AN ASSESSMENT OF DESERTIFICATION IN SOKOTO STATE, NIGERIA

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NOVEMBER, 2016

DECLARATION

I declare that the work in this Dissertation entitled "AN ASSESSMENT OF DESERTIFICATION IN SOKOTO STATE - NIGERIA" has been carried out by me in the Department of Geography. The information derived from the literature has been acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

______________________	______________	________
Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled "AN ASSESSMENT OF DESERTIFICATION IN SOKOTO STATE - NIGERIA" by Mohammad Hadi AHMAD meets the regulations governing the award of the degree of Masters of Science in Remote Sensing and GIS of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To Almighty ALLAH (SWA) who guide and protect me through this research and to my father Late Ahmad Abubakar Ishaq (Tijjani Garba).

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LIST OF ABBREVIATIONS

AU	African Union
AVHRR	Advanced Very High Resolution Radiometer
CEN-SAD	Community of Sahel-Saharan States
ECOWAS	Economic Community for West African States
ENSO	El-Niño/Southern Oscillation
ETM	Enhanced Thematic Mapper
EVI	Enhanced Vegetation Index
FCC	False Colour Composite
FCT	Federal Capital Territory
FEPA	Federal Environmental Protection Agency
FMEnv	Federal Ministry of Environment
GDP	Gross Domestic Product
GGW	Great Green Wall
GGWSSI	Great Green Wall for the Sahara and the Sahel Initiative
GIS	Geographic Information System
MODIS	Moderate Resolution Image Spectroradiometer
NDVI	Normalized Different Vegetation Index
NEAP	National Environmental Action Plan
NEMA	National Emergency Management Agency
NEPAD	New Partnership for Africa's Development
NESREA	National Environmental Standards and Regulations Enforcement Agency
NIMET	Nigerian Meteorological Agency
NOAA	National Oceanic and Atmospheric Administration
NWRMP	National Water Resources Management Policy

SIDS	Small Island Developing States
TM	Thematic Mapper
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

ABSTRACT

Extreme Northern part of Sokoto plains is vulnerable to Sahel encroachment. Consequently, the zone has been designated as fragile and hard terms such as desertification, desert encroachment, aridity among others have popularly been used to accentuate the fact that the zone is undergoing serious vegetative disappearance. This study assessed desert encroachment into Sokoto state, Nigeria. 250m resolution Enhanced Vegetation Index (EVI) satellite imageries from AQUA-MODIS were used to obtain results for the vegetation decline. The data was downloaded as monthly composites initially and recomposed to annual composites and finally to five years' composites dating 1990-1994, 1995-1999, 2000-2004, and 2005-2009 within the Idrisi software environment. Field observation was carried out using Global Positioning System (GPS) together with a camera to observe the status of the selected sites and evaluated with the help of the EVI data. Regression analysis was performed. Results have shown that in 1990 to 1994, 1995 to 1999, 2000 to 2004 and 2005 to 2009 the mean EVI was found to be 4163246, 3808758, 6187252 and 5948497 respectively while Coefficient of Variation were 3.9%, 4.2%, 4.4% and 5.5% and the amount of rainfall receive within these years was increased from 675.8mm in 1990-1994 to 675.94mm in 1995-1999 and 727.44mm in 2000-2004 and 629.66mm in 2005-2009 respectively. This indicate that vegetation was declining, while desertification was increasing. Rainfall data was also used to test for relationship between EVI and rainfall, the results showed that as rainfall increase so also the vegetation strength increased and vice versa. As a results the following recommendations were suggest: sensitisation campaigns on the consequences of climate change and cutting down of trees should be re-invigorated by both the state and federal government, policies devoid to political consideration should be map out.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Environment is important to man's existence, and he is dependent on it to make a livelihood and take care of his basic needs; but the environment is undergoing changes that have implications to man's existence. Nigeria like some other countries of the world is experiencing various forms of environmental problems which range from oil spillage, flood, erosion, and desertification among others (Ayuba and Dami, 2011).

According to International Fund for Agricultural Development (IFAD), 2010 Desertification occurs when the tree and plant cover that binds the soil is removed. It occurs when trees and bushes are stripped away for fuelwood and timber, or to clear land for cultivation. It occurs when animals eat away grasses and erode topsoil with their hooves. It occurs when intensive farming depletes the nutrients in the soil. Wind and water erosion aggravate the damage, carrying away topsoil and leaving behind a highly infertile mix of dust and sand. It is the combination of these factors that transforms degraded land into desert (United Nations Convention to Combat Desertification [UNCCD], 2004). There are many factors that contribute to desertification. Prolonged periods of drought can take a severe toll on the land. Conflict can force people to move into environmentally fragile areas, putting undue pressure on the land. Mining can cause damage. In the coming years, climate change will accelerate the rate of desertification in some areas, such as the drier areas of Latin America (Tasihu, 2008).

The effects of desertification can be devastating. Desertification reduces the land's resilience to natural variations in climate. It disrupts the natural cycle of water and nutrients. It intensifies strong winds and wildfires. The effects of dust storms and the sedimentation of water bodies can be felt thousands of kilometres away from where the problems originated. The cost of desertification is high, and not just in economic terms. Desertification is a threat to biodiversity. It can lead to prolonged episodes of famine in countries that are already impoverished and cannot sustain large agricultural losses. Poor rural people who depend on the land for survival are often forced to migrate or face starvation (World Meteorological Organization [WMO], 2007).

Desertification not only means hunger and death in the developing world, it also increases threats to global security for everyone. War, social disorder, political instability and migration can all result from scarce resources. For millions of people, halting desertification is a matter of life and death. Desertification is not always inevitable (WMO, 2007). Human factors, such as overgrazing and clear-cutting of land, can be controlled by improving agricultural and grazing practices. Other factors, such as rising temperatures, can be predicted and dealt with proactively. Degraded land can sometimes be rehabilitated and its fertility restored. In many cases, the best methods of rehabilitating land involve using traditional or indigenous knowledge and land management techniques. But rehabilitation efforts can fail or eventually have a negative impact on ecosystems, human well-being and poverty reduction. It is less costly, and less risky, to limit the damage in the first place (Tasihu, 2008).

Desertification is one of the most glaring of these environmental hazards and the phenomenon has affected some states in the northern part of Nigeria, but the impact has been more glaring since the famine of 1971 – 1973 in this part of the country.

By location, Northern Nigeria is situated in the semiarid areas with average annual rainfall or less than 600 mm bordering on the Sahara desert (Folaji, 2007) which is considered as the hottest and longest desert in the world. The soil in this area face a lot of threat ranging from deforestation for domestic fuel, overgrazing by livestock and agricultural practices that fail to conserve soils such pollution from the improper use of agricultural pesticides, herbicides and chemical spills from both liquid and solid fertilizers.

Generally, desertification affects eleven (11) northern states of Nigeria referred to as the frontline state, these include: Adamawa, Borno, Yobe, Jigawa, Kano, Katsina, Zamfara, Sokoto, Kebbi, Bauchi and Gombe. These states are agricultural producing areas and are affected by desert encroachment that is fast moving southwards. Desertification is attributed to loss of the lands biological productivity in arid, semiarid and dry sub humid areas (Abubakar and Eniolorunda, 2016). The impact is significant in developing countries especially Africa which is the most affected because its economy is predominantly agrarian, rain fed and fundamentally dependent on the vagaries of weather (Mcharry, Scott and Green, 2002). However, it has been difficult for Africans to take advantage of their environment because of the lack of adequate technology to convert negative aspects of their environment to best uses.

Satellite remote sensing has become a common tool of investigation, prediction and forecast of environmental change and scenarios through the development of GIS-based models. The progress of the performance capabilities of both remote sensing technique and GIS technology have further improved the potentials of decision-support instruments to acquire information on the environment for global, regional and local assessment. With the advent of new high spatial and spectral resolution satellite and aircraft imagery, new applications for precision mapping and accurate monitoring have become feasible. The integration of multi-source georeferenced spatial data within a GIS database allows a synergistic processing of a considerable amount of information, the standardization of data and the elaboration of digital maps that are the basis of decision-making (Ghiribi, 2005).

Drylands are frequently subjected to drought which is the main limiting factor on biomass production and crop yields. Human induced factors such as over cultivation, overgrazing and other forms of inappropriate land use, when practiced under the conditions prevailing in the drylands, may result in significant degradation of vegetation, soil leaching and, in many cases, desertification (Kelly and Hulme, 1993).

The application of satellite imageries coupled with rainfall data would help in assessing Desertification in the study area. The fundamental goal of this study was to assess Desertification in Sokoto State - Nigeria. The present threat of desertification in the Sahel has reached an alarming stage where crop cultivation and animal rearing/grazing are no more productive, soil has lost its nutrient/fertility, various infrastructure have given way because of windstorm from the neighboring Niger Republic and sand dunes have taken over (Medugu, 2007).

1.2 Statement of the Research Problem

The dryland region of Africa is facing serious climate variation including, frequent droughts compounded by poorly managed land and water resources that have resulted in degradation of natural resources. Occasioned by climate change and human activities, desertification poses serious challenges to food security, sustainable livelihoods and socio-economic development in the dryland communities. Affected countries, including Nigeria, have been making efforts to reverse the situation by implementing projects and programmes such as Great Green Wall for the Sahara and Sahel Initiative (GGWSSI).

A recent regional attempt in Africa to address desertification in a more coherent manner is the GGWSSI. The initiative was developed by the African Union (AU), through its New Partnership for Africa's Development (NEPAD). The project was originally conceived as a 15 km wide strip of greenery (of trees and bushes) of some 7,775 km long, from Dakar in the west to Djibouti in the Horn of Africa in the east. The belt is expected to pass through eleven countries (Burkina Faso, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal, Sudan and Chad), and embraces the circum-Sahara enclaves such as Cape Verde. Such a biological corridor along the southern border of the Sahara is seen as a means of halting the progression of the Sahara Desert southward, protecting water sources, which have been drying up for decades, and restoring habitats for biodiversity (for energy resources and foodstuffs) United Nation Convention to Combat Desertification (UNCCD, 2004).

According to Suleiman (2005) while traveling from Katsina to Sokoto via Kaura Namoda in the company of a former Managing Director of the Sokoto-Rima River Basin Development Authority, as a student in 1968, he had to regularly stop his motorcycle to allow elephants, giraffes, antelopes and other wild animals to cross the road. So rich was the vegetation and water resources. Today, one can drive along that same road for many kilometers without seeing a grass, not to talk of animals. The vegetation is gone, the water has disappeared and the animals long extinct, also reported that in 1964, the Lake Chad covered an area of 25,000 square kilometers. Today, it barely covers 2,500sq.km. The once prodigious fishing has all but dwindled to a trickle.

The lives and property of the 15 million or so people that depend on the lake are anything but assured.

Yelwa and Eniolorunda (2012) simulates desertification in Sokoto and its environs using 1 km resolution Normalized Difference Vegetation Index (NDVI) data from the SPOT instrument. The data was downloaded as ten daily composites. The extracted data of the study area was clipped using the VGTExtract Software. The ten daily composites were initially recomposed to monthly and finally to 13 annual composites (time series) using Maximum Value Composite (MVC) algorithm within the Idrisi Andes GIS environment. The Multidimensional Choice (MDCHOICE) tool of Idrisi Andes was applied on the time series for temporal vegetation dynamism assessment while 1st and 2nd order surface trend fitting were carried out to assess the direction and pattern of desertification. Desertification was categorized by 1 standard deviation to the mean and temporal profiling was also carried out to probe into NDVI values of the time series at curious points. Results show that the inter-annual vegetation vigour exhibited a diminishing trend over the time series. The direction of desertification is North-West to South-East. Site 1 is located at Illela and Bamgi in Nigeria and Site 2 around Koukadin falling in Niger Republic are the worst affected by desertification within the study area.

According to the literature reviewed on desertification researches carried out by Yelwa and Isah (2010), Billy (2011), Yelwa and Enilorunda (2012), Edris, Dafalla, Ibrahim and Elhag (2013), is either they covered a section of Nigeria with or without climatic data or combination of both but never covered Sokoto State. Although Yelwa and Isa (2010) studied the vegetation trend in Sokoto from 1982 to 1999 their study utilized coarse resolution imageries and the time series span was limited to 1999. This is the knowledge gap the research work intends to fill.

In view of this, the study intended to bridge the gap in terms of utilizing better spatial and temporal resolution data from AQUA-MODIS Enhance Vegetation Index (EVI) satellite imagery in carrying out the research.

In line with the problems outlined, the research addressed the following questions:

1. What is the trend of vegetation Strength in the study area between 1990- 2009?
2. What is the relationship between rainfall and the vegetation in the study area?
3. Where are the desert-prone areas in Sokoto State?
4. What is the spatial extent of the Sahara Desert in the area?

1.3 Aim and Objectives

The aim of the study is to assess Desertification in Sokoto State - Nigeria. The aim was achieved through specific objectives which include to:

i. examine the spatial pentad trend of vegetation strength in the study area between 1990 to 2009.
ii. determine the relationship between rainfall and vegetation in the study area.
iii. identify areas prone to the desertification in the study area.
iv. map out the spatial extent of the desertification in the study area.

1.4 Scope and Limitation of the Study

The spatial scope of this study was to covers all the Local Government areas of Sokoto State with much emphasis to Ilela, Gada, and Tangaza Local Government Area. Special emphasis attached to this study involved the examination of pentad trend of vegetation strength and determination of the relationship between rainfall and EVI data limited only from 1990-2009. Identifying prone areas as well as mapping out the spatial extent of the Sahara Desert. The study considered the period 1990 – 2009 (20 years) as temporal scope. This is because the data available at the metrological stations and the satellite imageries of these years are more accessible and are in decadal format.

1.5 Significance of the Study

This study is expected to contribute to other similar researches on monitoring the movement of the Sahara Desert boundary in Nigeria. The beginning of the mitigation and adaptation to Sahara Desert is the baseline sensitization of the populace. There is an urgent need for advocacy in the area of the Sahara Desert, in order to enlighten the people on the dynamics of Sahara Desert (Metrological and hydrological). This cannot be done effectively without any evidence. Therefore, there is the need for research in this area for evidence-based advocacy. It is these facts that this work wants to provide. It will therefore be very useful for local planning in order to develop early warning strategies for the people.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Introduction

This chapter examines different conceptions and perceptions of scholars on desertification and drought/aridity, its definition, processes, causes, characteristics, dynamics, effects as well as corrective measures, control and solution to the problem especially in Northern Nigeria with a particular emphasis on Sokoto State. It also discusses the relevant literature concerning desertification and desert encroachment.

2.2 Conceptual Framework

2.2.1 Concept of Desert

There are many definitions of desert and this varies with individual interests. According to Farlex (2003) the word "Desert" refers to a barren or desolate area especially a dry, often sandy region of little rainfall, extreme temperatures, and sparse vegetation, a region of permanent cold that is largely or entirely devoid of life or an apparently lifeless area of water is termed as desert.

According to Encyclopedia Britannica (2010) any large, extremely dry area of land with sparse vegetation is said to be desert. It is one of the Earth's major types of ecosystems, supporting a community of distinctive plants and animals specially adapted to the harsh environment. Desert environments are so dry that they support only extremely sparse vegetation; trees are usually absent and, under normal climatic conditions, shrubs or herbaceous plants provide only very incomplete ground cover. Extreme aridity renders some deserts virtually devoid of plants; however, this barrenness is believed to be due in part to the effects of human disturbance, such as heavy grazing of cattle, on an already stressed environment (UNEP, 2013).

Deserts cover about one-third of the Earth's land surface area but the deserts of the world are much more than just the sandy, lifeless dunes of storybooks. The deserts found on Earth are extremely diverse, each unique in their own way. The dunes of the Saharan Desert, the icy tundra of Antarctica, and the Pacific coastline of the Atacama Desert are all deserts. That is right; they are all scientifically classified as deserts despite their differences (Acosta-Michlik, Klein and Compe, 2005, June). It is quite simple, really, as they all share one common trait that qualifies them as desert regions: they all receive less than 250 mm of rainfall a year. As a result of the diversity of deserts under this definition, they have been split into sub-regions: Sub-Tropical Deserts, Cool Coastal Deserts, Cold Winter Deserts, and Polar Deserts (Ellis, 1987).

Land covers 14.9 billion hectares of the earth's surface. According to a study by the United Nations Environmental Programme (UNEP) 6.1 billion hectares are dryland of which 1 billion hectares are naturally hyperarid desert. The rest of the dryland has either become desert or is being threatened by desertification. One quarter of the world's population inhabit the drylands and depend on this area for their livelihood (UNEP, 1992).

