow a people to live. Livelihood systems are at the heart of poverty reduction and food security issues in different policy environment. Livelihoods are 'means of making a living', the various activities and resources that allow people to live. Different people have different lifestyles and ways of meeting their needs. Households perform various activities to gain and maintain their livelihoods. The nature of these activities depends on the availability of assets, resources (including climate), labour, skills, education, social capital and gender. Within a household, members perform different activities in accordance with their culturally defined gender roles and age. Livelihood comprises the capabilities, assets (including both material and social) and activities required for a means of living. Livelihood is sustainable when it can cope with and recover from stress and shocks (drought, flood, war, etc.), maintain or enhance its capabilities and assets, while not undermining the natural resource base. Usman and Abdulkadir (2019). Therefore, a sustainable livelihood is expected to be a panacea for poverty.

Livelihoods are carried out within the individual's social, natural and physical environment. According to Baro (2002), livelihood systems encompass means, relations, and processes of production, as well as household management strategies. The resources and values of specific physical and social environments determine the character of livelihood system components. Poverty reduction and food security are not the only goals of rural populace, the need for a sustainable livelihood is more central since it reflects the ability to take hold of other issues that guarantees good life. In rural areas and even in rural Nigeria, households' livelihoods are intricately tied to the natural environment. This is especially the case in Nigeria where over 65% of rural dwellers are involved in some form of agricultural activities. Livelihood options emerge based on the resources available and the potential of the rural households to tap into the resources. This has a direct pointer to the goal 2 (no hunger) and goal 11 (sustainable cities and communities) of the SDG's.

Usman and Abdulkadir (2019) in their study "Livelihoods Sustainability in Agriculture-Intensive Semi-Arid and Dry Sub-Humid Areas of West Africa - Pointers from Nigeria" opined that Agricultural intensification has been adopted as a viable option for Poverty eradication and hunger, attainment of food security, socio-economic wellbeing as well as sustainable livelihood across the West Africa sub-humid and semi-arid zones, they argued that if really there is need to identify and address the challenges of sustainable livelihoods in the agriculture-intensive semi-arid and dry sub-humid zones of West Africa, In their result the authors comes of up with various environmental uncertainties that threaten the sustainability of agriculture and human livelihoods across the ecologically fragile regions of West Africa, the research was able to identified the major challenges, adaptation and mitigation approaches to environmental constraints, and requirements for reducing risk, enhance agricultural resilience as well as livelihoods in the zones. They arrived at the based on the fact that largely, the use of adequate and accurately derived environmental information is crucial for increased agricultural productivity, sustainability of economic diversification and human livelihoods and by implication, enhanced regional and national security. Their research is a pointer to goal 1 (no poverty), goal 2 (no hunger) goal 12 (responsible consumption) and goal 15 (life on land).

2.7 Security Implication of Vegetation Loss in the Sudano-Sahelian Ecological Zone

According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA Annual Report 2012) Political instability has plagued some of the Sudan Sahel's region for years. In Mali, Chad, Nigeria and others, for example in Mali the military coup of March 2012 brought an abrupt halt to 20 years of stable democracy. In its aftermath, terrorists who had occupied most of the northern region started heading south, intent on taking control of the whole country. In January 2013 a French-led and Chad-supported intervention stopped their advance. The conflict compounded the security and humanitarian crisis, in part by disrupting supply routes and causing food shortages. In a region with porous borders, a political or security crisis in one country is often a serious threat to neighbours. These borders have benefited criminal networks and drug traffickers. The UN Office for Drugs and Crime (UNODC) has estimated that major illicit flows linked to criminal activities in the Sahel amounted to $3.8 billion annually.

A number of studies identified socio-political causes, specifically poverty, underdevelopment and waste of human and financial resources, behind older concerns such as desertification, arable land erosion and deforestation (Frederick, 1993). Recently, climate change concerns combine with the older, broader environmental concerns. However, even before trying to clarify relationship between these variables, the interactions among all environmental factors and between environmental and socio-political factors already promise to be complex and multidimensional.

2.8 Remote Sensing and Geographic Information System Application

Remote Sensing (RS) and Geographic Information Systems (GIS) have become critical tools in scientific research and Natural Resources Management (NRM), yet their utilization in the study area is minimal and inadequate. Utilization of GIS spatial-interpolation techniques such as Inverse Distance Weighted (IDW) and Spline and Kriging interpolation techniques are some of the ArcGIS application tools essential for data reconstruction. To aid in understanding spatiotemporal occurrence and patterns of agro-climatic variables (e.g., rainfall), accurate and inexpensive quantitative approaches such as GIS modeling and availability of long-term data are essential. Most meteorological data in the study area are inconsistent, unrecorded, or missing, leading to more discrete and unreliable datasets for analysis. Besides the main stations themselves being several kilometres from the target area. These call for use of data reconstruction through interpolation.

The long-term observations of spatiotemporal variations on the Earth's surface improve the understanding of variability required by numerous global change studies to explain annual and inter-annual trends to understand the climate change impact on the bio-atmosphere (Sultan & Gaetani 2016). Likewise, accurate quantitative estimation of vegetation biophysical characteristics is necessary for a large variety of agricultural, ecological, and meteorological applications (Hansen 2002 and Hourbog *et al.* 2003). Due to its synoptic view, global coverage and daily repetitiveness, remote sensing provide relatively inexpensive source of information. It has been recognized as a reliable and practical method for various bio-physiological environmental variables estimation, and the fragility of bio-ecosystem diversity evaluation (Hansen 2002, Weiss and Baret 2004 and Cohen *et al.* 2003). Many remote sensing devices operating in the visible (blue, green and red) and near infrared (NIR) regions of electromagnetic spectrum can discriminate among several properties of vegetation cover (Bannari *et al.* 1995). In fact, vegetation cover assessment and mapping was one of the first uses of satellite remote sensing imagery and has been one of the most common ever since. In this perspective, the monitoring of Earth vegetation cover involves the utilization of vegetation indices as a radiometric measurement of spatial and temporal patterns of vegetation photosynthetic activity (Yengoh, 2014). These play an important role in the derivation of biophysical parameters, such as percentage of vegetation cover, leaf area index (LAI), absorbed photosynthetically active radiation (APAR), the rate of the biomass production, etc. Their interest lies in the detection of changes in land use and the monitoring of the seasonal dynamics of vegetation on local, regional and/or global scales. In the literature, over fifty vegetation indices were developed to measure the vegetation cover in different applications and under quite particular conditions, mainly in forestry and agriculture. However, the Normalized Difference Vegetation Index (NDVI), which is spectro- radiometric reflection measurements in the red (R) and NIR wavelengths, is the most popular and the most used index, especially for vegetation cover investigation at the global scale (Mather, 2004).

Additionally, the relationship between vegetation mapping and Geographic Information System (GIS) is mutually beneficial for ecological system assessment and environmental modelling. The integration of auxiliary data in GIS environment with derived biophysical parameters from remote sensing images has greatly improved the vegetation mapping process (Curtis *et al*. 2002). Indeed, the vegetation indices are used extensively within GIS for environmental modeling purposes, climate change impact analysis, land use change detection, etc. The integration of these biophysical parameters through the GIS applications has greatly improved the ecological environmental study process and enhanced the ability to detect and to measure changes in this environment in time over long periods and vast areas (Wang *et al.* 2010b). Sudan Sahel Ecological Region is a verse land area that covers a wide range of area, in studying this type of large land scape, a tool that can give real and repetitive result is required. Therefore, remote sensing becomes an excellent alternative and the only feasible data source that can be used to map changes in vast and remote areas, particularly in developing countries where cartographic documents are inexistent, incomplete or out of date. Moreover, the synergy between remote sensing and GIS provides a valuable information for analysis, automated mapping and integration of several thematic maps to obtain useful data about environmental changes (Verbyla 2003) and also it was sited in (Harvey 2008). The main objectives of their study are to measure the ecological zones change and degradation over the study area throughout the last five decades (1958-2010). To achieve these objectives, SPOT-VEG NDVI data acquired between 2000 and 2010 were used to produce a vegetation map that was integrated with rainfall maps in GIS to produce updated ecological zones map. Then, the latter was compared to that established in 1958.

How vegetation responds to rainfall changes at the beginning, at the end, and throughout a given season, is yet to be fully investigated in the Sudano-Sahelian region of Nigeria. Consequently, there still exists a knowledge gap with respect to vegetation dynamics in relation to onset and cessation of rainfall. There is also the need to establish whether, like in the case of crop production, vegetation response is influenced any differently by the quality of seasonal rainfall as it is by annual rainfall receipt. It also try to examine how rainfall variability, onset and cessation impacts the vegetation response. The study is important in such a way that it will allow researchers, scientists, farmers and pastoralists to know how the changes in vegetation affect their decision making and contribute to the efforts for identifying climate change adaptation options to guide sustainable livelihoods decisions. The research could also contribute important insights into the causative factors of security challenges as they affect the North East and North West and help reduce the farmers-herdsmen clashes in the country.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

This section deals with the materials and methods that was used for this research, In this research, the Advanced Very High Resolution Radiometer (AVHRR) of LANDSAT acquisition and Moderate Resolution Imaging Spectroradiometer (MODIS), NDVI (Normalize Differential Vegetation Index) data, along with yearly and monthly precipitation data of different synoptic Station in the Sudan Sahel Ecological Zone was used to examine the feedback mechanisms between rainfall and vegetation:

3.2 Type and Source of Data for the Study

The data for this study includes remotely sensed satellite imageries (MODIS, Landsat 8, Rainfall and Climate Research Unit (CRU) data), conventional maps and literature. The data and their sources were given in Table 3.1

Table 3.1: Type and Source of Data for the Study

S/N	Type of Data	Source	Amount/Scale/Resolution
1	MODIS	Earth Data	30 meter resolution
2	Satellite-derived Rainfall Data	Climate Research Unit	Gridded data at 15 meter resolution, 1981-2018 (37Years) Converted into Pentads
3	Temperature Data	Earth Data	1981-2018 (37Years) Converted into Pentads
4	Landsat 8	USGS Earth Explorer	30 meter resolution

3.3 Instrumentation for Data Collection and Analysis

Several materials were used to collect the data and for data processing and analysis. The equipment includes: Hardware, Software, slip of inventory, pencil, and pen. The following hardware and software was used:

3.3.1 Image processing and classification

i. Land Use and Land Cover (LULC) plays important role in the vegetation response to rainfall variability. LULC map for this study was extracted from a mosaicked Landsat 8 Operational Land Imager (OLI) series through supervised classification of the false colour composite of the bands 4, 3 and 2 to obtain the land use category in ERDAS IMAGINE 2015 software platform. Supervised classification was performed using maximum likelihood classifier since it is a land-use/land cover classification was used to produce the output layer. This method of classification involves the procedure of identifying pixels possessing the same spectral features. The pixels was grouped and organized into land cover classes. The classes will includes built-up, vegetation, bare land, agricultural area, and water bodies as suggested by U.S.G.S classification (Anderson's Classification, 1971)

ii. Spatial and temporal resolution, the essence of introducing MODIS is that MODIS images comes with preprocess features such as rainfall, temperature data, relative humidity and the like, aside from that MODIS Images are easy to process and any indices is easily seen.

iii. Due to discrepancies between LANDSAT Images and MODIS, cross calibration was also done to fuse the two datasets.

iv. Dry and wet season images of the study area was also required, this images were acquired in different time of the years that covers the years under study.

v. Rainfall data was also acquired, the cumulative precipitation (mm) in the present year (CP_0), and since November/December i.e. dry season (CP_1) and April/May i.e. wet season (CP_2) of the previous year until the month when the NDVI value was recorded

3.4 Technique for Data Analysis

Different analysis was carried out in this research in line with the objectives of the study, they are highlighted below:

3.4.1 Examination of vegetation response to early or late onset of rainfall in the study area

In order to achieve the objective I of the study, Intra Seasonal Rainfall Monitoring Index (IRMI) was used, it was developed by Usman and Abdulkadir (2012) as a tool for determining the real onset date of the summer monsoon rains. IRMI is computed on a pentad by pentad basis from the beginning of May using the expression:

$$IRMI = \frac{(C_{pt})^2}{(hpt \times Nb \times 100)} \qquad 3.1$$

Where: C_{pt} = cumulative pentad rainfall since May 1

hpt = is the highest pentad total rainfall since May 1

Nb = is number of breaks in rainfall (pentads with less than 5 mm of rainfall)

100 = working factor

IRMI model has been used to determine the effective onset of the rain at the individual synoptic station.

After the IRMI has been computed, NDVI was computed in ArcGIS 10.7 to show Change detection (LULC) for changes that occur in both wet and dry season. Finally the IRMI value was correlated against the NDVI result.

3.4.2 Spatiotemporal patterns of vegetation response to quality of rainfall across the study area

In order to achieve objective II of this study, Monsoon Quality Index (MQI) developed by Usman, (2000) was used. MQI is a measure of the quality of rainfall received in terms of both annual amount and seasonal spread.

MQI is expressed as:

$$MQI = \frac{(r_{mmi} \times Nb_i)}{(R_i)^2} \qquad 3.2$$

Where: i = Year identifier

r_{mm} = Highest monthly rainfall total

R = Annual monthly rainfall total

N_b = Number of „breaks" in rainfall. A break is taken as any pentad period with less than 5mm of rain.

The index is small if the annual amount is high and the rains is not concentrate in any month-in other words, if the spread of the rain is good. While the index value is high for the year with the smallest annual total and the most concentration of the rains in any single month.

The estimated MQI values was then interpreted according to the MQI classification table of Usman (2000) where:

Table 3.2: Monsoon Quality Index Classification

Class	MQI Value	Classifications
Class 1	<0.005	Good rainfall performance
Class 5	>0.02	Extremely poor rainfall performance

Source: Adapted from Usman 2000

Statistically, the derived onset, cessation dates and length of the rainy season and frequencies of pentad breaks, annual rainfall total and MQI values were all subjected to time trend analysis. Principal component analysis and the correlation analysis, estimated mean values and best fit trend line equations will was plotted for each rainfall parameter using graphs and charts.

3.4.3 Examination of the patterns in lag relationships between vegetation response and interannual rainfall variability.

In order to achieve the objective III of the study, Perpendicular Vegetation Index (PVI), the PVI was used, as proposed by Richardson and Wiegand (1977), which is the intercept of the vegetation images of the R and NIR band, and the soil images of the R and NIR band.

The PVI is expressed as:

$$PVI = \sqrt{(\rho G_{ir,s} - \rho P_{ir}) - (\rho G_{r,s} - \rho P_r)^2} \qquad 3.3$$

Where: $\rho_{r,s}$ and $\rho_{ir,s}$ = reflectance of soil background in R and NIR bands respectively

ρ_r and ρ_{ir} = reflectance of vegetation in R and NIR bands

NB: PVI is determined using the distance between the intersection point $(\rho G_{ir,s}\ and\ \rho G_{r,s})$ and the vegetation image pixel coordinate $(\rho P_{ir} - \rho P_r)$ by the pythagorans.

Vegetation Index (VI) provides information on vegetation vigour in the field was interpolated against the rainfall fall data in a Kriging like format in ArcGIS environment to show the relationship between vegetation response and rainfall variability.

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 Presentation of Data

This chapter deals with the presentation as well as the discussion of results. The results are presented in form of tables, charts, graphs and Images.

4.2 Examination of vegetation response to early or late onset of rainfall in SSEZ

In line with objective 1 of the study, IRMI value was used to compute the actual onset and cessation of rainfall in the study area, Table 4.1 and 4.2 presents the result of the inter-seasonal rainfall variability analysis of all the rainfall parameters of discussion in this study for the 37 years (1981-2018) period under review. The onset dates were the first to be estimated for each year using the earlier discussed methodology, followed by the respective cessation dates.

4.2.1 Rainfall onset in the sudano sahelian ecological zone of nigeria

Observed daily rainfall totals were aggregated into pentad totals. As described in Usman (1999), any pentad with less than 5mm of rainfall was taken as a break. The first of May (the 25th pentad of the year from first of January) was taken as the pentad of reference in this research work. This conform with the work of Usman and Abdulkadir (2019) and Ibrahim *et al.* (2018). This choice of the beginning of May was based on the identification of Sultan and Janicot (2000) of mid-May as the first time an increase occurs in the positive rainfall slope in Sudano-Sahelian West Africa. Cumulative amount of rainfall and the highest pentad total since the 25th pentad were noted and combined with the number of breaks to compute an Intra-seasonal Rainfall Monitoring Index (IRMI).

Table 4.1: Rainfall Onset in the Sudano-Sahelian Ecological Zone of Nigeria

Year	Bauchi	Gusau	Kano	Katsina	Maiduguri	Nguru	Sokoto	Yelwa
1981	24-Jun	15-May	5-May	10-May	15-May	10-May	15-May	10-May
1982	10-May	20-May	25-May	5-May	15-May	15-May	10-May	5-May
1983	10-May	20-May	15-May	10-May	20-May	10-May	10-May	15-May
1984	5-May	15-May	25-May	15-May	10-May	4-Jun	25-May	20-May
1985	5-May	20-May	25-May	20-May	15-May	15-May	30-May	10-May
1986	24-Jun	25-May	30-May	5-May	15-May	30-May	4-Jun	15-May
1987	20-May	25-May	4-Jun	15-May	20-May	15-May	15-May	15-May
1988	15-May	30-May	30-May	30-May	30-May	30-May	10-May	30-May
1989	10-May	20-May	25-May	15-May	25-May	4-Jun	20-May	25-May
1990	5-May	10-May	10-May	25-May	30-May	20-May	4-Jun	5-May
1991	10-May	10-May	10-May	25-May	20-May	30-May	25-May	5-May
1992	10-May	15-May	15-May	20-May	25-May	4-Jun	30-May	10-May
1993	5-May	25-May	25-May	25-May	20-May	30-May	10-May	10-May
1994	10-May	25-May	4-Jun	20-May	20-May	30-May	4-Jun	15-May
1995	4-Jun	20-May	25-May	30-May	15-May	4-Jun	30-May	15-May
1996	20-May	25-May	30-May	10-May	20-May	30-May	4-Jun	15-May
1997	25-May	15-May	20-May	30-May	20-May	25-May	30-May	10-May
1998	20-May	10-May	30-May	4-Jun	15-May	25-May	15-May	5-May
1999	10-May	25-May	25-May	15-May	20-May	30-May	4-Jun	15-May
2000	14-Jun	30-May	15-May	30-May	20-May	30-May	30-May	10-May
2001	15-May	4-Jun	4-Jun	30-May	20-May	4-Jun	30-May	5-May
2002	4-Jun	10-May	30-May	30-May	25-May	25-May	4-Jun	5-May
2003	30-May	25-May	10-May	5-May	25-May	30-May	15-May	15-May
2004	30-May	25-May	30-May	15-May	30-May	25-May	15-May	25-May
2005	20-May	10-May	4-Jun	4-Jun	4-Jun	20-May	30-May	10-May
2006	10-May	5-May	25-May	30-May	30-May	25-May	4-Jun	15-May
2007	15-May	4-Jun	15-May	15-May	20-May	25-May	30-May	10-May
2008	15-May	20-May	25-May	4-Jun	25-May	30-May	25-May	20-May
2009	25-May	30-May	30-May	10-May	30-May	25-May	4-Jun	20-May
2010	20-May	25-May	20-May	20-Jan	4-Jun	30-May	30-May	10-May
2011	25-May	25-May	5-May	10-May	30-May	25-May	25-May	10-May
2012	20-May	20-May	15-May	15-May	25-May	5-May	30-May	10-May
2013	4-Jun	15-May	30-May	25-May	4-Jun	10-May	4-Jun	20-May
2014	30-May	30-May	10-May	10-May	30-May	20-May	25-May	25-May
2015	15-May	4-Jun	15-May	4-Jun	30-May	30-May	30-May	10-May
2016	30-May	4-Jun	15-May	15-May	4-Jun	25-May	4-Jun	20-May
2017	10-May	30-May	20-May	25-Jun	30-May	25-May	30-May	10-May
2018	5-May	25-May	10-May	15-Jun	4-Jun	30-May	20-May	5-May

Table 4.1 shows the onset period of 8 synoptic stations in the Sudano-Sahelian Ecological Zone of Nigeria namely Bauchi, Gusau, Katsina, Kano, Maiduguri, Nguru, Sokoto and Yelwa respectively, the result shows wide variability in onset dates in SSEZ. The average onset period for each synoptic stations shows a slight variability, Bauchi has it average onset date to be 20th May, Gusau is 21st May, Kano also is 21st of May, Katsina is 21st of May, Maiduguri is 24th of May, Nguru is 25th of May, while Sokoto is the 26th of May and finally Yelwa is 13th of May. The average rainfall onset recorded in this region is on the 28th pentad which is 21th May of every year. The onset dates were derived using the IRMI which implies that the "actual" or "real" onset of rains was taken as the pentad within which the index is greater than or equal to 1 (≥1), for the first time.