According to UNEP (1992) the desert itself is a somewhat stable environment. The landscape varies from flat terrain to lofty sand dunes and mountains. Extreme aridity and powerful winds characterise the Sahara Desert. These winds reach 100km/h, carry sand long distances, erode rocks and reduce visibility to zero in severe storms. Unprotected car windows become 'frosted' and car paint is quickly removed in such storms. Ozenda (1991) mentioned that the Sahara boasts the highest shade temperature recorded in the world (58°C) in a locality in Libya - and the average maximum for the hottest month reaches 45°C in several places. Many locations experience an average annual rainfall below 25mm. Sand dunes move during violent storms and would be a huge threat if they reached farmers' fields. Deserts generally support a very sparse vegetation cover and this is certainly true of the Sahara. Wild animals live off the meagre resources and have special mechanisms to conserve water. Pastoralists use the desert where possible for grazing while isolated oases sustain date palms and other thirsty crops. These small pockets of human activity are minute compared to the vast expanse of the desert.

2.2.1.1 The Physical Environment of Desert

The largest desert of the planet, the Sahara of Africa, is between 7,000,000 and 9,000,000km^2 in area. The northern boundary has been arbitrarily set to follow the south side of the Atlas Mountains to Biskra (Algeria) where it dips southward through Tunisia to the Gulf of Gabes and through Mediterranean to the Suez Canal (Thompson, 1984). The southern boundary stretches from east to west for 6000km from the Atlantic Ocean in Mauritania to the Red Sea in Sudan ranging between 16° to 17°N. At this boundary is a gradient of plants, animals, and physiographic characteristics into steppe vegetation of the Sahel zone (Amsel, 2009) resulting from a mean annual precipitation gradient of 1mm/year for a coverage of 1km north to south. Uncertainty in and variation of the location of the boundary between the Sahara and the Sahel zone has prevented precise estimates of the extent of the Sahara (Thompson, 1984).

There are many kinds of land in the Sahara. Great flat areas of gravel and stone, rocky plateaus, mountains, and vast seas of endless sand all make up this huge desert. The great sandy areas are called ergs. The Sahara’s ergs have huge wind-blown dunes and greatest erg is found in Libya (Amsel, 2009). Small oases of water are found throughout the Sahara. In these places, a few people can live and even grow crops. Where water is near, herbs and small shrubs can grow. Deep-rooted trees survive in wetter areas. Plants that can survive the heat, drought and salt of the Sahara Desert include; the olive tree, acacia, cypress, mastic tree, oleander, thyme, and grasses.

Deserts share a number of features (climate, weather, and a low density of vegetation), most researchers have defined "Desert" according to their discipline (Amsel, 2009). "Desert" is used synonymous with "arid." "Semiarid" representing the gradation of desert into "steppe" and denotes areas that the Sahara has expanded toward (Tucker, Holben and Goff, 1984). The alleged expansion was attributed in part to climate variation (droughts) (Smith, Kalluri, Prince and Defries, 1997) and to land mismanagement, such as overgrazing, increased cultivation, and firewood cutting (Tucker, et al., 1984). This process of land degradation is called "desertification" by some and "desertization" by others (Tuker, et al., 1984).

2.2.2 Desertification

2.2.2.1 Definition of Desertification

One of the most accepted definitions up to date is the definition which was accepted at the 'Earth Summit' of the UN Conference on Environment and Development (UNCED, Agenda 21) in Rio de Janeiro in 1992 which defined desertification as: land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climate variation and human activities (United Nations Convention to Combat Desertification [UNCCD], 2004). From the various definitions, desertification simply means land degradation by which biodiversity of land is reduced. Desertification is a gradual process which manifests itself after a long period of time. However, most of the definitions emphasize three aspects of the problem:

i. Partial or total loss of biological productivity.
ii. Both climate and human activity as essential causal elements.
iii. Vulnerability of the arid and semi-arid ecosystems.

Considerable differences in opinions exist among scientists with regard to the meaning of desertification; Oladipo (1993) defined desertification as a process of sustained land degradation (loss of primary production) that results in the inability of the environment to sustain the demands being made upon it by socio-economic systems at the existing levels of technology and economic development and under prevailing climatic conditions especially recurrent drought. Otegbeye (2004) reported that desertification is a process of turning a tract of land into an arid barren one that can no longer support any considerable population without an artificial water supply. Desertification is a gradual process and it operates through systems of land use that overtax the inherent bio-productive capacity of land (Oppong, 1993). Hillel and Rosenzweig (2002) observed that desertification is an environmental term that covers a wide variety of effects involving the actual and potential biological productivity of an ecosystem in arid, semi-arid and dry sub- humid regions.

The effects of desertification can be devastating. Desertification reduces the land's resilience to natural variations in climate. It disrupts the natural cycle of water and nutrients. It intensifies strong winds and wildfires (Andreas, 2005). The effects of dust storms and the sedimentation of water bodies can be felt thousands of kilometres away from where the problems originated (Otegbeye, 2004).

The cost of desertification is high, and not just in economic terms. Desertification is a threat to biodiversity. It can lead to prolonged episodes of famine in countries that are already impoverished and cannot sustain large agricultural losses. Poor rural people who depend on the land for survival are often forced to migrate or face starvation. Desertification not only means hunger and death in the developing world, it also increases threats to global security for everyone. War, social disorder, political instability and migration can all result from scarce resources. For millions of people, halting desertification is a matter of life and death by African Policy Research Network (APRN, 2005).

Desertification is not always inevitable. Human factors, such as overgrazing and clear-cutting of land, can be controlled by improving agricultural and grazing practices. Other factors, such as rising temperatures, can be predicted and dealt with proactively. Degraded land can sometimes be rehabilitated and its fertility restored. In many cases, the best methods of rehabilitating land involve using traditional or indigenous knowledge and land management techniques (Ballad and Brown, 1982). But rehabilitation efforts can fail or eventually have a negative impact on ecosystems, human well-being and poverty reduction. It is less costly, and less risky, to limit the damage in the first place.

Desertification is not the advance of deserts, though it can include the encroachment of sand dunes on land. Rather, it is the persistent degradation of dryland ecosystems by human activities and climatic variations. Because of its toll on human well-being and on the environment, desertification ranks among the greatest development challenges of our time (Conserve Africa, 2006).

Desertification occurs when the tree and plant cover that binds the soil is removed. It occurs when trees and bushes are stripped away for fuelwood and timber, or to clear land for cultivation. It occurs when animals eat away grasses and erode topsoil with their hooves. It occurs when intensive farming depletes the nutrients in the soil. Wind and water erosion aggravate the damage, carrying away topsoil and leaving behind a highly infertile mix of dust and sand. It is the combination of these factors that transforms degraded land into desert (Chan, 1995).

2.2.2.2 Causes of Desertification

There are many factors that contribute to desertification. Some prolonged periods of drought can take a severe toll on the land. Conflict can force people to move into environmentally fragile areas, putting undue pressure on the land. Mining can cause damage. In the coming years, climate change will accelerate the rate of desertification in some areas, such as the drier areas of Latin America (Federal Ministry of Environment, 2005).

Desertification is caused by multiple direct and indirect factors. It occurs because dryland ecosystems are extremely vulnerable to over-exploitation and inappropriate land uses (Hulme, 2014). Whereas over cultivation, inappropriate agricultural practices, overgrazing and deforestation have been previously identified as the major causes of land degradation and desertification, it is in fact a result of much deeper underlying forces of socio-economic nature, such as poverty and total dependency on natural resources for survival by the poor. It is also true to reiterate that desertification problems are best understood within the dictates of disparities of income and access to or ownership of resources (Hulme, 2014).

The causes of desertification are more complex to unravel. Desertification is driven by a group of core variables, most prominently climatic factors (Kelly and Hulme, 1993: Yang and Prince, 2000) that lead to reduced rainfall (Reynold and Stafford, 2002) and human activities involving technological factors, institutional and policy factors, and economic factors (UNCCD, 2006) in addition to population pressures, and land use patterns and practices. The technological factors include innovations such as the adoption of water pumps, boreholes, and dams. The institutional and policy factors include agricultural growth policies such as land distribution and redistribution (UNEP, 2013). These variables drive proximate causes of desertification such as the expansion of cropland and overgrazing, the extension of infrastructure, increased aridity, and wood extraction

Since most economies of African countries are mainly agro-based, a greater proportion of the desertification problems in rural areas are a result of poverty related agricultural practices and other land use systems. Inappropriate farming systems such as continuous cultivation without adding any supplements, overgrazing, poor land management practices, lack of soil and water conservation structures, and high incidence of indiscriminate bushfires lead to land degradation and aggravate the process of desertification (Medugu, 2007). These factors prevail in many parts of the region. In Uganda, as a result of overgrazing in its drylands known as the "cattle corridor," soil compaction, erosion and the emergence of low-value grass species and vegetation have subdued the land's productive capacity, leading to desertification (Lester and Brown, 2006). In the Gambia, it is reported that fallow periods have been reduced to zero on most arable lands. Between 1950 and 2006, the Nigerian livestock population grew from 6 million to 66 million, an eleven-fold increase. The forage needs of livestock exceed the carrying capacity of its grasslands (Lester and Brown, 2006). The rates of land degradation are particularly acute when such farming practices are extended into agriculture on marginal lands such as arid and semi rid lands, hilly and mountainous areas and wetlands.

Deforestation, especially to meet energy needs and expand agricultural land, is another serious direct cause of desertification in the region. Globally, there is evidence demonstrating a heavy negative impact of the energy sector on forest and other vegetation cover and land productivity (UNCCD, 2004). More than 15 million hectares of tropical forests are depleted or burnt every year in order to provide for small-scale agriculture or cattle ranching, or for use as fuel wood for heating and cooking (African Regional Review Report on Energy for Sustainable Development, 2005). Production and consumption of fuel wood is said to have doubled in the last 30 years of the 20th century, and it is rising by 0.5 percent every year (UNCCD, 2006).

This high dependence on biomass fuel has resulted into an alarming rate of tree felling and deforestation, which is exposing large tracts of land to desertification. In Ghana, where the population density has reached 77 persons per km^2, 70 percent of the firewood and charcoal needed for domestic purposes comes from the savannah zones (Andreas, 2005). In Uganda where 90 percent of the population lives in rural areas and directly depends on land for cultivation and grazing, forestland shrank from 45 percent of the country’s surface area to 21 percent between 1890 and 2000. In Nigeria where more than 70 per cent of the nation’s population depends on fuel wood, it is feared that the country might be left with no forest owing to the present level of deforestation activities (Nigerian Conservation Foundation [NCF], 2007). It is also feared that if the current rate of tropical forests deforestation is maintained, the tropical forest could be almost entirely harvested by the year 2050, thus devastatingly contributing to climate change, loss of biodiversity, land degradation and desertification (UNCCD, 2006).

The direct causes of desertification are driven by a complex set of underlying factors including the high levels of poverty in the region, high population growth rates, poor natural resources tenure and access regimes, conflicts, and climate change (UNCCD, 2004). Without alternatives, poor people are forced to exploit land resources including fragile lands, for survival (food production, medicine, fuel, fodder, building materials and household items). Given that most drylands in Africa are poverty hotspots as well, the risk of desertification is high in many of these areas, as the poor inevitably become both the victims and willing agents of environmental damage and desertification. In Sub-Saharan Africa alone, 270 million people live in absolute poverty. In Uganda, over 40 percent of the pastoralists, who constitute the majority in the country's drylands, live below the poverty line (UNCCD, 2004).

Insecure and unclear land and other natural resources tenure and access rights are some of the main reasons the natural resources end users are unwilling to invest in long-term Sustainable Land Management (SLM). For instance, it is reported that in Uganda, insecurity of land tenure in parts of the cattle corridor under communal land ownership systems does not encourage farmers to invest in sustainable land management practices (Poigreen, 2007).

An illustration of the processes of desertification in Nigeria is presented in Figure 2.1.

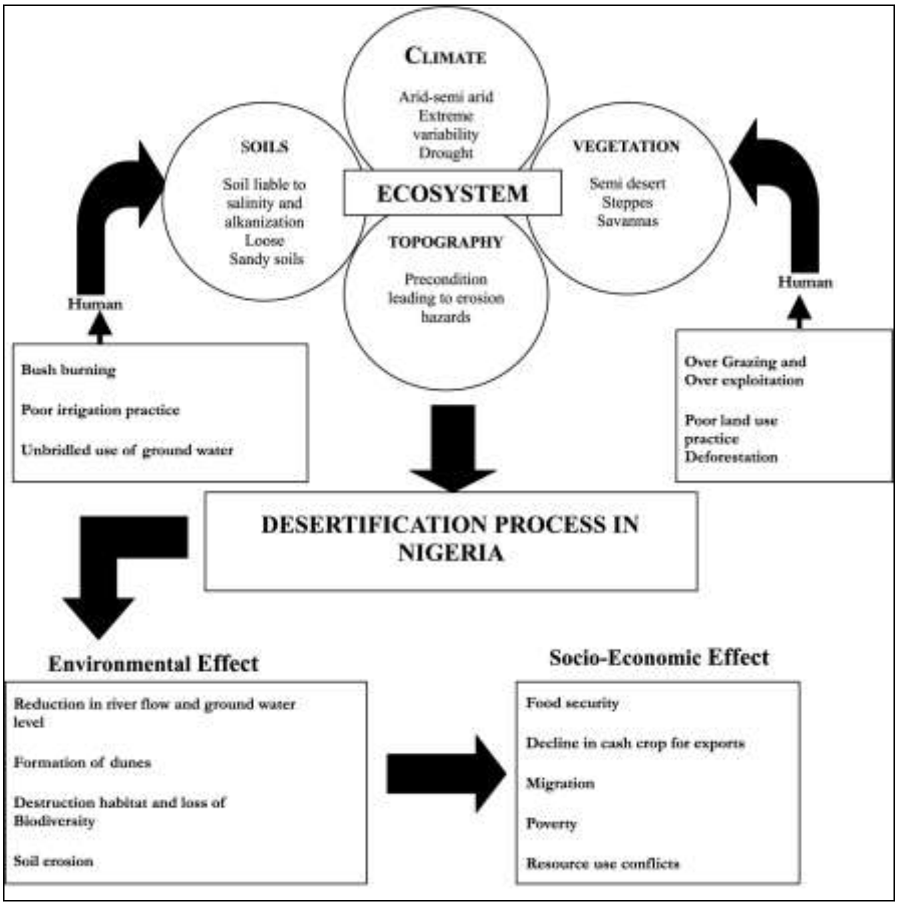

Figure 2.1 Processes of Desertification
Source: Adapted from Medugu (2007)

Figure 2.1 shows that there are four primary causes, notably overexploitation, overgrazing, deforestation and poor irrigation practices; and these are influenced by factors such as changes in population, climate and socio-economic conditions (Medug, 2007). It is obviously a complex inter-relationship, which includes: poor physical conditions in terms of soils, vegetation, topography and inherent extreme variation of climate as manifested in frequent drought; disruption in ecological balance caused by poor land use and ever increasing demand being made on the available resources by the expanding population and socio-economic systems of the affected areas; and improper land-use practices and poor land management. Thus, desertification is a result of complex inter-relationships between social and natural systems. Marguba (1991) and National Action Program (NAP, 2000) wood extraction for fuel and construction, bush burning, grazing, cultivation of marginal land, faulty irrigation management and poverty are some of the main anthropogenic causes of desertification in Nigeria and Sokoto State itself.

2.2.2.3 Impact of Desertification

The impacts of desertification are among the costliest events and processes in Africa (Medugu, 2007). The widespread poverty, the fact that a large share of Africa's economies depends on climate-sensitive sectors mainly rain fed agriculture, poor infrastructure, heavy disease burdens, high dependence on and unsustainable exploitation of natural resources, and conflicts render the continent especially vulnerable to impacts of drought and desertification (Goldsmith and Hilyard, 1990). The consequences are mostly borne by the poorest people in the region, women and children in particular bear the greatest burden when land resources are degraded. As a result of the frequent desertification, Africa has continued to witness food insecurity including devastating famines, water scarcity, poor health, economic hardship, social and Political unrest (Emordi, 2013).