4.2.2 Rainfall cessation in the sudano-sahelian ecological zone of nigeria

Cessation dates of rainfall are also very important information of great interest to farmers, agro-meteorologists and hydro-meteorologists. In this study, we try to look at its effects on vegetation and how the vegetation responds to it. It is worthy of note that cessation the opposite of Onset of rains, it's the termination of effective rainy season. It does not imply the last day rain fell, but when rainfall can no more be assured or be effective for plant growth.

Table 4.2 shows a notable variation in the cessation dates of rainfall in the Sudano-Sahelian Ecological Zone of Nigeria. Early cessation was recorded in Katsina in 1985, 1989, 1991, 1993, 2005, 2006, 2007, 2010, 2011, 2013, 2014, 2017 and 2018 while Maiduguri in 1981, 1987, 1989, 1994 1996, 2000, 2002, 2005. 2007, 2013, 2014 and 2017, Kano in 2017 (2nd-Oct), and Nguru also experience early cessation in 1983,1984,1985,1991, 1996, 2001, 2007, 2009, 2014, Sokoto recorded early cessation in 1984 and finally Yelwa experience early cessation of rainfall in 1981, and 2005.

Table 4.2: Rainfall Cessation in the Sudano-Sahelian Ecological Zone of Nigeria

Year	Bauchi	Gusau	Kano	Katsina	Maiduguri	Nguru	Sokoto	Yelwa
1981	17-Oct	27-Oct	27-Oct	7-Oct	2-Oct	27-Oct	7-Oct	2-Oct
1982	22-Oct	27-Oct	22-Oct	12-Oct	17-Oct	12-Oct	7-Oct	7-Oct
1983	12-Oct	27-Oct	27-Oct	7-Oct	7-Oct	2-Oct	12-Oct	7-Oct
1984	27-Oct	27-Oct	27-Oct	17-Oct	22 cot	2-Oct	2-Oct	12-Oct
1985	27-Oct	27-Oct	27-Oct	2-Oct	27-Oct	2-Oct	12-Oct	17-Oct
1986	27-Oct	27-Oct	27-Oct	7-Oct	2-Oct	7-Oct	27 cot	12-Oct
1987	22-Oct	27-Oct	27-Oct	12-Oct	12-Oct	27-Oct	22-Oct	7-Oct
1988	27-Oct	27-Oct	27-Oct	2-Oct	22 cot	22-Oct	27-Oct	12-Oct
1989	27-Oct	27-Oct	27-Oct	7-Oct	2-Oct	7-Oct	22-Oct	22-Oct
1990	27-Oct	27-Oct	27-Oct	22-Oct	7-Oct	12-Oct	27-Oct	22-Oct
1991	22-Oct	22-Oct	27-Oct	2-Oct	12-Oct	2-Oct	27-Oct	27-Oct
1992	27-Oct	27-Oct	27-Oct	7-Oct	7-Oct	7-Oct	27-Oct	27-Oct
1993	17-Oct	27-Oct	27-Oct	2-Oct	2-Oct	12-Oct	27-Oct	22-Oct
1994	27-Oct	27-Oct	27-Oct	17-Oct	2-Oct	22-Oct	22-Oct	22-Oct
1995	22-Oct	27-Oct	27-Oct	22-Oct	7-Oct	7-Oct	27-Oct	22-Oct
1996	22-Oct	27-Oct	27-Oct	7-Oct	2-Oct	2-Oct	27-Oct	22-Oct
1997	27-Oct	27-Oct	27-Oct	12-Oct	12-Oct	7-Oct	27-Oct	27-Oct
1998	27-Oct	27-Oct	27-Oct	17-Oct	22-Oct	22-Oct	27-Oct	17-Oct
1999	27-Oct	27-Oct	27-Oct	17-Oct	17-Oct	7-Oct	27-Oct	22-Oct
2000	27-Oct	17-Oct	27-Oct	17-Oct	2-Oct	7-Oct	27-Oct	27-Oct
2001	27-Oct	27-Oct	27-Oct	17-Oct	22-Oct	2-Oct	27-Oct	22-Oct
2002	22-Oct	27-Oct	17-Oct	27-Oct	2-Oct	12-Oct	27-Oct	17-Oct
2003	27-Oct	27-Oct	27-Oct	12-Oct	7-Oct	27-Oct	27-Oct	22-Oct
2004	27-Oct	27-Oct	27-Oct	12-Oct	7-Oct	12-Oct	27-Oct	7-Oct
2005	27-Oct	22-Oct	27-Oct	2-Oct	2-Oct	17-Oct	22-Oct	2-Oct
2006	27-Oct	22-Oct	27-Oct	2-Oct	7-Oct	12-Oct	22-Oct	7-Oct
2007	27-Oct	27-Oct	27-Oct	2-Oct	2-Oct	2-Oct	27-Oct	27-Oct
2008	27-Oct	27-Oct	27-Oct	7-Oct	7-Oct	27-Oct	27-Oct	27-Oct
2009	22-Oct	27-Oct	27-Oct	7-Oct	7-Oct	2-Oct	27-Oct	22-Oct
2010	22-Oct	27-Oct	27-Oct	2-Oct	7-Oct	12-Oct	22-Oct	27-Oct
2011	27-Oct	27-Oct	27-Oct	2-Oct	7-Oct	17-Oct	27-Oct	27-Oct
2012	17-Oct	27-Oct	27-Oct	7-Oct	12-Oct	12-Oct	22-Oct	27-Oct
2013	27-Oct	27-Oct	27-Oct	2-Oct	2-Oct	22-Oct	27-Oct	27-Oct
2014	27-Oct	27-Oct	27-Oct	2-Oct	2-Oct	2-Oct	27-Oct	27-Oct
2015	27-Oct	27-Oct	22-Oct	2-Oct	7-Oct	12-Oct	17-Oct	17-Oct
2016	27-Oct	27-Oct	17-Oct	17-Oct	7-Oct	7-Oct	22-Oct	12-Oct
2017	27-Oct	27-Oct	2-Oct	2-Oct	2-Oct	17-Oct	22-Oct	22-Oct
2018	27-Oct	27-Oct	7-Oct	2-Oct	7-Oct	22-Oct	17-Oct	22-Oct

As shows on Figure 4.1, areas coloured with deep blue received more rainfall while a fade in colour signify a reduction in rainfall in the Sudano-Sahelian Ecological Zone of Nigeria.

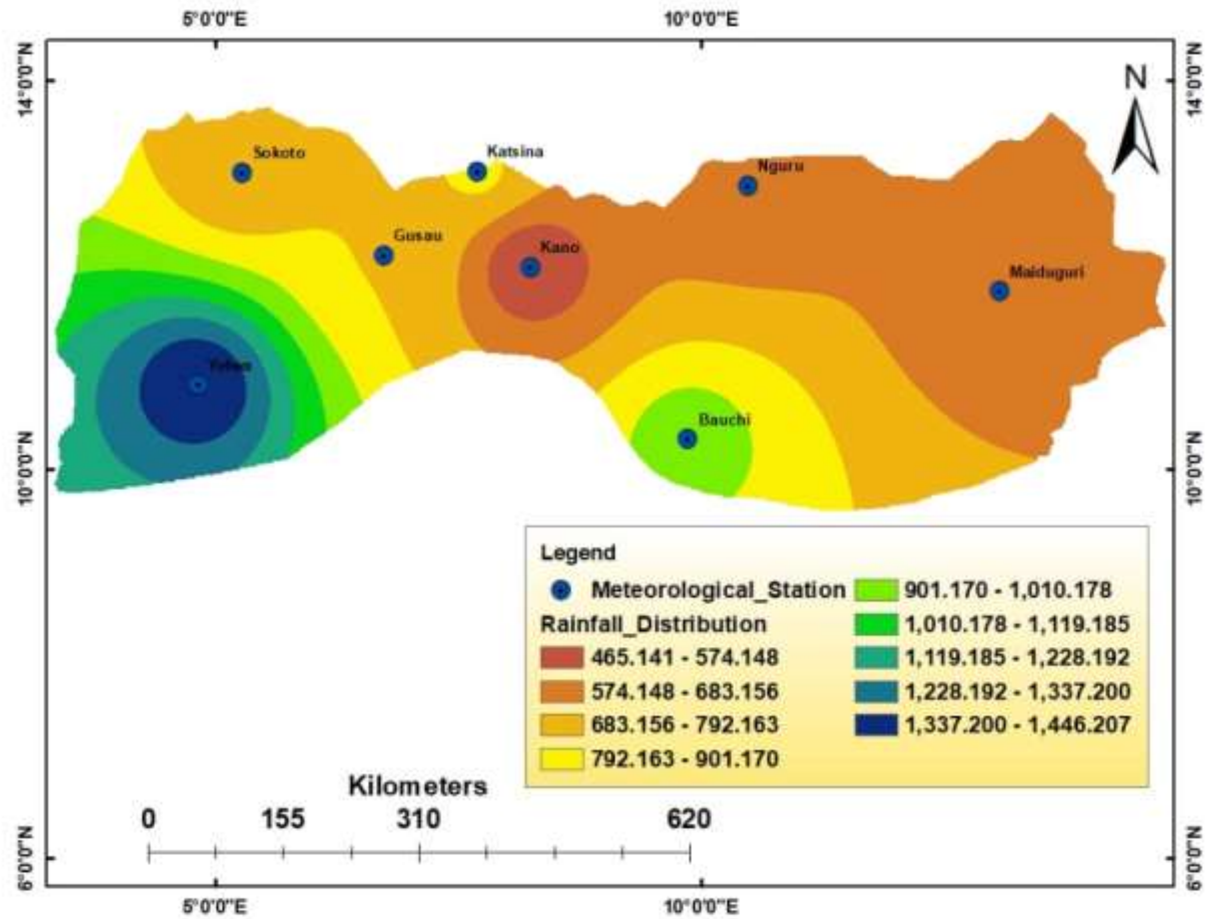

Figure 4.1: Thematic Map of Annual Average Rainfall Distributions in the Sudano-Sahelian Ecological Zone of Nigeria

Figure 4.1 is the thematic map of rainfall distribution in the Sudano-Sahelian Ecological Zone of Nigeria, the map is depicted using colour variable to shows how rainfall is distributed, areas marked with red are meteorological stations that have poor rainfall distribution between (465.141-574.148mm, 574.148-683.156mm and 683.156-901.170mm) respectively, Stations that fall in to this region are Maiduguri, Nguru, and part of Kano area of medium rainfall distribution are depicted in lemon green (901.170-1,010.178, 1,010.178-1,119.185 and 1,119.185-1,228.192) areas in this region are Bauchi and part of Yelwa and areas of high rainfall are depicted in blue, 1,228.192-1,337.200 and 1,337.200-1446.207) this can be found in Yelwa and environs.

Vegetation respond to rainfall in different ways, rain give life to vegetation and an increase in amount of rainfall received in an area has a resultant effect on the vegetation vigour, Figure 4.2 shows vegetation vigour in the Sudano-Sahelian Ecological Zone of Nigeria. Early or late onset or early rainfall has effect on, Figure 4.2 is a Landsat image captured in 2018 and was correlated with rainfall of that year. Some Stations in the Region experience early onset (5th May for Bauchi and Nguru, 10th May for Kano, 20th May for Sokoto, 25th May for Gusua, and 30th May for Nguru) these stations has early rainfall except for Katsina and Maiduguri with late onset of around 15th and 4th June respectively. The implication for this is that NDVI computed for that region increased a bit for station that has early onset and decrease for those with late onset. A look at the cessation date also show slight variability. In the year 2018, Kano, Katsina and Maiduguri experienced early cessation of 7th, 2nd and 7th October respectively. While late cessation was notice in Bauchi and Gusau 27th –Oct, Nguru and Yelwa 22nd-Oct and Sokoto with 17th-Oct. the late cessation also has implication for vegetation vigour which also increase the NDVI (0.440-0.874) value as compare to the previous years understudy which shows NDVI value of (0.782).

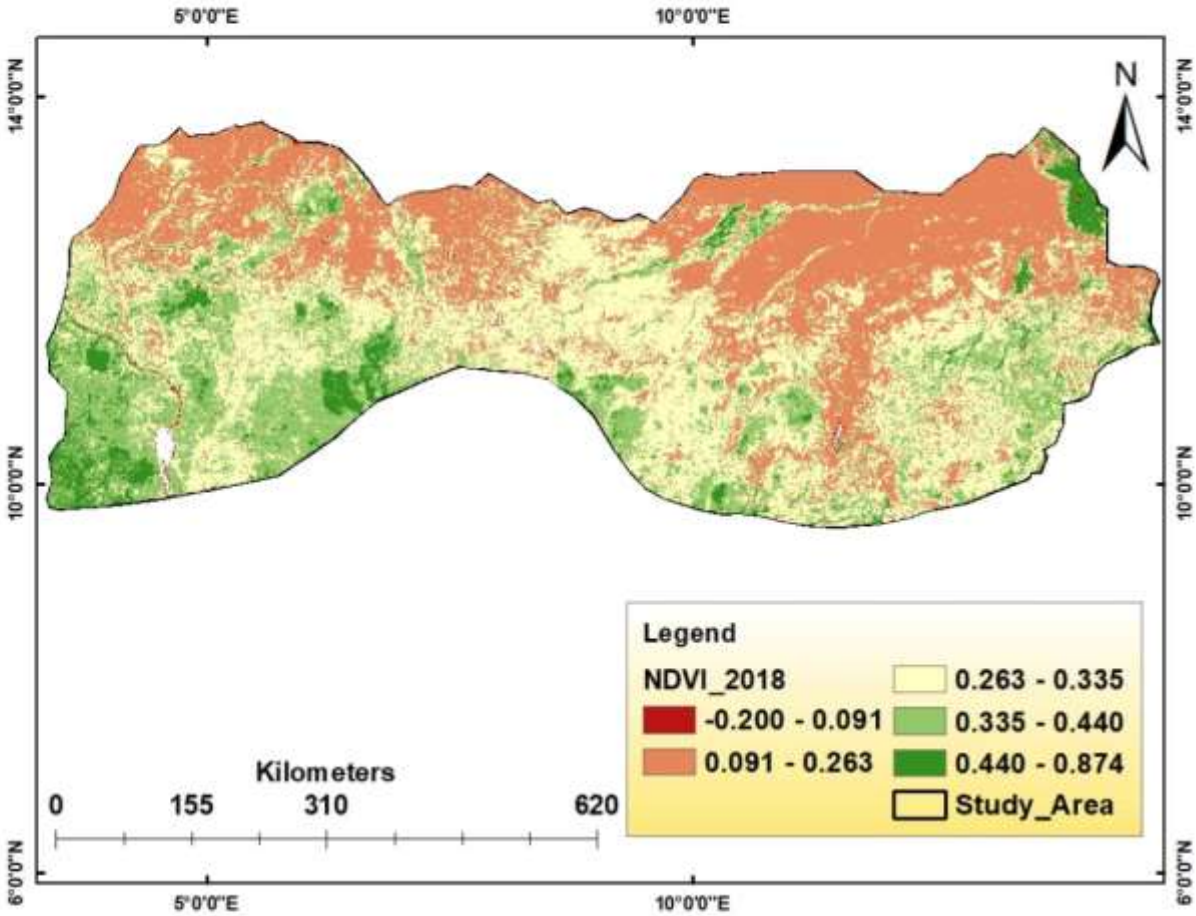

Figure 4.2: NDVI Analysis with rainfall Onset and Cessation Period in the SSEZ

Table 4.3 Annual Average Rainfall Distributions in the Sudano-Sahelian Ecological Zone of Nigeria

S.N	Stations	Annual Average Rainfall
1.	Nguru	536.91
2.	Sokoto	567.15
3.	Maiduguri	631.04
4.	Katsina	652.48
5.	Kano	663.18
6.	Gusau	797.52
7.	Bauchi	856.71
8.	Yelwa	1090.65

4.2.4 Areas of Equal Rainfall Distribution in the Sudano-Sahelian Ecological Zone of Nigeria

Figure 4.4 shows the area of equal rainfall distribution in the Sudano-Sahelian Ecological Zone of Nigeria 2000, studies have shown that areas with equal or close rainfall have similar response to vegetation, from the analysis of satellite imagery and interpolation of rainfall data, Nguru and Maiduguri synoptic stations has similar or close rainfall variability, the vegetation response in this two region shows relative close changes. Similar thing was noticed in Sokoto and Gusau which has close average annual rainfall, same with Yelwa and Bauchi. The implication of this is that areas of equal rainfall has similar or close vegetation and vice versa.

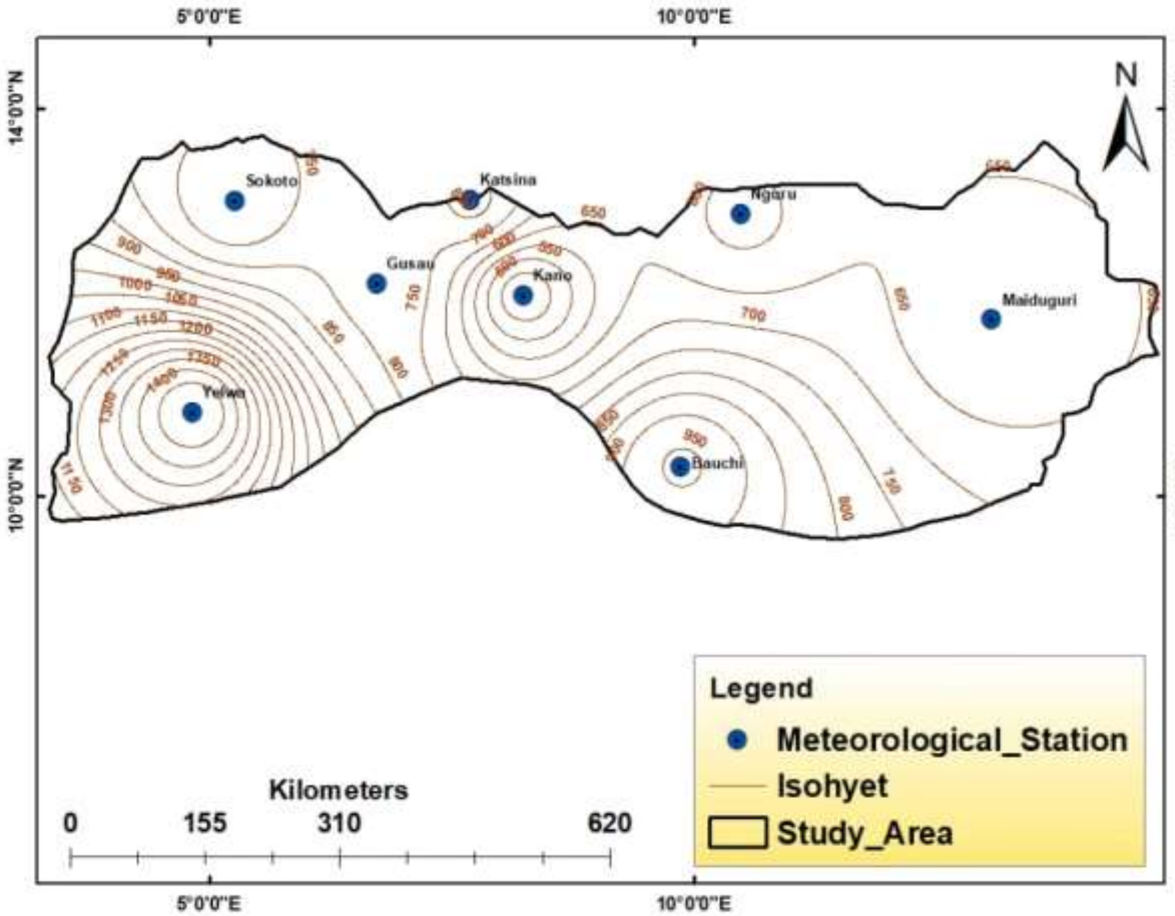

Figure 4.3: Areas of Equal Rainfall Distribution in the Sudano-Sahelian Ecological Zone of Nigeria

4.3 Spatiotemporal Patterns of Vegetation Response to Quality of Rainfall Across the Study Area

The study also tries to capture the spatiotemporal patterns of vegetation response to the quality of rainfall across the study area, as discussed in the methodology of the study, the Monsoon Quality Index (MQI) was computed for the rainfall of the study area to check the quality of the rainfall as it affects the vegetation. Normalise Differential Vegetation Index (NDVI) for the area understudy was also processed using IDRISI ANDES, to show the greenness and vegetation vigor of the Sudano-Sahelian Ecological Zone of Nigeria.