Nigeria has about 91, 0770 sq. km land area, with 38.429% of arable land area and 7.356% of permanent crop land area (Federal Ministry of Environment, 2008). The affected areas (eleven frontline states) cover about 43.3% of total land area of the country (Olasupo, 2014). A large percent of the people in this area like in some other parts of Nigeria, are dependent on agriculture for a livelihood. Grains such as millet, corn, wheat, sorghum among others and livestock are produced. For some time now, bad weather conditions and environmental degradation have depleted land fertility to a degree that has affected food security (Ojo and Adebayo, 2012). This impact is significant because Nigeria's agriculture is rain-fed and the people have not taken full advantage of its irrigation potential estimated to be between 2 to 2.5 million hectares. The area under irrigation is estimated at about 220,000 hectares or less than 1% of the total areas under cultivation (Tell Magazine May 5, 2008 in Ojo and Adebayo, 2012). The level of irrigation in relation to crop production is minimal and cannot guarantee food security. About the 35 million people located in the eleven (11) frontline states in northern Nigeria are facing threats of hunger and extreme weather conditions (Simon and Allen, 1998).

The people in these areas are small scale farmers who use simple farming technology that cannot subdue the threats posed by their environment as well as the increasing aridity and desert encroachment (Emordi, 2003). Desert encroachment has negatively affected agricultural production in these areas. For instance, more than 65% of Sokoto state is said to be under siege while about 55% of Borno State is afflicted (Ayuba and Dami, 2011), and in some areas of these state, sand dunes have invaded vast areas of farm land and people cannot make proper use of the land because the dunes have made it inaccessible. These areas are the major producers of livestock and staple cereals such as millet, corn, sorghum wheat, beans, groundnut which are essentials for food security.

2.3 Literature Review

2.3.1 Status and Extent of Desertification

According to IFAD (2007) two thirds of Africa is classified as deserts or drylands. These are concentrated in the Sahelian region, the Horn of Africa and the Kalahari in the south. Africa is especially susceptible to land degradation and bears the greatest impact of drought and desertification. It is estimated that two-thirds of African land is already degraded to some degree and land degradation affects at least 485 million people or sixty-five percent of the entire African population (UNCCD, 2007). Desertification especially around the Sahara has been pointed out as one the potent symbols in Africa of the global environment crisis. Climate change is set to increase the area susceptible to drought, land degradation and desertification in the region. Under a range of climate scenarios, it is projected that there will be an increase of 5-8% of arid and semi-arid lands in Africa (Reuters, 2007).

Estimates of the extent of land degradation within Swaziland suggest that between 49 and 78 % of the land is at risk, depending on the assessment methodology used (Nanyunja, 2004). Nigeria is reported to be losing 146.18km^2 of rangeland and cropland to desertification each year. According to Federal Ministry of Environment (FME, 2008) this affects each of the 10 northern states of Nigeria. The region north of latitude 10^{0}N is generally regarded as the most desert prone area. They include Adamawa, Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara States. Visible signs of desertification in the sub-region includes the gradual shift in vegetation from grasses, bushes and dotted trees to expansive areas of desert-like sand. Between the period of 1976/78 and 1993/95, sand dunes increased by approximately 17 % from 820 km2 to 4,830 km2 (FME, 2008). Some villages and major access roads have been buried under sand dunes in the extreme northern parts of Katsina, Sokoto, Jigawa, Borno and Yobe states. In addition, many rivers and lakes have silted, leading to rapid drying up of water bodies after the rains. Gully erosion, that hitherto was not a major threat, increased and threatening about 18, 400 km2 compared to only 122 km2 in 1976/78 (FME, 2005, 2008).

It has been estimated that between 50% and 75% of the 11 frontline states of Nigeria are under severe threat. These states, with a population of about 35 million people account for about 43% of the country's total land area (Nwafor, 2006). The pressure of migrating human and livestock populations from these states are being absorbed by buffer states (Benue, Kaduna, Kogi, Kwara, Nasarawa, Niger, Plateau and Taraba) and FCT, to the south, resulting in an intensive use and degradation of the fragile and marginal ecosystems of these areas, even during years of normal rainfall (FGN, 2004). States are reported to have about 10% to 15% of their land areas threatened by desertification. It is estimated that the country, on the whole, is currently losing about 351,000 hectares of its landmass to desert conditions annually, and such conditions are estimated to be advancing southwards at the rate of about 0.6 km per year (Tiffen and Mortimore, 2002; FGN, 2004; Wood and Yapi, 2004). However, there is urgent need for up-to-date information on the rate and severity of desertification in Nigeria.

2.3.2 Vegetation Indices

Vegetation Indices are robust, empirical measures of vegetation activity at the land surface. They are designed to enhance the vegetation reflected signal from measured spectral responses by combining two (or more) wavebands, often in the red (0.6 - 0.7µm) and NIR wavelengths (0.7-1.1µm) regions (Miller, Bryant and Birnie, 1998**)**. Vegetation indices are derived from examination of typical spectral reflectance signatures of leaves.

Vegetation indices play an important role in monitoring variations in vegetation. The Enhanced Vegetation Index (EVI) proposed by the MODIS Land Discipline Group and the Normalized Difference Vegetation Index (NDVI) are both global-based vegetation indices aimed at providing consistent spatial and temporal information regarding global vegetation. However, many environmental factors such as atmospheric conditions and soil background may produce errors in these indices. The topographic effect is another very important factor, especially when the indices are used in areas of rough terrain. In a research conducted by (Sabrino and Raissouni, 2000) differences in the topographic effect on the EVI and the NDVI based on a non-Lambertian model and two airborne-based images was theoretically analyzed and acquired from a mountainous area covered by high-density Japanese cypress plantation were used as a case study. The results indicate that the soil adjustment factor “L” in the EVI makes it more sensitive to topographic conditions than is the NDVI. Based on these result the researcher strongly decide to use EVI instead of NDVI also EVI more response to canopy background signal while the NDVI is more on chlorophyll content and most of the researches were carried out using NDVI.

Oppong (1993), Eltahir and Nagi (2010), stated that the most conspicuous feature of desertification includes the rapid reduction in the amount of vegetative cover. Enhanced Vegetation Index (EVI) is an optimized index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coping of the vegetation canopy background signal and a reduction in atmospheric influences. According to the work of Van der Meulen and Janssen (1992), EVI is computed as:

$$\text{EVI} = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L}$$

Where EVI = Enhanced Vegetation Index

L = soil adjustment factor or canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy

Blue = (0.45-0.52μm),

RED = (0.6-0.7μm),

NIR= Near-Infrared i.e. wavelengths (0.7-1.1μm)

C1, C2 = coefficient of aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the MODIS EVI algorism are; L=1, C1=6, C2=7.5, and

G (gain factor) =2.5.

The EVI has been used to view vegetation growth of Amazon forest by Huete, Liu, Batchily and YanLeeuwen (2006) using MODIS Enhanced Vegetation Index (EVI) product. The result shows that the Amazon forest exhibit monotonous growing season where vegetation growth has no particular pattern contrary to the notion that it has a distinct growth during the dry season with serious implications for our current understanding of the carbon cycle, sinks and subsequently the questions surrounding greenhouse gases and global warming.

Abubakar and Eniolorunda (2016) Normalised Different Vegetation Index (NDVI) to assess the vegetation condition, vegetation change detection hotspots and the soil properties in the hotspots of Sokoto state in order to find out whether desertification has effect on the Soil Organic Carbon (SOC) and particle size. Biennial time series (1998 and 2014) of 1-km 10-day SPOT Normalized Difference Vegetation Index (NDVI) was subjected to Time Series Analysis (TSA). Vegetation change detection was carried out to isolate hotspots (improved and degraded areas) from which soil samples were taken. ANOVA was used to test for difference in the measured soil properties at $P < 0.05$. Results show a general reduction vegetation cover, typical of a semi-arid environment. SOC was generally low but higher in improved vegetation areas. While the degraded areas were purely sandy, improved vegetation was either Sand clay loam or Loamy sand, indicating a relationship between SOC and soil texture. However, the research was limited to the use of coarse resolution imagery with 1km.

2.3.3 Desertification and Climate Change

Climate change is now real as humans are now feeling the ill effects brought by this major environmental problem. There is therefore growing consensus in the scientific literatures that in the coming decades, the world will witness higher temperatures and changing precipitation levels (Akpata, 2011).

IPCC (2007) projected that the humid tropical zone of southern Nigeria, which is already too hot and too wet is expected to be characterized by increase in both precipitation (especially at the peak of the rainy season) and temperature. Already, temperature increase between 0.2^oC to 0.3^oC per decade has been observed in the various ecological zones of the country, while drought persistence has characterized the Sudan-Sahel regions, particularly since the late 1960s. For the tropical humid zones of Nigeria, precipitation increase of between 2 to 3% for each degree of global warming may be expected. Thus, it is reasonable to expect that the precipitation would probably increase by approximately 5 and 20% in the very humid areas of the forest regions and southern savanna areas.

In contrast, the savanna areas of northern Nigeria would probably have less rainfall, which, coupled with the temperature increases, would reduce soil moisture availability. This situation may be worsened by the expected decrease in rainfall larger inter-annual variation and greater drought probabilities (IPCC, 2007).

Greenhouse gas presence in the atmosphere is a natural component of the climate system and helps to maintain the Earth as a habitable planet. Greenhouse gases are relatively transparent to incoming solar radiation, allowing the sun's energy to pass through the atmosphere to the surface of the Earth. The energy is then absorbed by the Earth's surface, used in processes like photosynthesis, or emitted back to space as infrared radiation (Akpata, 2011). Some of the emitted radiation passes through the atmosphere and travels back to space, but some is absorbed by greenhouse gas molecules and then re-emitted in all directions. The effect of this is to warm the Earth's surface and the lower atmosphere. Water vapor (H_2O) and carbon dioxide (CO_2) are the two largest contributors to the greenhouse effect. Methane (CH4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and other greenhouse gases are present only in trace amounts, but can still have a powerful warming effect due to their heat-trapping abilities and their long residence time in the atmosphere. Without the greenhouse effect, Earth's average temperature would be 18°C, rather than the present 15°C. Concentrations of greenhouse gases and especially carbon dioxide have risen over the past two hundred and fifty years, largely due to the combustion of fossil fuels for energy production Climate Change Information Resources (CCIR, 2005). Since the Industrial Revolution in the eighteenth century the concentration of carbon dioxide in the atmosphere has risen from about 270 parts per million (ppm) to about 370 ppm. Concentrations of methane have also risen due to cattle production, the cultivation of rice, and release from landfills (CCIR, 2005).

Nearly one-third of human-induced nitrous oxide (N_2O) emissions are a result of industrial processes and automobile emissions. The combustion of fossil fuels is not the only anthropogenic source of carbon dioxide (CO_2). When ecosystems are altered and vegetation is either burned or removed, the carbon stored in them is released to the atmosphere as carbon dioxide. The principal reasons for deforestation are agriculture and urban growth, and harvesting timber for fuel, construction and paper. Currently, up to a quarter of the carbon dioxide emissions to the atmosphere can be attributed to land use change (Van Crowder, Lindley, Bruening and Doron, 1998).

Moreover, as time goes by and as industrialization gives its fair share of toxic gases, the atmosphere has become over saturated that the warming of the earth is now beyond normal (Green Earth choice, 2011). Warming in the 21st century was projected to be greatest over land and at the highest northern latitudes. For the next two decades a warming of about 0.2°C per decade is projected. Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions. Drought-affected areas will likely increase in extent. It is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent. Given these projections of future climate change, there will be increased land degradation owing to droughts and increased soil erosion owing to heavy rainfall events (Raynold and et al., 2002).

The interaction between land surface and the atmosphere involves multiple processes and feedbacks, all of which may vary simultaneously. It is frequently stressed that the changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes (Simms, 2005). Changes in surface energy budgets resulting from land surface change can have a profound influence on the Earth's climate. Following deforestation, surface evapotranspiration and sensible heat flux are related to the dynamic structure of the low-level atmosphere. These changes in fluxes within the atmospheric column could influence the regional, and potentially, global-scale atmospheric circulation (Meier and Bond, 2005). Climate change may exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation and winds.

According to Arnab and Dipanwita (2011) used Remote sensing and GIS to monitor desertification risk in India. It was found out that about 64.54% of the area under desertification was affected by climate induced processes while 35.46% was affected by human induced changes. High evapotranspiration exceeding rainfall along with strong winds is lowering the soil moisture and making them dry while fine sand grains blowing from the Thar Desert slowly altering the texture of soil and declining the primary productivity. Besides this, increasing trend of population pressure also accelerates the problem of overgrazing and over ploughing which made the area vulnerable. The study shows, this area is gradually desertifying as a complex consequence of both climate and anthropogenic factors hence, the research did was limited to the republic of India.

Edris, Dafalla, Ibrahim, and Elhag (2013) assess and monitor desertification in Al-Butana Area of Sudan, using Remote Sensing and GIS techniques. False Colour Composite (FCC) subsets images from Landsat TM and ETM covering the study area with approximately 120,000 sq. km were used in the research. Two Images of 1987, and 2000 from Enhance Thematic mapper (ETM+) and the other image thematic mapper were utilized. Radiometric and image to ground points geometric correction was conducted. In addition, Global and Linear Enhancement was also performed. Supervised, unsupervised classifications analyses were used based on visual interpretation and the field work. The research shows that area of sand has decreased from the year 1987 to 2000; there was reduction in area. This is attributed to the increased amount of water during year 1987 and 2000. This might be due to increase in rainfall, which of course led to sand fixation.

Area covered by water was increased in 1987 to 2000. Vegetation cover was decreased in 1987 to 2000. This was unexpected but might be due to decrease in cultivated area in WadiHalfa scheme in that year. However, this was likely to be an indicator of degradation of vegetation cover (one of desertification process). The area of clay land has increased in 1987 to 2000. Changes in Land Use Land cover classes between year 2000 and year 2005, this might be due to human activity such as removal of vegetation cover by overgrazing or fuelwood production. This was an indicator for sand creeping which would ledd to desertification.

Haruna and Shaib (2010) monitor desertification in the Crop-rangeland area of Yobe State, Nigeria found that sand encroachment increased rapidly during the study period. However, rangeland degradation in the study area was aggravated by the expansion of the areas under shifting cultivation leading to the destruction of vegetative cover in the area. Hence, according to Billy (2011) the magnitude and rate of desertification in Yobe State, Nigeria (1970 – 2005) Landsat MSS, and ETM dataset of 1987 and 2005, indicated a progressive shift of sand dune in the direction of the prevailing wind and decreased in vegetated cover based on the NDVI results.

Sand dune area coverage has recorded 3124.99km2 representing 6.78% of the total area in 1970, 4241km2 represent 9.22% of the entire area in 1987 and 4448.73km2 of the entire area in 2005 represent 6.96%. Result also revealed desert encroachment therefore through vegetal loss and progressive movement of sand dunes which is encroaching northwards and threatening settlement and claiming arable lands for agricultural purposes. Hence, there is need for mitigation measures to be put in place in order to prevent or minimized this trend.

2.3.4 Trends in Vegetation

Increase in rainfall over decades enhances vegetation greenness, other factors such as land use change and population density are better explain changing trends of vegetation greening which in turn serves as an indices for desertification. Several researches were conducted as follows.

Yelwa and Eniolorunda (2012) simulates desertification in Sokoto and its environs using 1 km resolution Normalized Difference Vegetation Index (NDVI) data from the SPOT instrument. The data was downloaded as ten daily composites. The extracted data of the study area was clipped using the VGTExtract Software. The ten daily composites were initially recomposed to monthly and finally to 13 annual composites (time series) using Maximum Value Composite (MVC) algorithm within the Idrisi Andes GIS environment. The Multidimensional Choice (MDCHOICE) tool of Idrisi Andes was applied on the time series for temporal vegetation dynamism assessment while 1st and 2nd order surface trend fitting were carried out to assess the direction and pattern of desertification. Desertification was categorized by 1 standard deviation to the mean and temporal profiling was also carried out to probe into NDVI values of the time series at curious points. Results show that the inter-annual vegetation vigour exhibited a diminishing trend over the time series. The direction of desertification is North-West to South-East. Site 1 is located at Illela and Bamgi in Nigeria and Site 2 around Koukadin falling in Niger Republic are the worst affected by desertification within the study area.

Vegetation change and productivity across Nigeria generally and indeed in Sokoto State in particular is being affected by the ongoing climatic change and other anthropogenic factors. Several investigations have been carried out on the land surface utilizing data from the National Oceanic Atmospheric Administration (NOAA) 1km SPOT - NDVI Data Pathfinder (PAL) dataset particularly to monitor vegetation (Yelwa and Eniolorunda, 2012).