4.3.1 Moisture quality index in the sudano-sahelian ecological zone of Nigeria

According to Usman (2000), when the MQI value is small, it indicates that the season receives quality moisture which has effect on how the vegetation response to rainfall variability and the reverse is the case for high MQI values. In Bauchi for example the MQI value is 0.0593 in 2006 which is the highest value recorded over the year under study, and the lowest record was 0.006 recorded in 1994, same is applicable for Gusau with highest recorded 0.0345 which was recorded in 2013 and the lowest was 0.0088 which was recorded in 1994. The situation is similar in Kano with highest MQI value of 0.0632 recorded in 2006 and lowest is 0.0116 in 1996. The highest MQI value for Katsina is 0.0418 and was recorded in 2013 and the lowest is 0.0153, while that of Maiduguri highest is 0.0566 in 2004 and lowest is 0.016 in 1986, The highest MQI value in Nguru is 0.0559 in 2015 and the lowest is 0.0186 in 1998, while that of Sokoto highest MQI value is 0.0548 in in 1985 and the lowest is 0.0221 in 2018 and finally the highest MQI value for Yelwa is 0.0135 in 1987 and the lowest is 0.0052 in 2018.

Table 4.4 Moisture Quality Index

Year	Bauchi	Gusau	Kano	Katsina	Maiduguri	Nguru	Sokoto	Yelwa
1981	0.0111	0.0117	0.0229	0.0275	0.0251	0.0438	0.0366	0.0085
1982	0.0069	0.0106	0.0253	0.0281	0.0196	0.0421	0.0376	0.0061
1983	0.0142	0.0132	0.0262	0.0274	0.0325	0.0421	0.0278	0.008
1984	0.0091	0.0113	0.0187	0.0236	0.0297	0.0432	0.0371	0.0092
1985	0.0079	0.0158	0.0196	0.0268	0.0213	0.036	0.0548	0.0115
1986	0.0074	0.0111	0.0139	0.0198	0.016	0.0281	0.0258	0.0076
1987	0.0119	0.0141	0.0243	0.0254	0.0401	0.0445	0.0313	0.0135
1988	0.008	0.012	0.0174	0.021	0.0183	0.0285	0.0264	0.011
1989	0.0087	0.0102	0.014	0.0204	0.017	0.0304	0.0324	0.0082
1990	0.0107	0.0151	0.0195	0.0282	0.0225	0.048	0.0374	0.0092
1991	0.0121	0.0109	0.0168	0.0209	0.0219	0.0376	0.0237	0.0076
1992	0.0091	0.0143	0.0165	0.0209	0.0174	0.0293	0.0283	0.009
1993	0.0102	0.0136	0.0172	0.0269	0.0308	0.0365	0.0356	0.01
1994	0.006	0.0088	0.0138	0.0161	0.0202	0.0211	0.0213	0.0069
1995	0.0075	0.0124	0.0158	0.0215	0.0184	0.0269	0.0341	0.0101
1996	0.0084	0.0119	0.0116	0.0156	0.0162	0.0244	0.0233	0.0078
1997	0.0075	0.0107	0.0161	0.0192	0.0163	0.0267	0.0255	0.0059
1998	0.0086	0.0115	0.0139	0.0176	0.0241	0.0186	0.0247	0.0063
1999	0.0317	0.0188	0.0505	0.0316	0.0355	0.0384	0.0285	0.011
2000	0.0119	0.0149	0.0214	0.021	0.0366	0.0331	0.0294	0.0099
2001	0.0146	0.0164	0.0209	0.0234	0.0353	0.0284	0.034	0.0112
2002	0.018	0.0131	0.0239	0.0206	0.0392	0.0361	0.0326	0.0082
2003	0.0164	0.0156	0.018	0.023	0.0408	0.0313	0.0342	0.0087
2004	0.0253	0.0263	0.0384	0.0309	0.0566	0.0439	0.0403	0.0088
2005	0.0218	0.0219	0.0274	0.0255	0.0335	0.034	0.0223	0.0074
2006	0.0593	0.0307	0.0632	0.0383	0.0374	0.0488	0.0301	0.0114
2007	0.0144	0.0142	0.0226	0.0275	0.0247	0.0317	0.0328	0.0102
2008	0.0184	0.0162	0.0228	0.0231	0.0211	0.041	0.0266	0.0106
2009	0.0223	0.0252	0.0362	0.034	0.0283	0.037	0.0333	0.0085
2010	0.0135	0.0141	0.0153	0.0174	0.0211	0.0199	0.0224	0.0072
2011	0.0251	0.0192	0.0336	0.0291	0.0206	0.034	0.0318	0.0116
2012	0.0077	0.0113	0.012	0.0153	0.0164	0.0195	0.0223	0.0074
2013	0.0328	0.0345	0.0463	0.0418	0.0214	0.0413	0.0386	0.013
2014	0.0207	0.0161	0.0311	0.0313	0.0289	0.0532	0.0353	0.01
2015	0.0195	0.0202	0.048	0.02	0.0464	0.0559	0.0235	0.0102
2016	0.0101	0.0142	0.0334	0.0165	0.0241	0.0322	0.0203	0.0083
2017	0.0126	0.0148	0.0304	0.0214	0.0219	0.0397	0.0317	0.0056
2018	0.0113	0.0157	0.0384	0.0159	0.0286	0.0331	0.0221	0.0052

The implication of the above data for this research is that high MQI value were observed in the past 30 years and of recent in the past 10-20 years, the MQI value has been increasing which shows that the quality of rainfall has been reducing in term of quantity and spread. MQI analysis is a function of number of breaks, it also includes the integration of highest rainfall monthly total and the annual rainfall total received in a particular year.

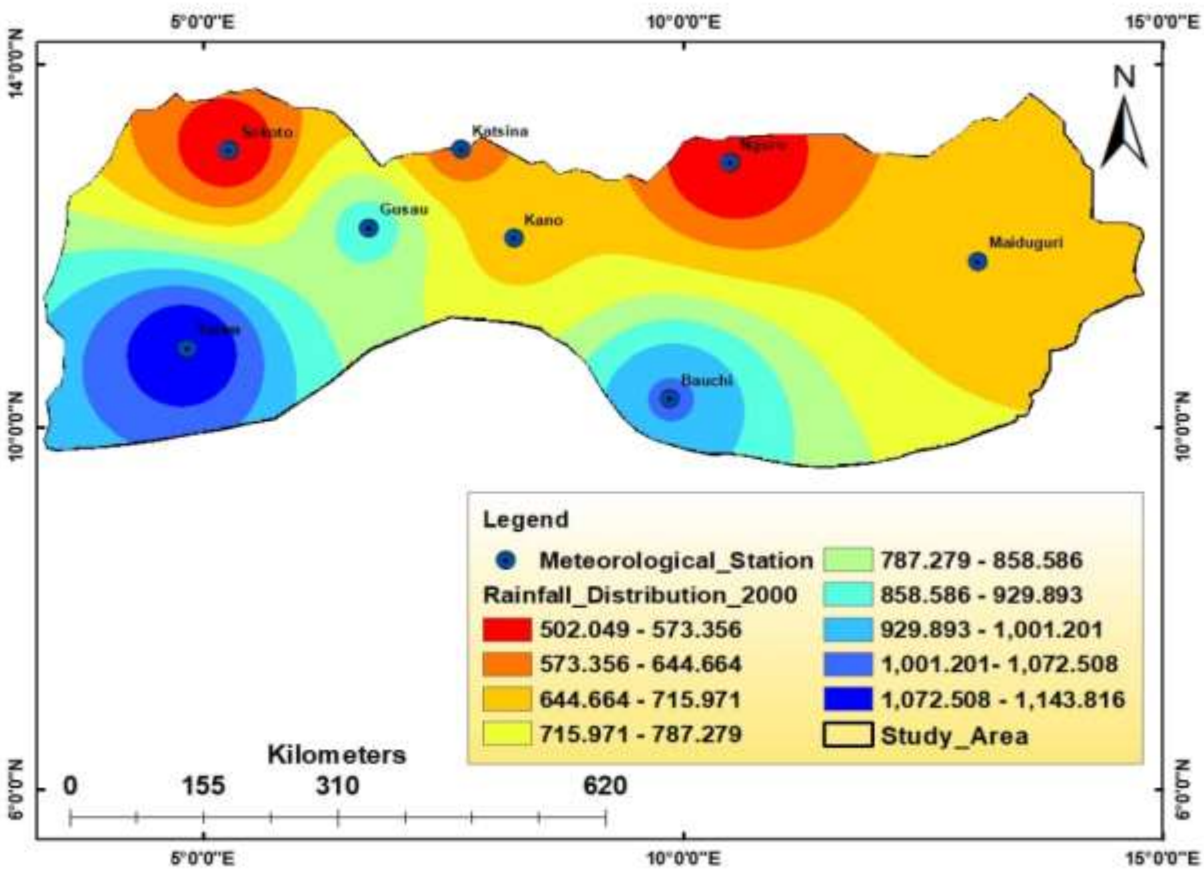

Figure 4.4: Moisture Quality in the Sudano-Sahelian Ecological Zone of Nigeria

Figure 4.4 shows annual average rainfall distribution which was used to compute the MQI in the Sudano Sahelain Ecological Zone, it ranges from Poor, Moderate and Good rainfall area. The region with poor rainfall distribution are depicted with red colour, in this area annual average rainfall range between 400.305-556.896mm and it is mostly area between Maiduguri, Nguru and part of Sokoto. The region with moderate rainfall distribution was depicted with yellow colour, in this region annual average rainfall range between 635.192-870.079mm, areas like Kano, Kaduna and part of Zamfara falls within this region and finally areas that considered with good rainfall are depicted with blue colour, this area receive annual average rainfall of between 870.079-1104.966mm, areas like Yelwa nd Bauchi falls within this region.