According to Yelwa and Isah (2010) analyses the trend of vegetation across Sokoto State. Time-series remotely sensed data within Geographic Information System environment was utilized to monitor the trajectory across the state. The study used a period of ten days (decadal) NDVI data derived from NOAA (AVHRR) Pathfinder (PAL) dataset, NDVI productivity for 5-year growing seasons (July, August and September) within seven selected sites of irrigated and rainfed croplands across Sokoto State from 1982 to 1986. Ground truthing was conducted using Global Positioning System (GPS) and digital camera to establish typical status of the individual selected sites and evaluated with the IDRISI-ANDES GIS software. Profiles of the monitored sites were plotted using Excel Spreadsheet. Although studies have shown that NDVI from AVHRR has strong correlations with rainfall and net primary productivity particularly in the arid and semi-arid areas, the month of July 1985, August 1985 and September 1984 had shown very low vegetation NDVI productivity in all the sites monitored compared to the productivity of the preceding months. This is likely to be connected to the Elnino Southern Oscillations (ENSO) warm phase (changes in sea surface temperature) which other studies have shown that it affected the world primary net production (NPP). In view of this, the research on the assessment of desert encroachment into Sokoto state is being undertaken so as to map out the extent of its spatial spread into Sokoto state.

2.3.5 Relationship between Vegetation and Rainfall

Several studies estimated trends in vegetation cover or monitor land performance and land degradation respectively by analyzing relationship between rainfall and vegetation dynamics (Yelwa and Isa, 2010). Beyond, other studies analysed the correlation between time series of vegetation and precipitation data considering different time lags and sums. Outcomes for response time maximum correlations range among lags of one and three month (e.g. Wang, Price and Rich 2001). This seems rather vague and answers to the question which parameters influence this lag are still missing. Others focused on phenology and specific dates within the growing cycle deriving several indicators from time series (Yelwa and Eniolorunda, 2012). However, spatially, most studies focus on the Sahel region. However, only few studies, like Billy, 2011 specify rainfall variation or vegetation dynamics in more detail. Beyond, concrete comparisons between test sites and measured data are hardly found.

Atedhor (2015) examines agricultural vulnerability to climate change in eight selected rural settlements in Sokoto State, Nigeria adopting the integrated approach which combines environmental and socio-economic determinants. Monthly rainfall, rain days and temperatures (minimum and maximum) data for Sokoto (1951-2010) were sourced from the archives of the Nigerian Meteorological Agency, Lagos. The annual rainfall, total of rain days and mean temperature were computed and used for the trends analyses of the climatic variables while the annual drought intensities for Sokoto synoptic weather station were computed from the annual rainfall data. Data on the environmental and socio-economic determinants of agricultural vulnerability to climate change were collected from 234 selected farmers using structured questionnaire.

Multiple linear regression was used to examine the relationship between the agricultural vulnerability of the sampled farmers and the determinants. Stepwise regression was used to resolve the issue of multi-collinearity in the independent variables and consequently enhance the strength of the model. Results show that while there were downward trends of annual rainfall and rain days in Sokoto, annual mean temperatures show upward trend. Annual droughts were of slight and moderate intensities during the period under review. The results also revealed that unreliable rainfall, desertification, increasing temperatures, scarcity of pastures and inaccessibility to credit facilities accounted for 86% of the variation of agricultural vulnerability to climate change in the selected settlements in Sokoto State.

Audu (2013) assess the degree of fuel wood consumption in Nigeria using data of the percentage (%) distribution of households by type of fuel for cooking in 2007, areas of the desert – prone states in km2 and the population figures of the affected states. The results are presented in tables, analyzed using descriptive and comparative methods, discussed with mitigation measures suggested. The result shows that fuel wood is there about the only means of domestic fire in the desert – prone states leading to desertification as other sources of domestic fire are almost not in use.

2.3.6 Remote Sensing and Geographic Information System Methods in Vegetation

Remote Sensing in the broadest sense is the measurement or acquisition of information of some property of an object or phenomenon by a recording device that is not in physical or intimate contact with the object or phenomenon under study; e.g., the utilization at a distance (as from aircraft, spacecraft, or ship) of any device and its attendant display for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, and scintillation counters (Levin, 1999).

Remote Sensing is not a scientific discipline in the classical sense; it is rather a collection of a large variety of diagnostic methods, mainly using electromagnetic waves covering the spectrum from radio waves (wavelength $\lambda > 1$ m) to gamma rays ($\lambda <$ 10-12 m). In some cases, sound waves or other elastic waves are also in use, especially where electromagnetic methods fail. It is obvious that very different techniques and skills are required in the different parts of remote sensing. Not only the techniques are multidisciplinary, the applications cover a wide range of human disciplines, e.g. archaeology, botany, climatology, geology, hydrology, meteorology, security aspects etc (Singh, 1989).

One of the major applications of remotely sensed data obtained from earth- orbiting satellites is change detection (Anderson, 1977; Nelson, 1983). Change detection, defined as the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989), is useful in extracting environmental changes. Many change detection approaches have been developed since the 1970s. They include univariate image differencing, direct multidate classification and post-classification comparison (Weismiller, Kristof, Scholz, Anuta and Momen, 1977), image rationing, vegetation index differencing (Tucker, 1979), principal component analysis (Byrne, Crapper and Mayo, 1980), background subtraction (Ballard and Brown 1982), image regression (Singh, 1986), and fuzzy set operation.

Remote sensing has been used to estimate the extent of specified land cover types and to detect changes in land cover that occurred in the past. For instance, Hall, Botkin, Strebel, Woods and Goetz (1991) detected large scale patterns of forest succession. Bauer, Burk, Ek, Coppen, Lime, … and Heinzen (1994) detected forest cover in Minnesota, USA. Miller, Bryant, and Birnie (1998), Bryant, Birnie, and Kimball *(*1993) and Bryant and Birnie (1991) used Landsat data to estimate vegetation types and wildlife habitats and to detect changes in land cover in the Northern Forest region of Vermont, New Hampshire, and western Maine, USA.

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 Introduction

This chapter discusses the study area and the various methods employed in gathering, processing and analyzing data for the study. The section highlights the climate, vegetation, relief, and soil of the study area etc. then methodology: reconnaissance survey, sources of data, types of data, and the method of data processing.

3.2 The Study Area

3.2.1 Location

The study area is Sokoto State Nigeria. Sokoto State is found between Latitudes 12^0 00′N and 14^0 00′ N and Longitudes of 4^0 00′E and 7^0 00′ E. The state covers approximately 2.8 million hectares (27,825km^2). Sokoto is a city located in the extreme northwest of Nigeria, near the confluence of the Sokoto River and the Rima River (Yelwa and Enriolorunda, 2012).

The name Sokoto (which is the modern/anglicised version of the local name, Sakkwato) is of Arabic origin, representing “suk” which means market. It is also known as Sakkwato, Birnin Shaihu da Bello or "Sokoto, Capital of Shaihu and Bello". Being the seat of the Sokoto Caliphate, the city is predominantly Muslim and an important seat of Islamic learning in Nigeria. The Sultan who heads the caliphate is effectively the spiritual leader of Nigerian Muslims.

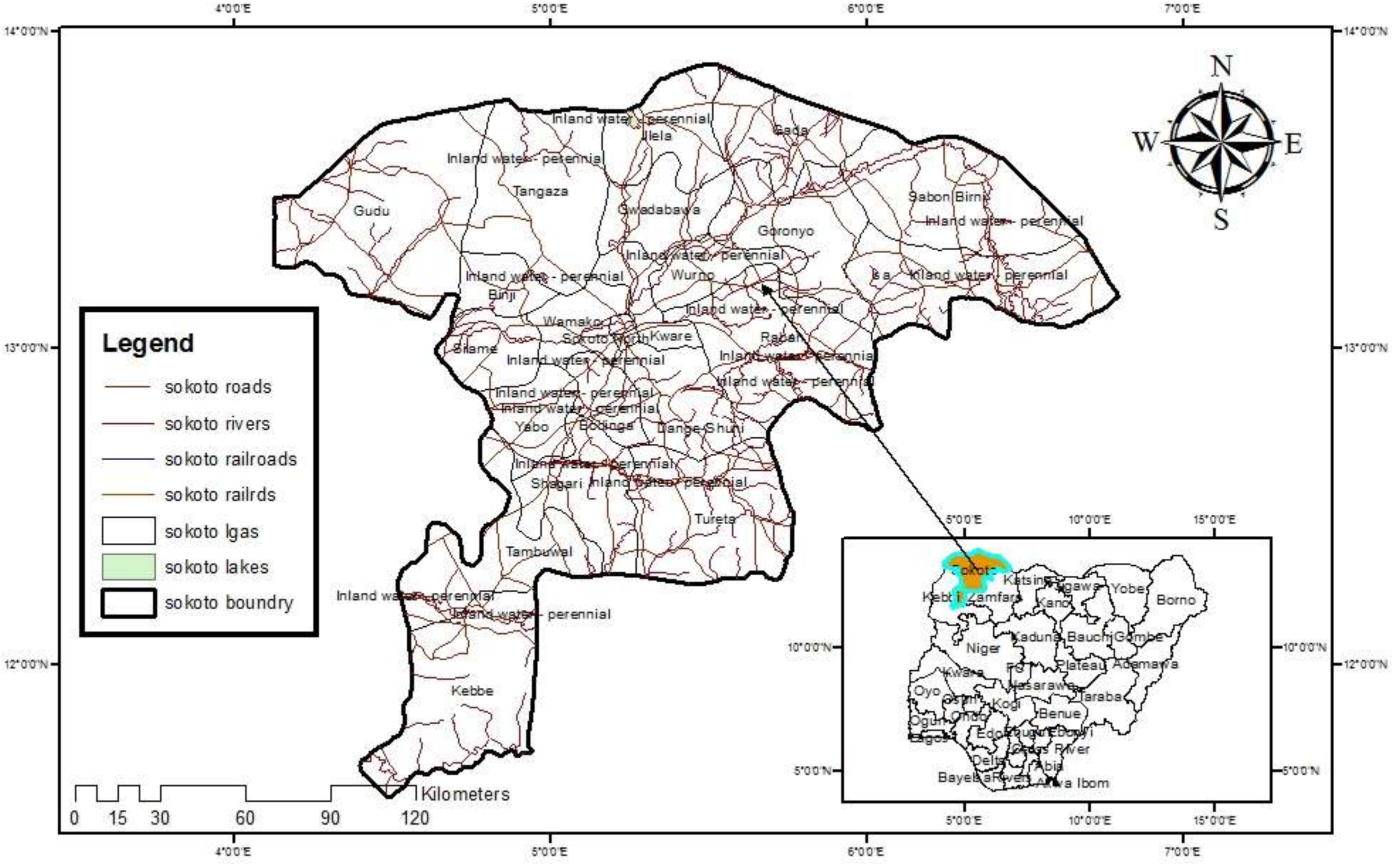

Figure 3.1. Study Area

Source: Adapted and Modified Administrative Map of Sokoto State

3.2.2 Climate

The climate of Sokoto State is tropical continental, dominated by two opposing air masses: tropical maritime and tropical continental. The tropical maritime is moist and blows from the Atlantic, while the tropical continental air mass, which is dry, blows from the Sahara Desert (Yelwa and Eniolorunda, 2012).

The tropical maritime predominates during rainy season while the tropical continental air mass predominates during the dry season. Much of the rain in Sokoto State falls between June and September in the north and from May to October in other parts. The annual rainfall is between 500mm in the north and 1000mm to the south (Mamman, 2003). With an annual average temperature of 28.3°C, Sokoto is one of the hottest cities in Nigeria, however the maximum daytime temperatures are generally under 40°C most of the year, and the dryness makes the heat bearable (Mamman, 2003).

Moreover, the State is characterised by two extreme temperatures relative to its tropical position namely the hot and cold seasons. The highest temperature during the hot season is experienced in the months of March/April. Between November and February, there is the prevalence of harmattan, characterized by very cold temperatures and dust laden winds often accompanied by thick fog of alarming intensity.

3.2.3 Drainage

Sokoto State is drained by the Rima River and its tributaries, most of which rise in the south eastern part of the state and in the neighboring Kaduna State. While the Bunsuru and Gangere Rivers flow in a northerly direction, joining the Rima near Sabon Birni, the Sokoto, Zarnfara and Katsina tributaries, on the other hand, flow west wards to join the

Rima (Yelwa and Eniolorunda, 2012). In their upper reaches, all the tributaries flow over basement complex rocks (Yelwa, 2008). Their valleys are rather narrow and restricted until the rivers enter the area of young sedimentary rocks, where they flow through broad valleys.

3.2.4 Soils

Ferruginous Tropical sandy soil with clayey subsoil are common, except along the floodplains of the river valleys where alluvial Hydromorphic soils predominate in the northern part, especially along the border with Niger Republic, the undulating plains are covered by aeolian deposits of variable depth. These support light sandy soils (Mamman, 2003).

3.2.5 Vegetation

The whole state falls within the Sudan Savannah. Sudan savanna belt is found in the north-west stretching from the Sokoto plains in the west, through the northern sections of the central highland. It spans almost the entire northern states bordering the Niger Republic and covers over one quarter of Nigeria's total area. The low annual rainfall of usually less than 1000 mm and the prolonged dry season (6-9 months) sustain fewer trees and shorter grasses than in the Guinea savannah. It is characterised by abundant short grasses of 1.5-2m and few stunted trees hardly above 15m.

The vegetation has undergone severe destruction in the process of clearing land for the cultivation of important economic crops such as cotton, millet, maize and wheat. This is in addition to devastation due to animal husbandry, especially cattle rearing, which is greatly favoured in this belt because the area is relatively free from tsetse fly (Mamman, 2003). The vegetation is also characterized by thorny species with a scatter of acacia, shear-butter, baobab and silk cotton. The river courses are lined with dum palms, which are interspersed with herbaceous covers of annual grasses (Abubakar and Eniolorunda, 2016). However, vegetation is the most important attribute used in assessing desertification.

3.2.6 Population and Culture

Sokoto state has a population of 3,702,676 people, (National Population Commission [NPC], 2006). Sokoto is dominated by two ethnic groups namely, Hausa and Fulani. Apart from Hausa and Fulani, there are the Zabarmawa and Tuareg minorities in the local government border areas.

Hausa people in the state are made up of Gobirawa, Zamfarawa, Kabawa, Adarawa and Arawa. The Fulani on the other hand are of two main groups; the town Fulani and the Nomads. The former includes the Torankawa, the clan of Shehu Usmanu Danfodiyo, Sullubawa and Zoramawa. The Torankawa are the aristocratic class since 1804 (Mamman, 2003).

Culturally the state is homogeneous. The people of the state are Muslims and Islamic religion provides them with a code of conduct and behavior. Their mode of dressing is also of Islamic origin. Two major festivals, namely Eid-el-Fitri and Eid-el-Kabir are celebrated in the state every year. The former marks the end of the Ramadan fast, while the latter features the slaughtering of rams in commemoration of an act of the Prophet Ibrahim (Abraham).

3.2.7 Economic Activities

Over eighty percent (80%) of the inhabitants of Sokoto State practice one form of agriculture or another. They produce such crops as millet, guinea corn, maize, rice, potatoes, cassava, groundnuts and beans for subsistence and produce wheat, cotton and vegetables for cash (Abubakar and Eniolorunda, 2016). Local crafts such as blacksmithing, weaving, dyeing, carving and leather works also play an important role in the economic life of the people of Sokoto State; as a result, different areas like Makera, Marina, Takalmawa and Majema in Sokoto became important (Rank, 2015). Sokoto State is also one of the fish producing areas of the country. Thus a large number of people along the river basin engage in fishing as well.

Sokoto State is equally endowed with natural and mineral resources. Agro allied industries using cotton, groundnut, sorghum, gum, maize, rice, wheat sugar cane, cassava, gum Arabic and tobacco as raw materials can be established in the area. Large scale farming can also be practiced in the state using irrigation farming. Minerals such as kaolin, gypsum, limestone, laterite, red mills, phosphate both yellow and green, clay, sand etc., are available in commercial quantities. Mineral based industries using these raw materials could be established in the State (Tasihu, 2008).

The absence of the tsetse fly on the open grassland benefits both wild and domestic animals. The availability of animal population provides good investment opportunities, particularly in agro-allied industries such as flour mills, tomatoes processing, sugar refining, textiles, glue, tanning, fish canning, etc. however, this economic activities are some of the factors causing and exacerbating desertification in Sokoto State (Mohammed, 2015).

3.3 Methodology

In this section, the various methods involved in gathering, processing and analyzing data for the study are framed.

3.3.1 Reconnaissance Survey

Reconnaissance survey was carried out in the study area so as to acquaint the researcher with information about the area which helped in primarily field data collection technique. This make the researcher to have adequate understanding of the physical situation on ground. During this survey, efforts were made in observing the physical nature of the area.

3.3.2 Types and Sources of Data

Different types and sources of data were used to achieve the desired aim and objectives of this study.

3.3.2.1 Data Used

Data used for this study includes:

i. Administrative map of Sokoto State
ii. EVI Aqua-MODIS (1990 to 2009) with 250m spatial resolution
iii. Rainfall Data (1990 to 2009)
iv. Ground Control Points (coordinates)

3.3.2.2 Sources of Data

The data used for the study were sourced via primary and secondary sources.

Primary Source of Data:

MODIS Enhanced Vegetation Index (EVI) was downloaded from http://ipdaac.usgs.gov/ as monthly synthesis set dating January 1990 to December,

2009. Global Positioning System (GPS) was used to obtain (coordinates) Ground Control Points of strategic locations which were used to establish typical status of the individual desertification sites visited and later evaluated with the IDRISI software. Administrative map of Sokoto State was then digitized in ArcGIS 10.1 software environment to obtain the LGA boundary of the study area.

Secondary Source of Data:

Rainfall data covering a span of 1990 to 2009 (20 years) was collected from the Nigerian Meteorological Agency (NIMET) Sokoto Station in order to determine the relationship between rainfall data and EVI. Literature materials were got from related previous thesis/dissertations, journals, published books, information download from internet, articles and magazines were also used.

3.3.3 Data Processing

3.3.3.1 Derivation of mean image

The EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy and canopy architecture whereas Normalized Difference Vegetation Index (NDVI) is chlorophyll sensitive but the two vegetation indices complement each other in global vegetation studies and improve upon the detection of vegetation changes and extraction of canopy biophysical parameters.

EVI data from AQUA-MODIS satellite images of 1990-1994, 1995-1999, 2000-2004 and 2005-2009 were downloaded from http:ipdaac.usgs.gov as monthly synthesis set to derive EVI Statistics.

MODIS EVI of 1990 to 1999 was received with a different projection to the one of 2000 to 2009. The former has a projection of clabsha as a reference system, layer type is raster, data type byte, reference unit of kilometres (km), Minimum X Value of 1093.776001, Maximum X Value 8906.2236328, Minimum Y value 117.2200012, maximum Y Value 9882.7802737, Number of Rows is 1280 and a Number of columns is 1024 with a unit distance of 1 in contrast to 2000 to 2009 images that was obtained with a reference system of latlong, and a reference unit of degree with 58 columns and 49 rows both images were converted to the same reference system of latlong and a total of 58 columns together with 49 rows using reformat and project tabs together with grid referencing transformation in Idris software.

3.3.3.2. Image windowing

Large size of many remotely sensed images made the acquired imageries to be windowed so as to get the segment of the full image that specifically pertain to the study area. Nigeria is windowed from the global Aqua MODIS image within Idrisi32, Release2, from the reformat option, reference system, layer type and reference unit were all checked and later study area was subset from Nigeria.

3.3.3.3. Creation of EVI mean images

To determine an overview of vegetation biomass change covering a specific time span using Aqua MODIS EVI satellite imageries, monthly synthesis sets dating from January 1990 to December 2009 were recomposed initially into annual composites and later into four sets covering five-year time periods. In order to demonstrate the procedures used to create annual composite image from the monthly synthetic images of the study area windowed from the main image using the following formula for each year on Idrisi32 release2 Remote sensing and GIS software.

(Jan+Feb+Mar+Apr+May+Jun+Jul+Aug+Sep+Oct+Nov+Dec)/12.

To further reduce the number images, the mean EVI covering five years each was composed to 1990 to 1994, 1995 to 1999, 2000 to 2004 and 2005 to 2009 periods using image calculator as illustrated in Figure 4.2 based on this formular (first year + second year + third year + forth year + fifth year)/5 for each period. This aided visual comparism of the images.

3.3.3.4. Analysis of trend and coefficient of variation

The converted ASCII format of the pentad was used to calculate the overall mean together with the standard deviation and coefficient of variation in EXCEL using the formula by Everitt (1998):

$$Cov = \boldsymbol{\sigma}/\mu \times 100$$

Where:

Cov = Inter-annual Coefficient of Variation

$\boldsymbol{\sigma}$ = Standard Deviation

μ = Mean

These were further re-converted to ASCII and exported back to Idrisi 32 release2 software for onward analysis. The images generated from the coefficient of variation was further used to generate trend images of the study area showing the trend and the direction of vegetation degradation in the area.

3.3.3.5 Image classification

Classification technique was performed using Idris32, Release2 GIS software to classify the images into various classes. Supervised classification was employed to achieve categorization of the imageries to a thematic classes. This method of classification involves the procedure of identifying pixels possessing the same spectral features using maximum likelihood algorithm such as areas of Low Change, Moderate Change and High Change. This pixel-based classification was performed within IDRISI software interface to produce an output raster layer. The procedure involve assembling groups of similar pixels into classes associated with information of interest.

The numerical information in all spectral bands for the pixels comprising these areas were used to "train" the computer to recognize spectrally similar areas for each identified class. The imageries were classified based on these features of depicted to ensure that the software did not classify other different.

3.3.4 Method of Data Analysis

Objective i: To examine the spatial pentad trend of vegetation strength in the study area. The two hundred and forty (240) monthly Enhanced Vegetation Index (EVI) images at 250m resolution from Aqua MODIS Satellite System covering the study area from 1990 to 2009 extracted and windowed in Idrisi32, release2 Geographical Information System (GIS) and image processing software. All data were converted into ASCII format and imported into EXCEL where they were re-composed into annual mean for each year and later to 5years interval thereby getting four Mean annual images. These were further re-converted and exported back to the Idrisi, software for analysis. Mean images were further used to generate trend images of the study area.

Objective ii: To determination the relationship between rainfall and EVI. Coefficient of variation was determine using the EVI and the rainfall data of the study area also regression analysis was performed to generate the relationship between the collected rainfall data and the EVI mean image of the study area. This was achieved using IBM SPSS Statistics software version 21 using rainfall as independent variable and the EVI images as dependent variable.

Objective iii: To identify prone areas to desertification. Analysis was done using database query from GIS Analysis on Idrisi32, release2, GIS software environment and processed in ArcMap 10.1. The area of the resulting thematic classes for each pentad coefficient of variation was calculated within the software interface. The area calculation of the desert prone areas and spatial extent of desertification in the study area was presented in km^2.

Objective iv: To Map out the spatial extent of desertification. The desert prone areas were used to map out the spatial extent of the Sahara Desert in the study area using idrisi32 release2 Geographic Information System (GIS) and image processing software and processed in ArcMap 10.1.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results of the study. It include results derived from mean EVI images of multi date AQUA-MODIS satellite imageries from 1990 to 2009, the spatial pentad trend of vegetation strength, the relationship between rainfall and vegetation of the study area, identification of areas prone to desertification and mapping the spatial extent of desertification.

4.2 Spatial Pentad Trend of Vegetation Strength

4.2.1. Mean EVI Image of Sokoto (1990 to 1994) and (1995 to 1999)

The mean EVI image of Sokoto State 1990 to 1994 and 1995 to 1999 are presented in Figure 4.1 and 4.2.

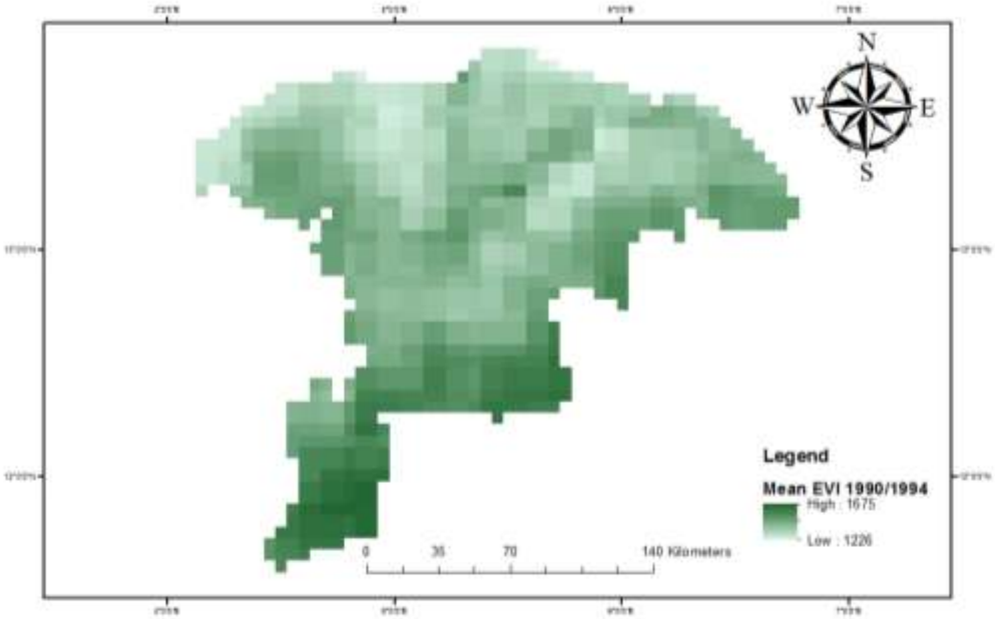

Figure 4.1 Mean EVI derived from AQUA-MODIS 1990/1994

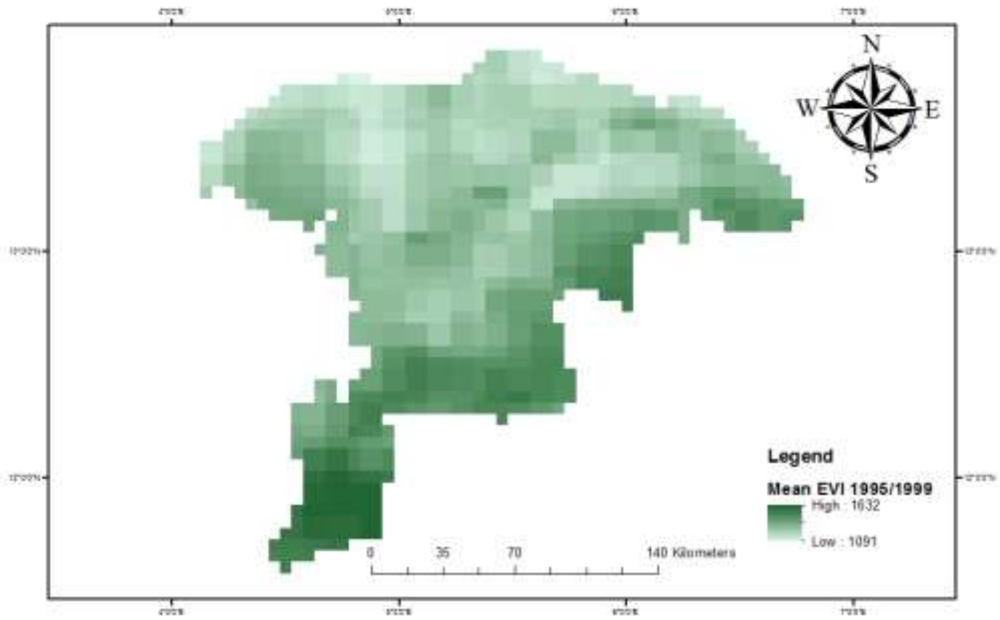

Figure 4.2 Mean EVI derived from AQUA-MODIS 1995/1999

Figure 4.1 and 4.2 shows the output of the study area EVI mean image for the years 1990 to 1994 and 1995 to 1999. The mean images shows a typical vegetation pattern of Sokoto state. The vegetation was more in the areas of dark green colour/areas of high

EVI values and these areas where found at the northern part of the state coming down to a moderately sparse vegetation within the central part of the state to areas of decreasing vegetation with light green colour/areas of low EVI values. The implication of the inconsistence vegetation strength could be as a result of population pressure in the areas that is to say high population pressure could lead to more anthropogenic activities in the areas and vice versa, also the vegetation strength confirms the sensitivity of EVI to spatiotemporal rainfall variation.

4.2.2 Mean EVI Image of Sokoto (2000 to 2004) and (2005 to 2009)

The mean EVI image of Sokoto 2000 to 2004 and 2005 to 2009 are presented in Figure 4.3.

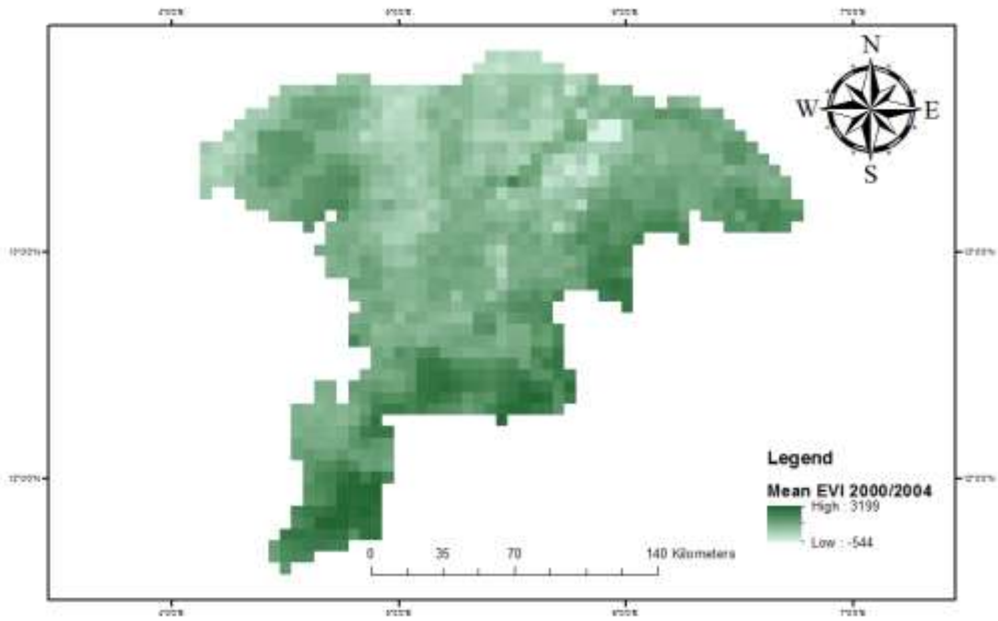

Figure 4.3 Mean EVI derived from AQUA-MODIS 2000/2004

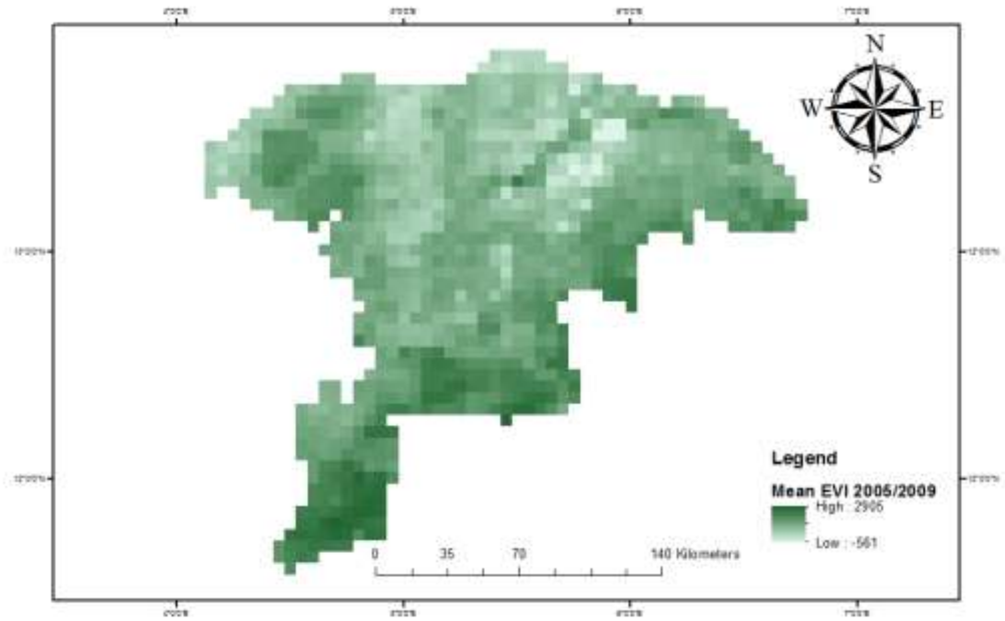

Figure 4.4 Mean EVI derived from AQUA-MODIS 2005/2009

Figure 4.3 and 4.4 Mean Image Derived from Aqua MODIS 2000 to 2004 and 2005 to 2009 shows a drastic change in comparison to the image of 1995-1999 and 1990-1994. It gives a visual impression of an approximate vegetation biomass of Sokoto State for the years. The mean EVI values on the scale ranges from -544 and -561 as minimum values indicating areas that are low vegetation including water bodies and this can be clearly seen at the northern part of the map to the area with a very sparse vegetation that is little bit greenish in colour around the central part of the state down to the areas of increasing vegetation biomass cover at the southern part of the map with a maximum value of 3199 and 2905. Although there are few areas of negative EVI in the southern areas, most of the areas with pronounced negative values in EVI are located at the extreme southern part of the map.