4.3.2 Vegetation response to quality of rainfall across the study area

Since rainfall varies across the region, it has great implication for vegetation growth, in this research we tried to compare rainfall value to check how the vegetation respond to it, it was notice that areas where annual average rainfall are poo, the vegetation vigour are also poor, for example the annual average rainfall in Maiduguri is around 420-500mm average annual rainfall and the NDVI value is also between -0.2-0.0564 which implies that a poor rainfall signifies a poor vegetation index. Nguru received annual average rainfall of 500-560mm and NDVI value between -0.2-0.0564 value same as Maiduguri this shows when region have similar or equal rainfall, the vegetation vigour respond in the same pattern. Kano received about 640-700mm annual average rainfall with NDVI value between -0.2-0.564, Katisna has similar rainfall intensity like Kano of about 600-640mm with NDVI value of -0.2-0.564, Gusau with annual average rainfall of around 700-780mm with NDVI same as others above of -0.2-0.564, Sokoto with an annual average rainfall of around 520-580mm also with NDVI value of -0.2-0.564. A look at the rainfall received at Yelwa station shows a considerable good annual average rainfall of about 960-1000mm and with a vegetation index of 0.569-0.826 NDVI value and finally Bauchi has a good annual average rainfall between 800-1000mm with NDVI value of 0.569-0.826. from the above result it can be deduced that the higher the rainfall receive in a place the better the vegetation vigour as show in the NDVI values.

Figure 4.5 shows the NDVI analysis of the Zone which comprises Bauchi, Gusau, Kaduna, Katsina, Maiduguri, Nguru, Sokoto and Yelwa, out of the 8 stations under study 6 of the areas has NDVI value of between -0.2-0.09 which shows poor vegetation vigour. Two of the Stations i.e. Yelwa and Bauchi has NDVI value of between 0.440-0.874 which significant healthy vegetation. The next image shows rainfall distribution in the region.

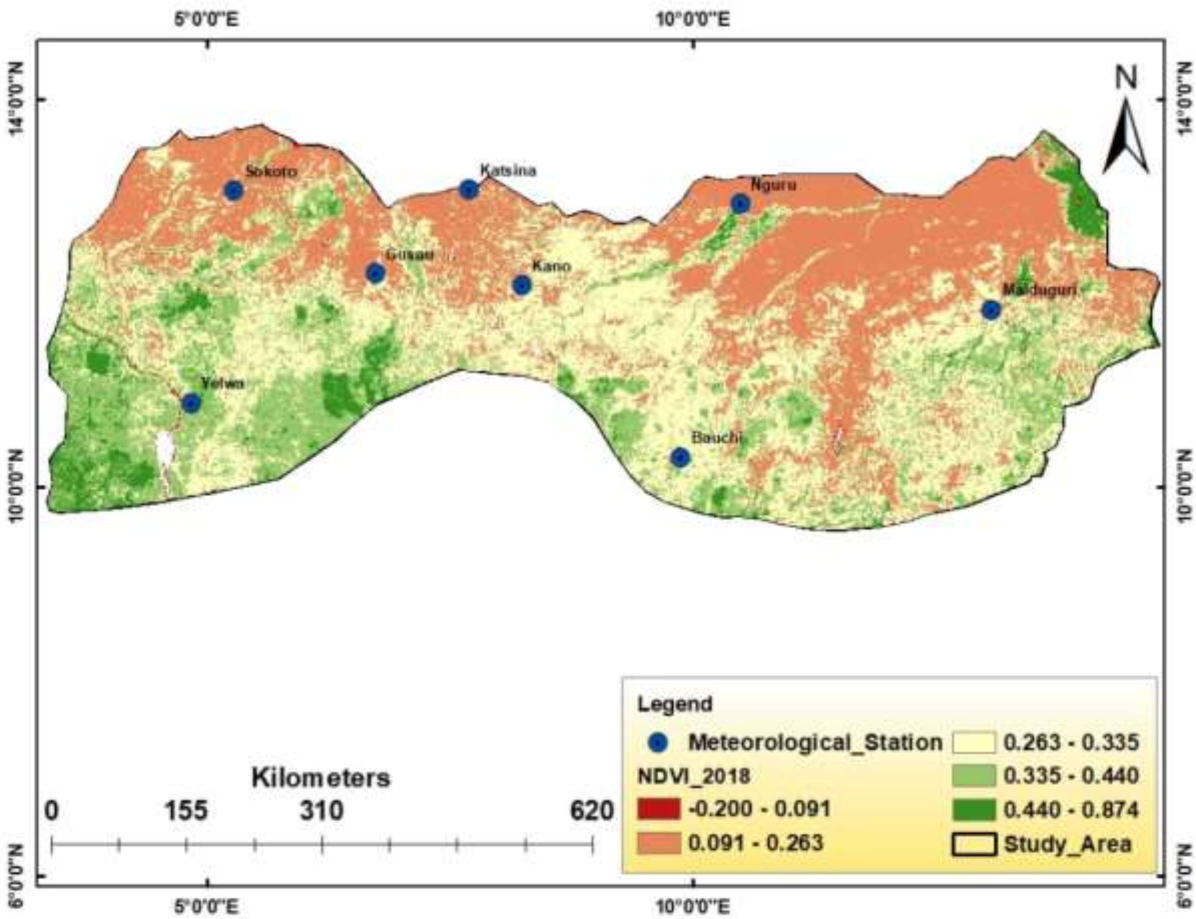

Figure 4.5: NDVI Analysis of vegetation Response to Rainfall Quality in the Sudano-Sahelian Ecological Zone of Nigeria

4.3.3 Break in Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria

A break is when the pentad value is less than 5, when there is a drop in pentad two times consecutively, and then a break is observed. A prolong break may result to a dry spell and when it last for too long it may result to a drought. From the analysis the average annual rainfall in the SSEZ varies from less than 500mm in the extreme northeastern part to 1000mm in the southern sub-region in only about five months in the year, especially between May and September. The rainfall intensity is very high between the months of July and August. The pattern of rainfall in the zone is highly variable in spatial and temporal dimensions with inter-annual variability of between 15 and 20%.

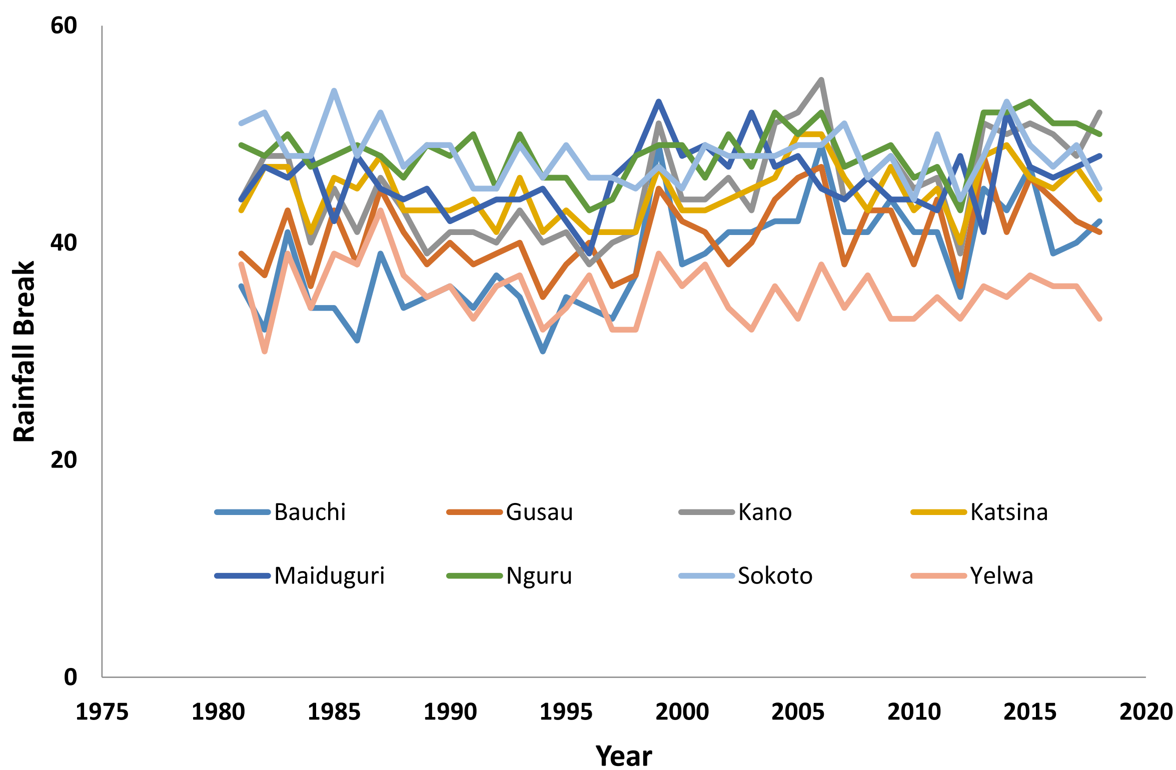

Figure 4.6: Break in Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria

Table 4.5: Break in Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria

Year	Bauchi	Gusau	Kano	Katsina	Maiduguri	Nguru	Sokoto	Yelwa
1981	36	39	44	43	44	49	51	38
1982	32	37	48	47	47	48	52	30
1983	41	43	48	47	46	50	48	39
1984	34	36	40	41	48	47	48	34
1985	34	43	45	46	42	48	54	39
1986	31	38	41	45	48	49	48	38
1987	39	45	46	48	45	48	52	43
1988	34	41	43	43	44	46	47	37
1989	35	38	39	43	45	49	49	35
1990	36	40	41	43	42	48	49	36
1991	34	38	41	44	43	50	45	33
1992	37	39	40	41	44	45	45	36
1993	35	40	43	46	44	50	49	37
1994	30	35	40	41	45	46	46	32
1995	35	38	41	43	42	46	49	34
1996	34	40	38	41	39	43	46	37
1997	33	36	40	41	46	44	46	32
1998	37	37	41	41	48	48	45	32
1999	49	45	51	47	53	49	47	39
2000	38	42	44	43	48	49	45	36
2001	39	41	44	43	49	46	49	38
2002	41	38	46	44	47	50	48	34
2003	41	40	43	45	52	47	48	32
2004	42	44	51	46	47	52	48	36
2005	42	46	52	50	48	50	49	33
2006	49	47	55	50	45	52	49	38
2007	41	38	44	46	44	47	51	34
2008	41	43	46	43	46	48	46	37
2009	44	43	48	47	44	49	48	33
2010	41	38	45	43	44	46	44	33
2011	41	44	46	45	43	47	50	35
2012	35	36	39	40	48	43	44	33
2013	45	48	51	48	41	52	48	36
2014	43	41	50	49	52	52	53	35
2015	47	46	51	46	47	53	49	37
2016	39	44	50	45	46	51	47	36
2017	40	42	48	47	47	51	49	36
2018	42	41	52	44	48	50	45	33

4.4 Lag Relationships between Vegetation Response and Interannual Rainfall Variability

In line with the objective 3 of the study, the research also tries to examine the lag relationship between vegetation response and Interannual variability. Rainfall data across the region was analysed and correlated with the NDVI value. Inter annual rainfall varies across the region considerably. As discuss in the introduction, rainfall and vegetation are tightly couples a change in rainfall will have effect on the vegetation, early or late onset or cessation has shown to affect vegetation growth, also the amount of rainfall received at a region also has effect on the vegetation vigour.