4.2.3 Overall Mean EVI Image of Sokoto (1990 to 2009)

The mean EVI image of Sokoto State is presented in Figure 4.5.

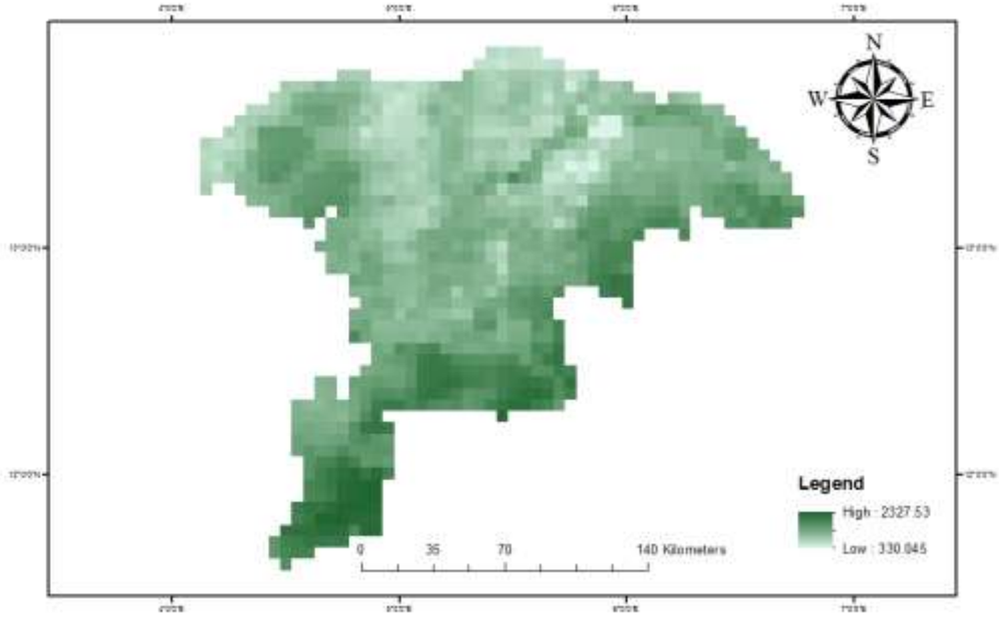

Figure 4.5 Overall Mean EVI derived from AQUA-MODIS 1990/2004

Figure 4.5 shows the overall mean image of the study area between 1990 and 2009. The minimum and maximum EVI value are 330 and 2327.5 respectively. Areas of low values are located in the central north to the center of the state, while the high values are the south, east, northeast and part of the northwest. The disparity in the vegetation biomass between northern and the southern part of the state is clearly shows that vegetation biomass is more degraded to the north west and north eastern part than to the southern part of the state.

4.3 Pentad trend of vegetation strength

The Pentad trend of vegetation together with the Coefficient of variation are presented in the following sections.

4.3.1 Pentad Trend of Vegetation Strength of study area 1990/1994

The pentad trend of vegetation strength covering Sokoto State 1990/1994 is presented in Figure 4.6.

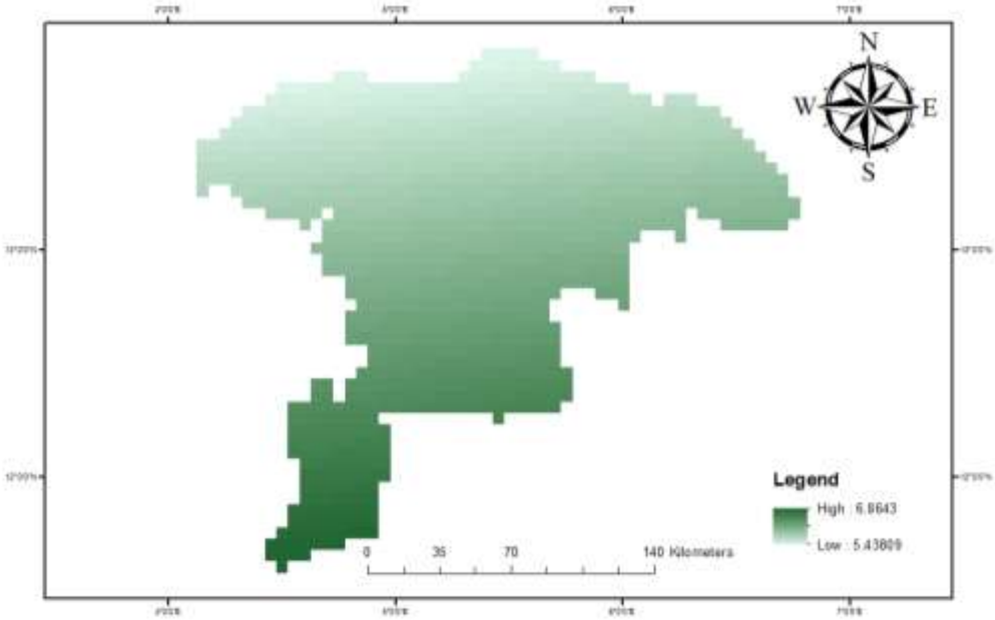

Figure 4.6 Trend image generated from the mean EVI 1990/1994

Figure 4.6 indicate the trend of vegetation within the study area. A downward trend of vegetation strength within the study area was observed from the northwestern area of the map moving diagonally to the extreme southern part of the state. The implication of this trend is that with time the vegetation trend will continue to diminish and the direction of vegetation degradation maintains a northwest to southeast direction.

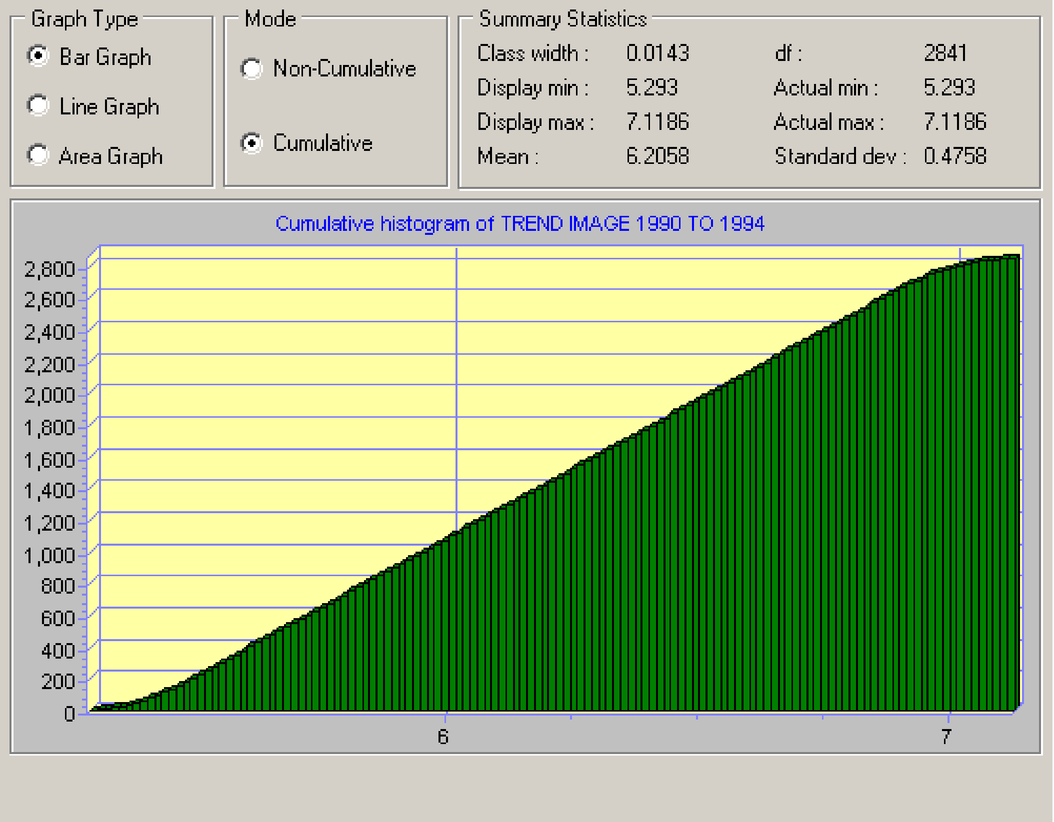

Figure 4.7 Cummulative histogram of trend image 1990/1994

Figure 4.7 shows the statistical values used in calculating the coefficient of variation of the study area limited to 1990 to 1994. The results indicate actual/display minimum and maximum values of 5.293 and 7.1186 respectively. It has a class width of 0.0143, mean 6.2058 and standard deviation 0.4758.

4.3.2 Pentad Trend of Vegetation Strength of the study area 1995/1999

The pentad trend of vegetation strength of Sokoto State (1995 to 1999) is presented in Figure 4.8.

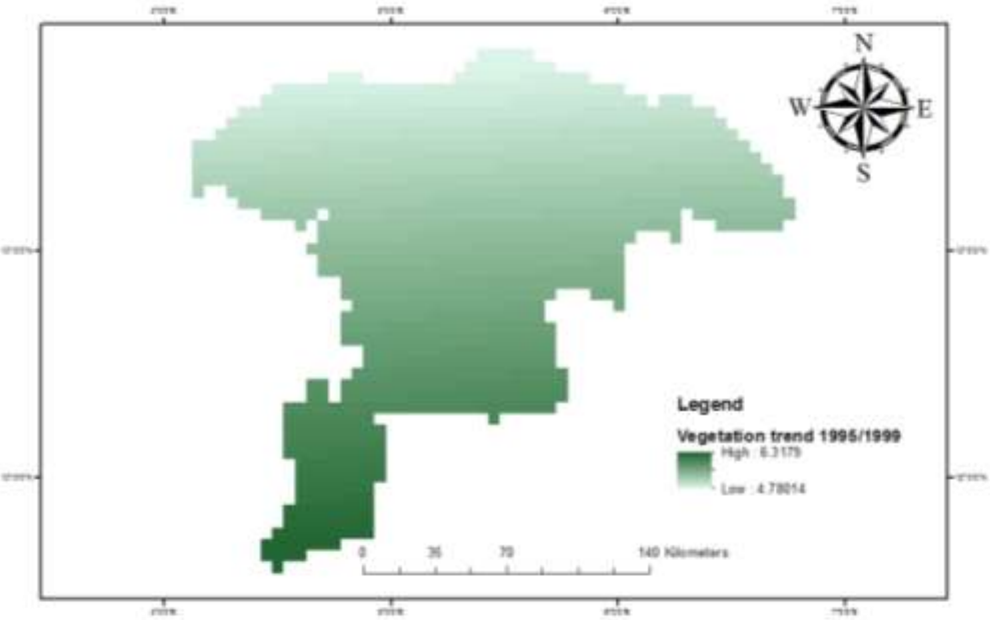

Figure 4.8 Trend image generated from the mean EVI 1995/1999

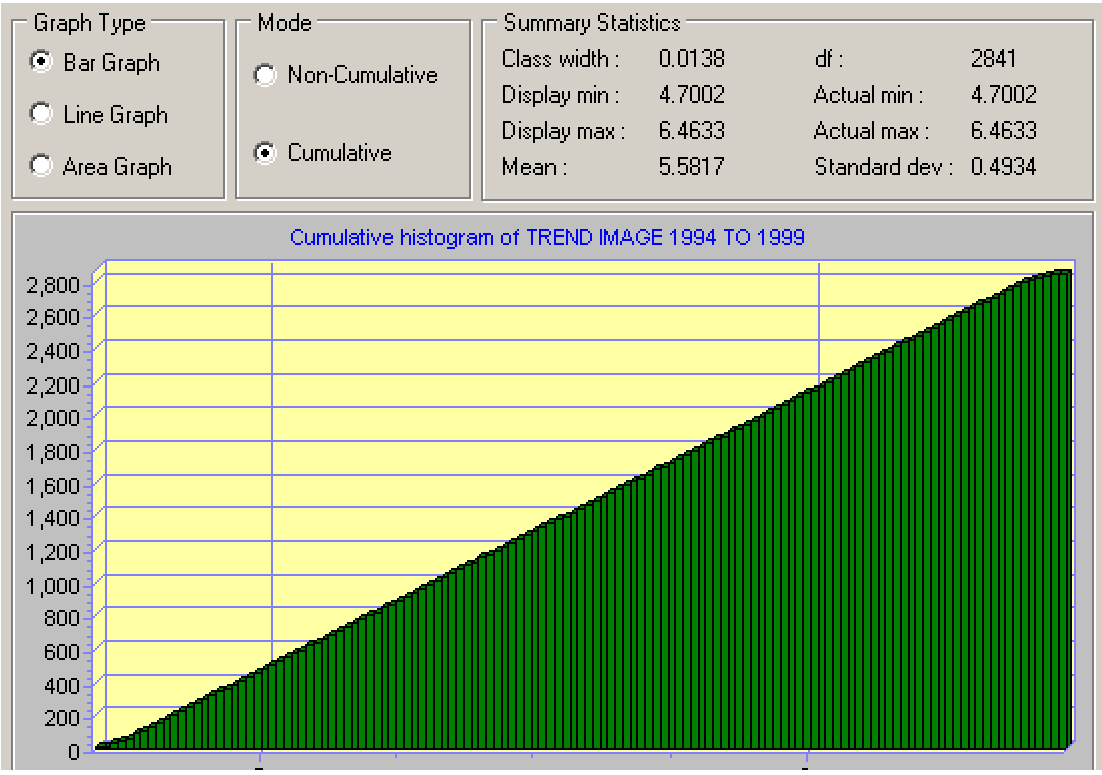

Figure 4.9 Cummulative histogram of trend image 1995/1999.

Figure 4.8 shows the trend of vegetation in the study area. The trend demonstrate the direction of vegetation moving from northwest to south east direction and the vegetation strength was found at the top-left corner (northwest) that is light yellow colour area this inconsistency pattern of vegetation confirms the sensitivity of EVI to rainfall variation.

Figure 4.9 shows a cumulative histogram generated from Figure 4.10. It displays the mean and standard deviation used to generate a coefficient of variation image of the study area. The result indicates actual/display minimum and maximum values of 4.7002 and 6.4633 respectively which show a decrease compare to the image of 1990-1994. It also has a mean of 5.5817, class width 0.0138 all of which shows a decrease, with an increase in standard deviation to 0.4934.

4.3.3 Pentad Trend of Vegetation Strength of the study area 2000/2004

The pentad trend of vegetation strength covering the study area dated 2000 to 2004 is presented in Figure 4.10.