4.4.1 Interannual Rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria

Figure 4.7 show the interannual rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria, the rainfall data is between 1981-2018 (37years), lowest annual average rainfall is between 466.675-575.155mm and the highest recorded is between 1,334-1,444.997mm across the region under the period under study. The region understudy is two region combined i.e. Sudan and Sahel all combined in this study. Rain fall very considerably between Sahel and Sudan, but from the study it was found that, rainfall in the Chad Basin is quite different despite the low rainfall experienced in the region this may be attributed to the recharging of the Chad Basin going on there.

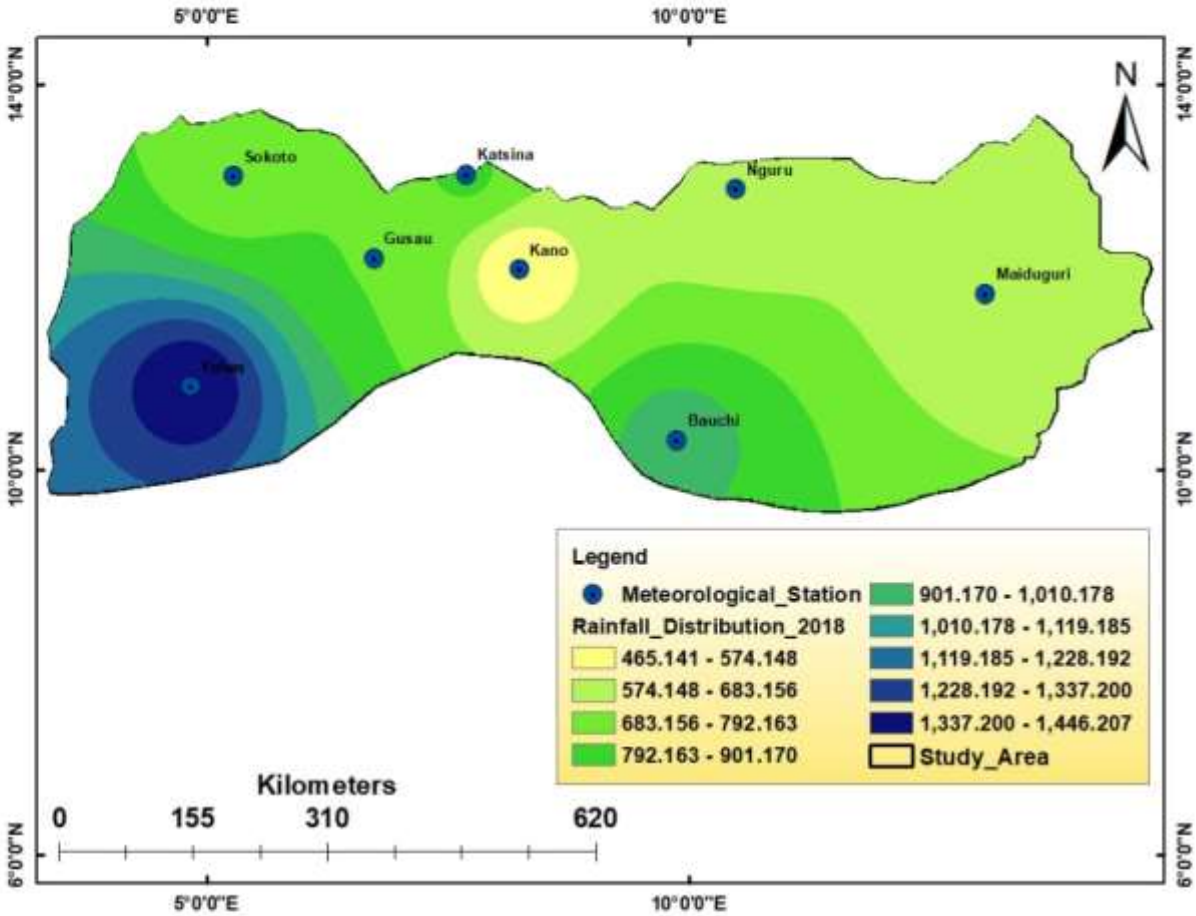

Figure 4.7: Interannual Rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria

4.4.2 Vegetation Index in the Sudaano-Sahelian Ecological Zone of Nigeria

Figure 4.8 shows the vegetation index of the Sudano-Sahelian Ecological Zone of Nigeria, the vegetation index depict the level of greenness of this zone and are measure using the Normaliszed Difference Vegetation Index (NDVI), most of the area under study has experience loss of vegetation due to its proximity to the Sahara Desert and with low rainfall throughout the year in region like Nguru, Sokoto, Maiduguri, Katsina, Kano and Gusau where average annual rainfall is less than 800mm, except places like Yelwa where average rainfall is more than 800m and Bauchi has a good amount of average annual rainfall throughout the year than any other location in the Sudano-Sahelian Ecological Zone of more than 1000mm throughout the year. This rainfall variability has great effect on the greenness of the vegetation, it can be notice that as rainfall increases, greenness level of the vegetation also increases.

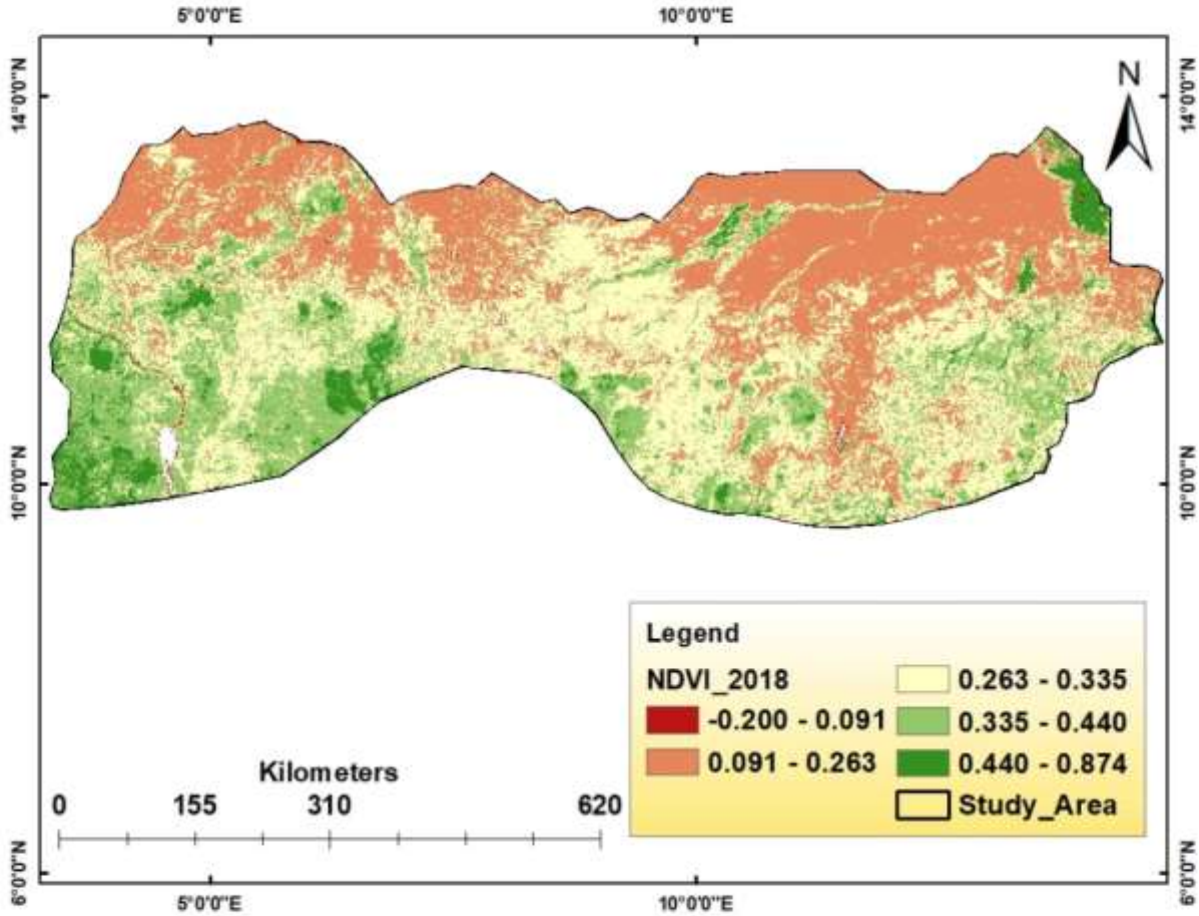

Figure 4.8: Vegetation Index in the Sudaano Sahelian Ecological Zone of Nigeria

4.4.3 Vegetation Response and Inter-annual Rainfall Variability

Rainfall give life to vegetation, and remain the chief source of energy for the ecosystem, a slight variability in rainfall for short or long period will have tremendous effect on the vegetation of the region. Out of the 8 locations selected in the Sudano Sahelian Ecologica Zone of Nigeria i.e. Nguru, Sokoto, Maiduguri, Katsina, Kano, Gusau, Bauchi and Yelwa in their order of annual average rainfall variability. As shown in Figure 4.10 rainfall data where super imposed on the NDVI analysis to show how rainfall variable changes and affect the vegetation greenness, for example the average annual average rainfall in Maiduguri from 1980-2018 has varied considerably, in the year 1908, the annual rainfall is 1001.12mm, in 1990 it was 577.66mm, in the year 2000 it was 400.3mm, in the year 2010 it was 731.19mm and in 2018 it is 606.29mm, the above data shows considerable variation in rainfall in this region. And a good look at the NDVI value of -0.100-0.108shows difference in the vegetation index which implies that a slight change in rainfall will have changes in vegetation vigour, Yelwa from 1980-2018 also has considerable variation in rainfall, for example, rainfall in the year 1980 is 1001.12mm, 945.42mm annual rainfall was recorded in 1990, 1104.99mm annual rainfall was recorded in 2010 while 2018 recorded the highest rainfall in Yelwa of about 1446.23, the above data shows considerable variability in rainfall as it varies throughout the year understudy. The NDVI value for the region is 0.508-0.874 vegetation index which signifies a robust vegetation aroung the region, the implication of the two scenario painted above is that vegetation respond to rainfall variability, that is rainfall variability is directly proportional to vegetation changes in the region.