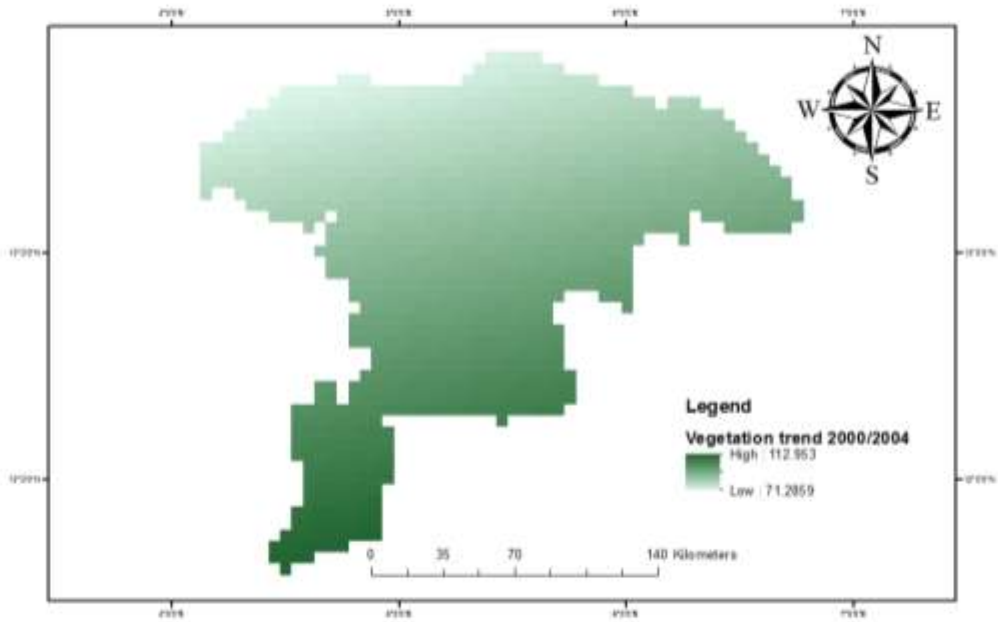

Figure 4.10 Trend image generated from the mean EVI 2000/2004

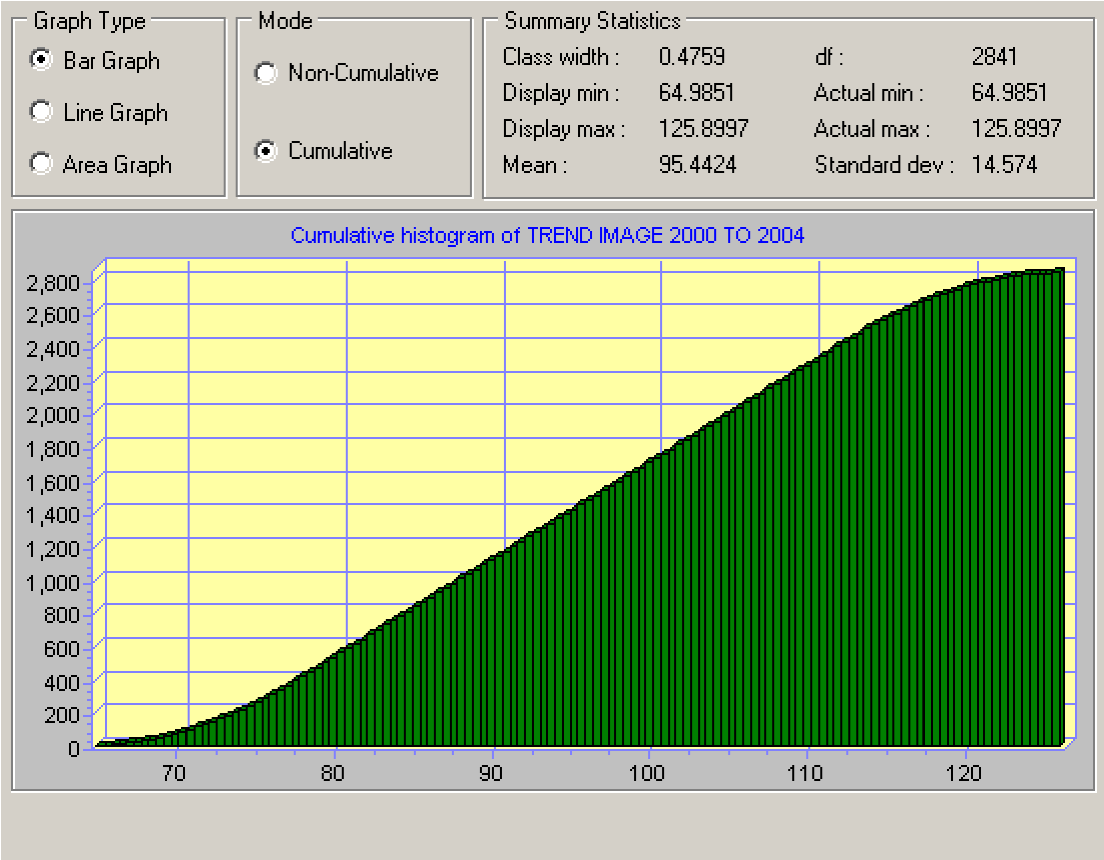

Figure 4.11 Cummulative histogram of trend image 2000/2004

Figure 4.10. shows the trend of vegetation generated by the EVI mean image of 2000 to 2004. The trend is similar to those of 1990/1994 and 1995/1999. It also shows vegetation strength will continue to diminish in a diagonal manner from the northwestern area to the north east down to central part of the state to the southwest and southeast.

Figure 4.11 shows the cumulative histogram of study area mean image (2000–2004). The result shows the Standard deviation and the mean generated from Figure 12. It indicates the actual/display minimum and maximum values of 64.9851 and 125.8997 respectively which means there is a rapid increase compare to the previous images of 1990-1994 and 1995-1999. It has a class width of 0.4759, mean 95.4424, and a standard deviation of 14.574 all of them indicate an increase.

4.3.4 Pentad trend of the vegetation strength of the study area 2005/2009

The pentad trend of the vegetation strength image of Sokoto State is presented in Figure 4.12.

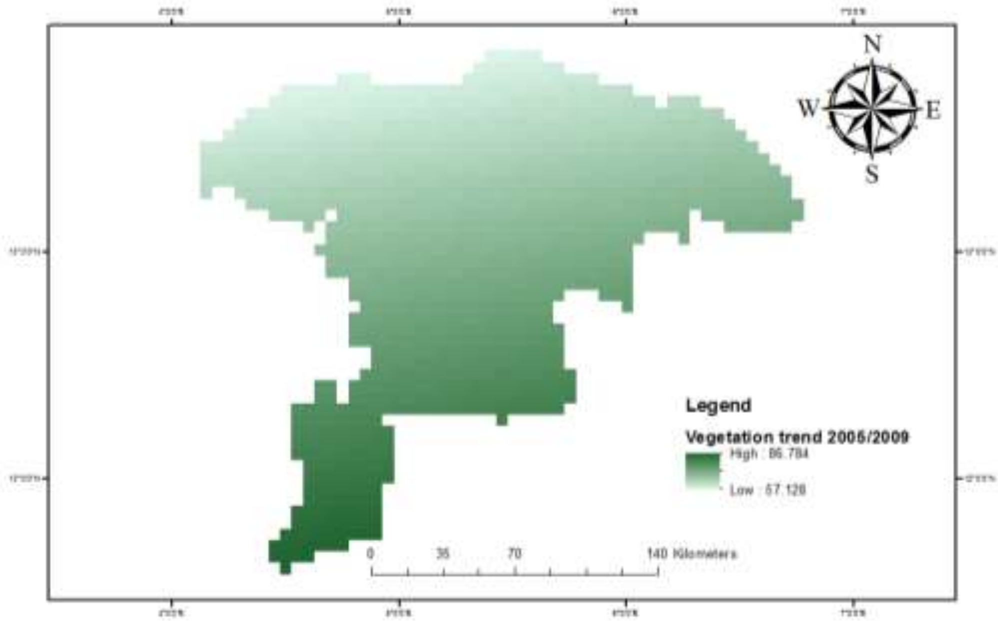

Figure 4.12 Trend image generated from the mean EVI 2005/2009

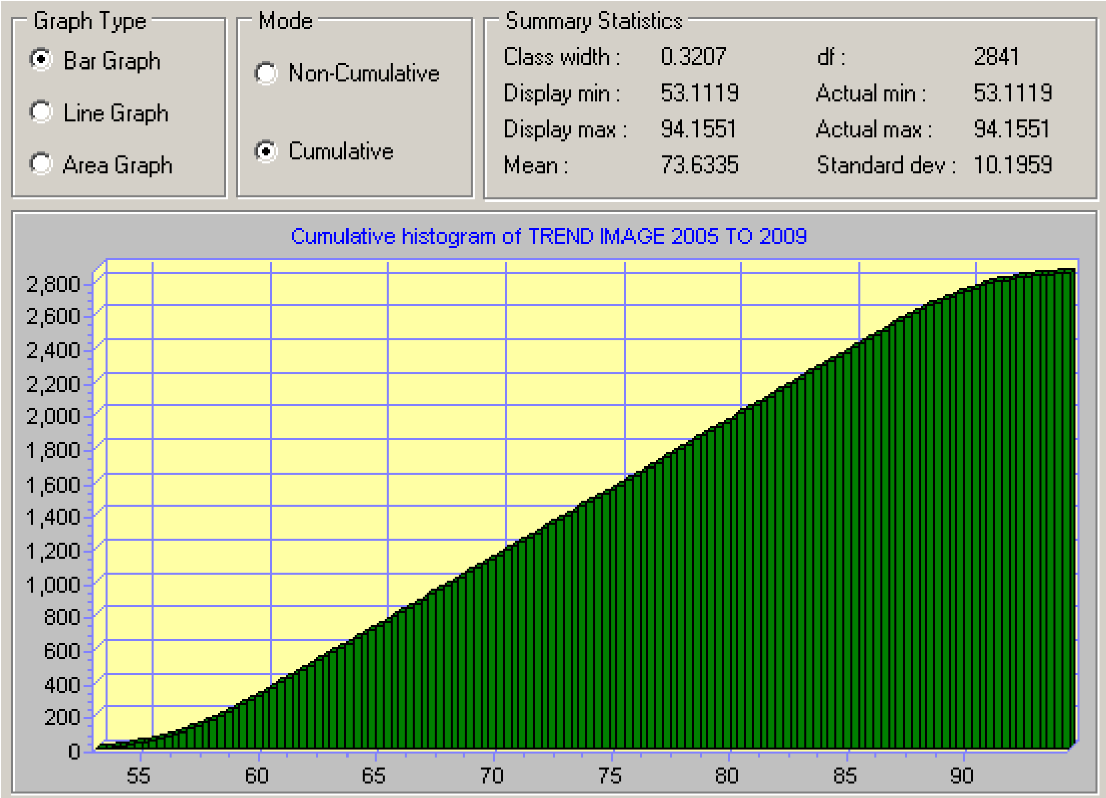

Figure 4.13 Cummulative histogram of trend image 2005/2009

Figure 4.12 depicts the trend of vegetation in the study area for 2005/2009. The observed trend is similar to those of 1990/1994, 1995/1999 and 2000/2004. It shows the direction of vegetation degradation from the northwestern area of the map to the southeastern part of the state.

Figure 4.13 shows the descriptive statistics used to classify the areas of high and low coefficient of variation. The results indicate the actual/display minimum and maximum values of 53.1119 and 94.1551 respectively and class width of 0.3207, mean 73.6335, and a standard deviation of 10.1959and all shows that there is a decrease compare to the one of 2000-2004.

4.3.5 Overall pentad trend of the vegetation strength in the study area 1990/2009

The pentad trend of vegetation strength image of Sokoto State is presented in Figure 4.14.

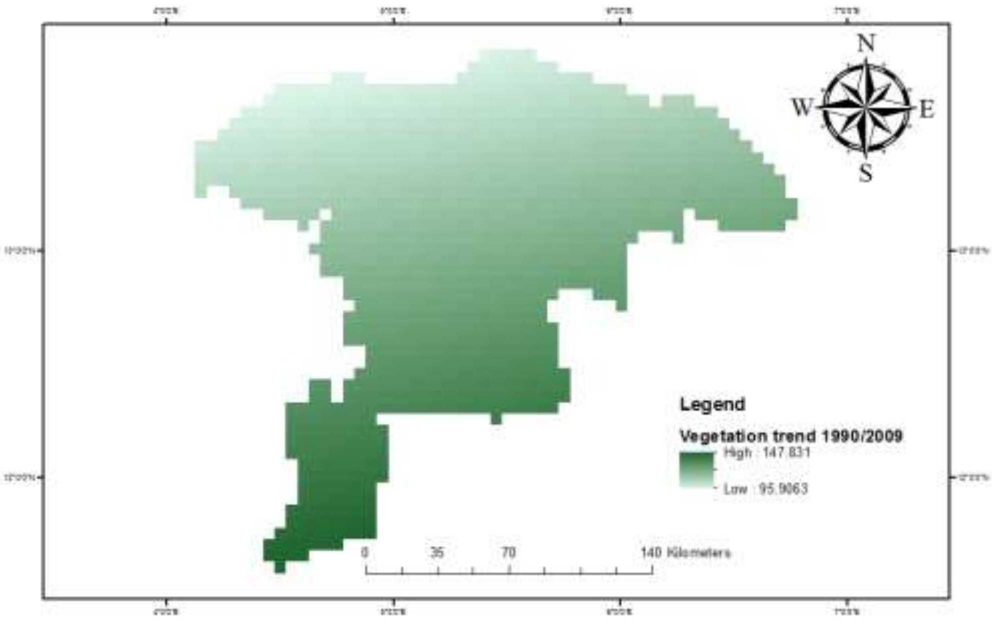

Figure 4.14 Overall trend 1990/2004

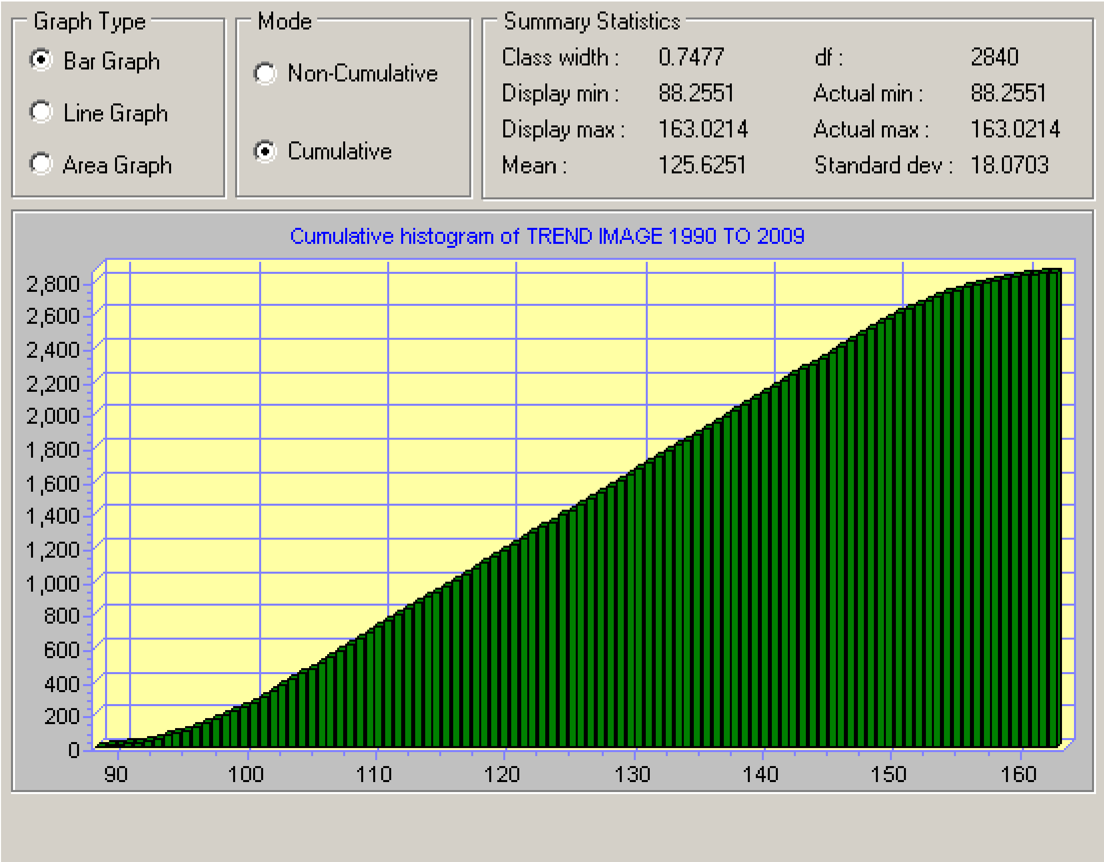

Figure 4.15 Overall cummulative histogram of trend image generated from mean image 1990/2009

Figure 4.14 shows the trend of the vegetation strength in the study area. The observed pattern indicate downward movement from the north to the southern. The implication of this variation express that the vegetation will continue to diminish as time goes on.

Figure 4.15 indicates the overall cummulative histogram of the study area mean image between (1990-2009). It shows the deccriptive statistical values of the image with actual/display minimum and maximum values of 88.2551 and 163.0214, mean of 125.6251, class width of 0.7477 and a standard deviation of 18.0703.

4.3.6 Coefficient of variation of 1990/1994 pentad trend

The inter-annual coefficient of variation image of the study area 1990 to 1994 is presented in Figure 4.16.