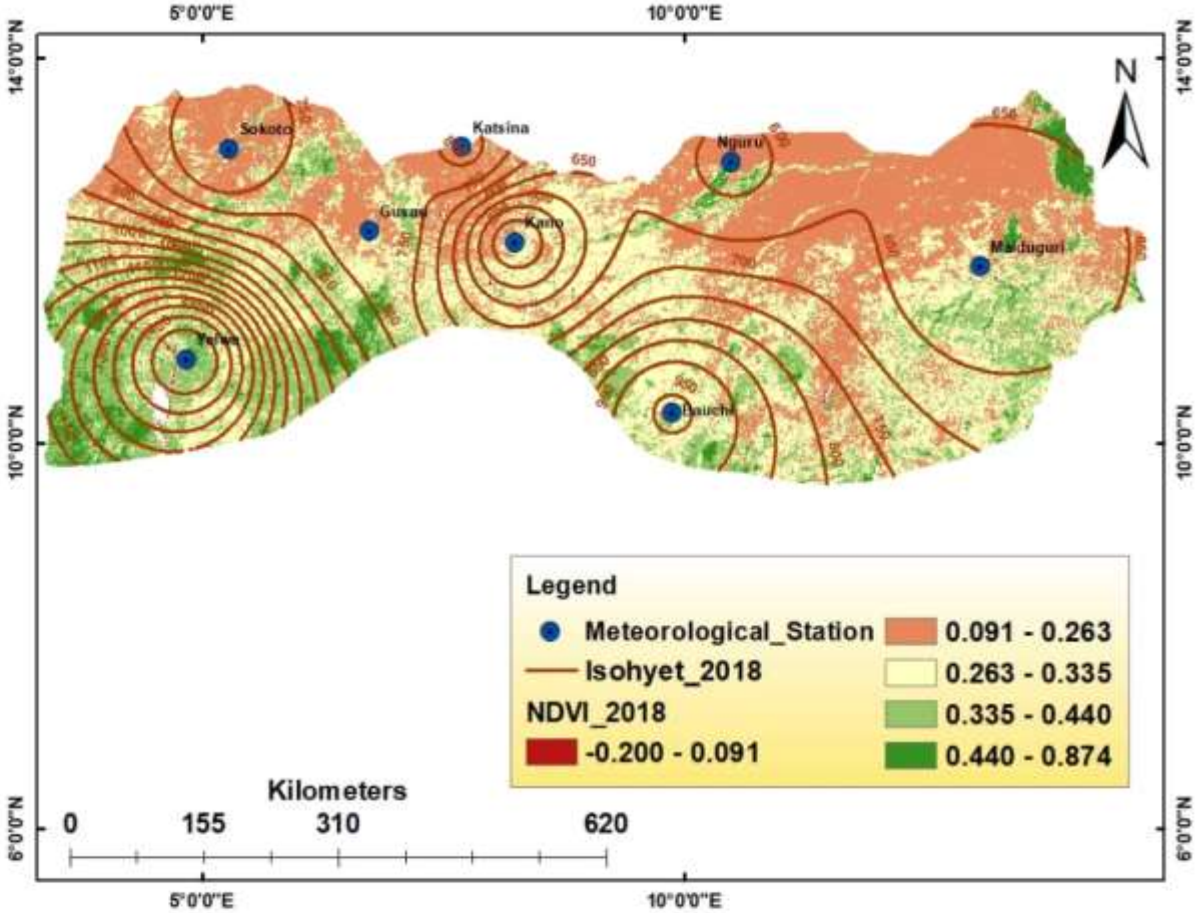

Figure 4.9: Vegetation Response and Interannual Rainfall Variability

CHAPTER FIVE

5.0 SUMMARY, CONCLUSSIONS AND RECOMMENDATION

5.1 Summary

Satellite sensors have played an important role in the investigation of vegetation responses to rainfall variability at regional and continental scales. Images form USGS Earth Explorer of Landsat and MODIS images of 30m resolution. Rainfall data and satellite for the period under study (37years) was acquired and analyzed in line with the objectives of the study. Satellites have had a key role in this activity because of their frequent observation (daily), large area coverage (continental) and historical record. This research work tries to examine the vegetation response to rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria. Monsoon Quality Index (MQI), Intra-seasonal Rainfall Monitoring Index (IRMI) and the Perpendicular Vegetation Index (PVI) were used in achieving the objectives. The satellite images was also analysed to show the vegetation dynamics as it changes with varying in onset and cessation of rainfall in the study area. Vegetation condition is typically indicated using the Normalized Difference Vegetation Index (NDVI) derived from the reflectance in the visible (VIS) and near-infrared (NIR) bands. The period has rainfall variability between 120-140 days throughout the year. Over the years, climate change has also affect precipitation in the study area.

The results confirm the utility of NDVI as an index of integrated vegetation variability on small, short (seasonal) scales in a region of very sharp gradients of topography and precipitation, despite the known heterogeneity of lifeforms and surface coverage within the study area. Thus remotely sensed surface data with the resolution of NDVI seem promising for additional future studies of land surface atmosphere interactions.

5.2 Conclusion

The research shows that over the years under study there is great inter-annual variability in rainfall in the Sudano Sahelian Ecological Zone of Nigeria which in turn has pronounced changes in vegetation greenness in form of response. The majority of former studies have only look at the rainfall variability, while this study tries to look at how the vegetation respond to a good or bad rainfall by using various models like the MQI and the IRMI, satellite images also shows the variation in the greenness of vegetation whenever there is variability in rainfall. Zuru and Maiduguri were majorly affected, as average rainfall in the region has dropped considerably.

The study was able to successfully integrate the AVHRR and MODIS NDVI series, as indicated during the period under review, as shown by the small error of pixels during the same period of high stability of the variability in the rainfall between 1986 to early 90's and this changes were notice for the three decades of trend analysis of vegetation dynamics.

Secondly, based on the correlation analysis, the study identified the mean air temperature and the cumulative monthly precipitation since December of the previous years as the key climatic parameters influencing vegetation dynamics in the study area.

Finally, the NDVI regression equation shows that the threshold for cumulative precipitation when it is high is around in around July-August which is the peak period for rain in the Sudano Sahelian Ecological Zone of Nigeria for vegetation germination is between 150-200mm. if precipitation is below this threshold, there will be significant negative impact on vegetation growth.

Results of this study also enhance knowledge of complex relationships between rainfall and vegetation. Variability of the meteorological regime needs to be fully understood in order to examine all of the various climatic factors that may influence the response of vegetation to rainfall variability in the Sudano Sahelian Ecological Zone of Nigeria. Differential responses between vegetation communities and meteorological variables (rainfall), as evidenced in this work, may have implications for climate and vegetation of Sudano Sahelian Ecological Zone of Nigeria in regards to water balance, vegetation response to rainfall variability and climate change, local species coexistence, and vegetation feedbacks to the atmosphere. There is a need to further inestigation of vegetation response due to other reason as rainfall alone is not the determine factor in vegetation dynamics it can occur due to possible ecological variation as well as socio economic impacts such as farming, grazing, urban sprawl/expansion, forest disturbance.

The arrival of remote sensing technology and GIS has brought about a new approach in on phenological studies in Sudano Sahealian ecological zone of Nigeria in the context of rainfall variability. The effective use of this technology can help improving the current knowledge of vegetation responses towards rainfall variability.

Considerable further research is required to improve the certainty of vegetation response to rainfall variability. For more detailed predictions to be made for natural forest communities, likelihood index, type of species information will be required not only on relationships between vegetation and rainfall, but also on the physiological response of plant species to changing climatic and carbon dioxide regimes, and the dynamic processes by which adjustment to new climatic regimes occurs.

5.2 Recommendations

The following recommendations are hereby made:

1. Data has been the greatest challenges of a research like this; accurate data gathering and accessibility should be encouraged or made affordable most especially for a research like this as it will help the researcher to have many data and information to work it.
2. There should be total national call on green approach to restore the lost forest of the Sudano Sahelian Ecological Zone, this will go a long way to mitigate the loss of the ecosystem and in turn mitigate the effect of climate change which has caused rainfall variability as there is great shift in onset and cessation of rainfall and the amount of rainfall in the area.
3. Government should invest more in the science of space technology so as to boost the use of Satellite remote sensing techniques and Geographic Information System (GIS) in forest resources management.
4. Reforestation projects have not been as successful as expected in and around the study area. This is partly because of the approach involved in previous reforestation programmes. The key to mobilizing ruralities is to promote multi-purpose trees that meet their immediate needs while also increasing the woody biomass available for fuel. Nitrogen-fixing trees planted in shelter-belts or interspersed with crops, can enhance soil fertility, increase soil moisture, and reduce erosion and most importantly increase the vegetation vigour.

5. For further studies, other factors that affect vegetation response should be considered such as urban sprawl, agricultural practices, soil type should be considered.

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