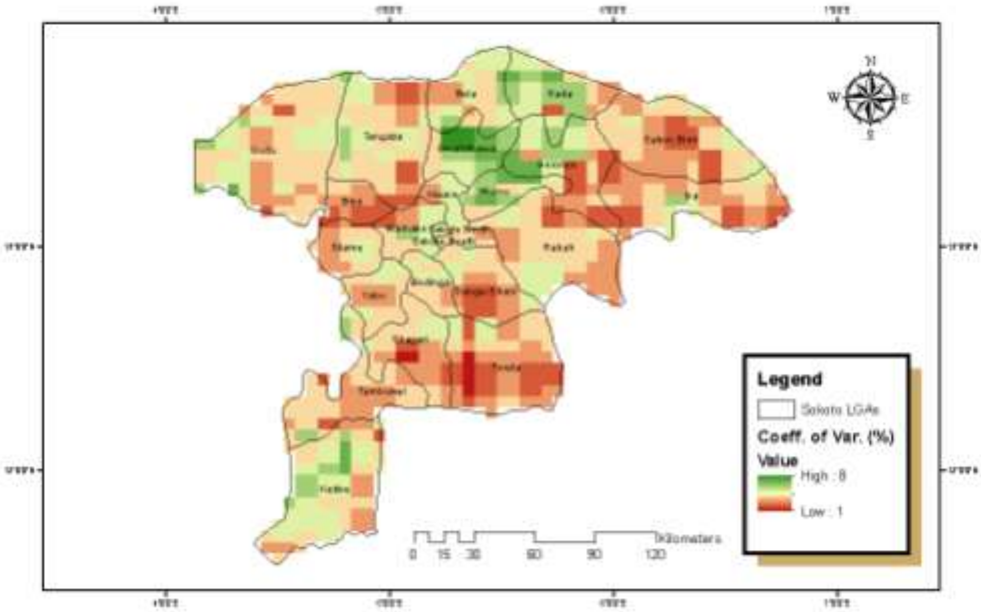

Figure 4.16 Pentad coefficient of variation image 1990/1994

Figure 4.16 shows the highest coefficient of variation of about 8% at Kaddi and Sabon Gida areas of Gada followed by Kaideji, Waria, and Gozange then Mamman Suka village in Illela all at the northern region of the state.

Plate 1: Shelter Belt at Kaideji Village, Gada LGA. Plate. I indicate the status of one of the areas with highest values of coefficient of variation within the study area. The Plate is located on a latitude 13^0 44′ 05.65″N and a longitude of 5^0 17′ 53.83″E.

Source: Field survey, 2016

Classified coefficient of variation pentad covering the study area 1990/1994 is presented in Figure 4.17.

Figure 4.17 shows the changes in relation to coefficient of variation within the first five years 1990/1994. Coefficient of variation within the study area were proved by the field observation restricted to areas of high coefficient of variation. Areas of no, very slight and slight change were found around Kebba and Bodinga Local government area while areas of moderate to moderately high change were around Rabah and Wurno local government areas followed by areas of high to very high change around Gada. Areas like Illela, Tangaza, Gudu and Sabon Birni that are found at the northwestern to the north eastern areas of Sokoto state were visited for ground truthing.

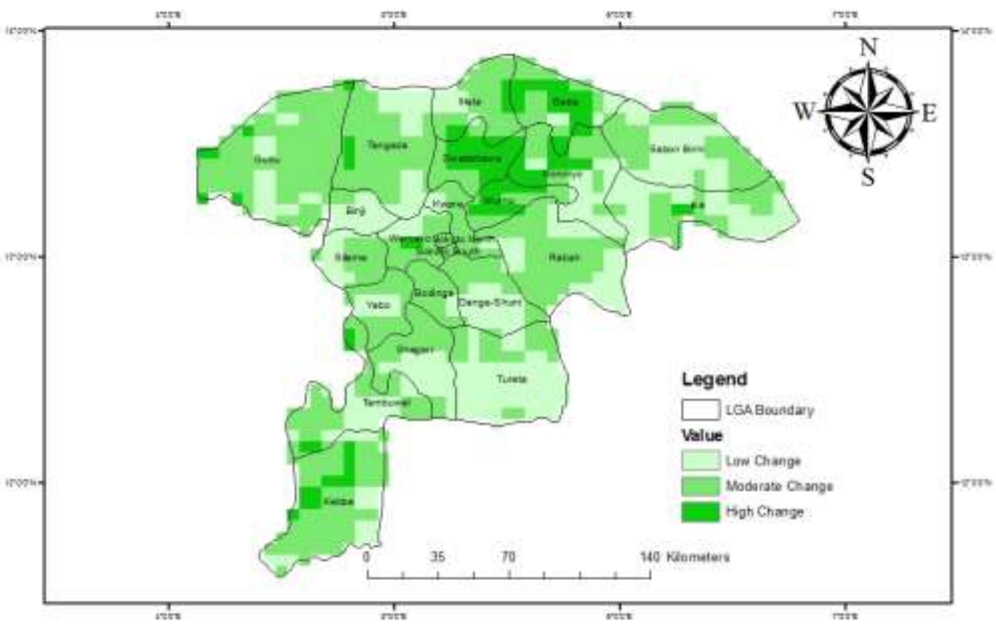

Figure 4.17 Classified coefficient of variation image 1990/1994

Plate II. Typical vegetation at Sabon Gida Village in Gada. Plate.II Indicate the status of the area found to be with a high value of the coefficient of variation within the study area. The area is located on a latitude 13^0 46′ 01.33″N and longitude 5^0 39′ 10.29″E.

Source: Field survey, 2016

Plate III. Vegetation status in Mamman Suka village at Illela. Plate.III Indicate the status of the area found to be with a high value of the coefficient of variation within the study area. The place is located on a latitude 13^0 44′ 07.81″N and a longitude of 5^0 17′ 52.90″E.

Source: Field survey, 2016.

4.3.6 Coefficient of variation pentad of image 1994/1999

The coefficient of variation pentad image covering the study area between 1994/1999 is presented in Figure 4.18.

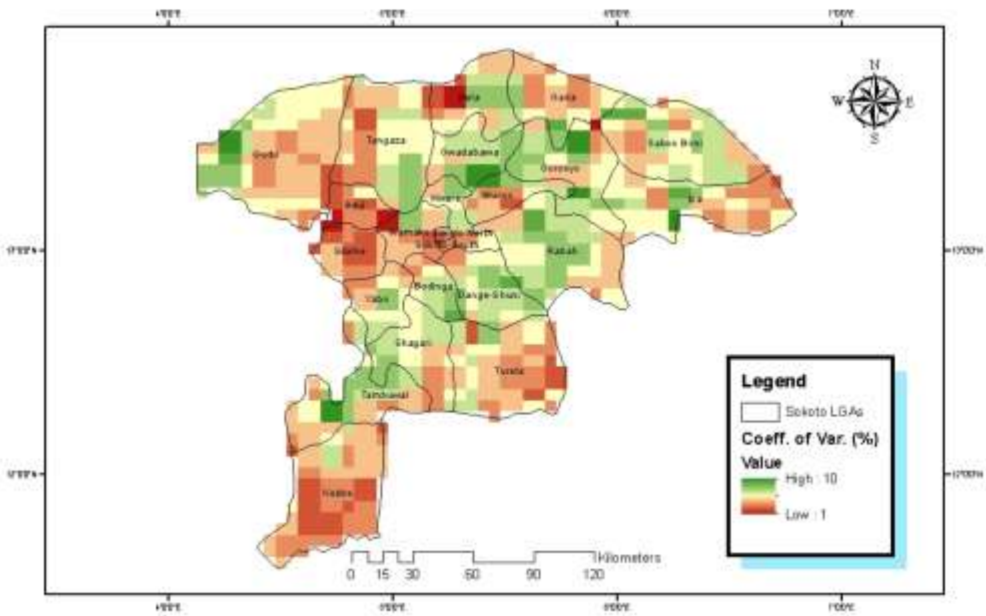

Figure 4.18 Coefficient of variation pentad of image 1995/1999

Figure 4.18 shows the coefficient of variation pentad image covering study area 1995/1999. The result shows moderate change compares to the first image 1990/1994. The maximum change ranges from 8% to 10% which indicates a little shift from the 1995/1999 image because the percentage of change increases and maintains the same trend of areas with a high coefficient of variation.

Classified of coefficient of variation pentad of the study area 1995/1999 is presented in Figure 4.19.

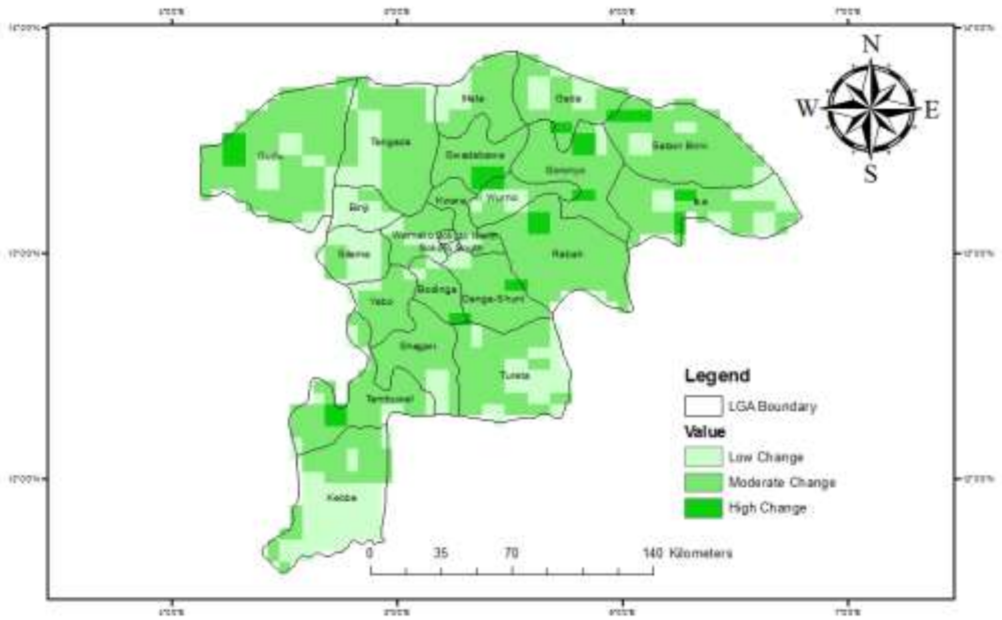

Figure 4.19 Classified coefficient of variation image 1995/1999

Figure 4.19 shows a classified coefficient of variation image. Gwaranyo and Gwadabawa are within the areas of high change while Kebba with low changes. It indicates areas of highest, medium or moderate and the lowest coefficient of variation ranging from the northern area of the state follow by the northcentral region with a moderate change down to southwest to the southeast that detect little or no change in relation to the coefficient of variation.

4.3.7 Coefficient of variation pentad image of study area 2000/2004

The pentad coefficient of variation covering the study area 2000/2004 is presented in Figure 4.20.

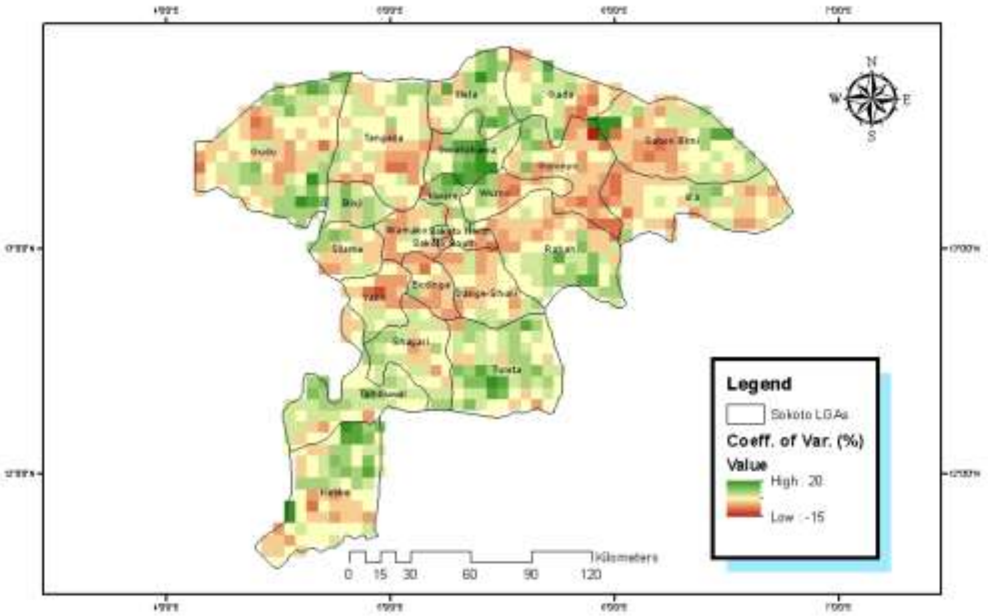

Figure 4.20 Coefficient of variation pentad image of the study area 2000/2004

Figure 4.20 indicates a maximum of 20% of change in the study area in contrast to 1990/1994 and 1995/1999. Areas of high coefficient of variation could be seen at the northern part of the state.

Classified coefficient of variation pentad image covering covering the study area 2000/2004 is presented in Figure 4.21.

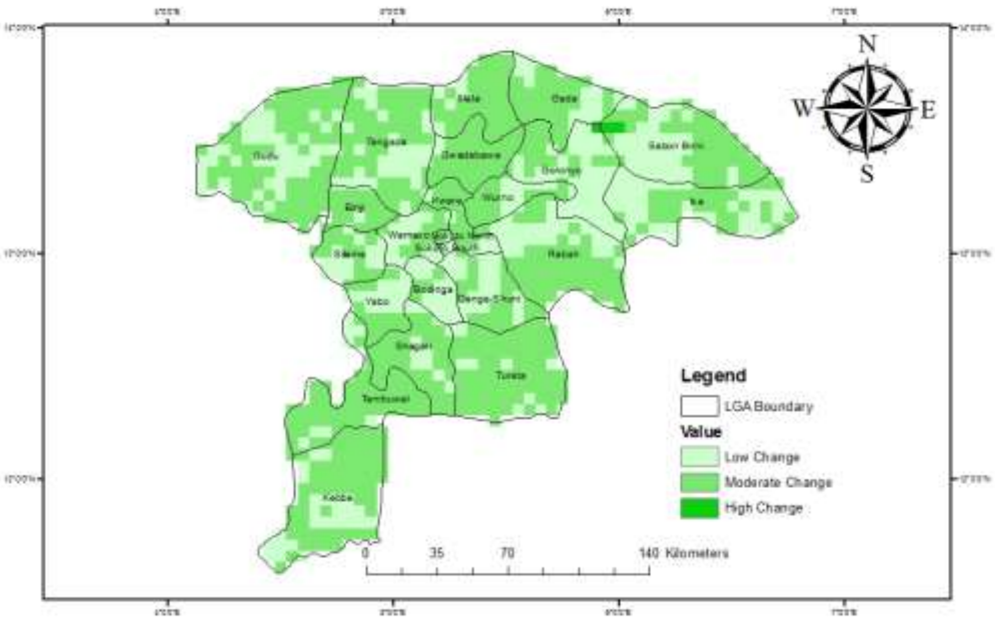

Figure 4.21 Classified coefficient of variation image 2000/2004

Figure 4.21 shows Areas like Tambuwal were classified as low because images show a steady condition of vegetation trend within the area others like Tureta, Rabah and Binji are classified as having moderate change while Illela Tangaza, Gada, Gudu and Sabon Birni at the northern part of the state fall in with high change which might actually either be bare or rendered bare due to combined effects of climate and human activities such as cultivation, animal rearing, fuelwood extraction, bush burning among others.

Study carried out by Yelwa and Isah (2010) and the field survey also confirm the fact that the area is really a dry zone with exposed soil surfaces with some shrubs and grasses.

Plate IV. Vast open land Kadagiwa Village in Tangaza. Plate. IV Indicate the status of the area found to be with a high value of the coefficient of variation within the study area. The Plate is located on a latitude 13^0 44′ 20.62″N and a longitude of 5^0 17′ 34.14″E.

4.3.8 Coefficient of variation pentad image of the study area 2005/2009

The Coefficient of variation pentad image covering the study area 2005/2009 is presented in Figure 4.22.

Figure 4.22 shows the inter-annual coefficient of variation image of Sokoto state dated 2005 to 2009 with a range between -13% and 18%. This indicates a decrease in comparison to the image of 2000/2004. Areas with high coefficient of variation changes are small which means the change was insignificant within these years.

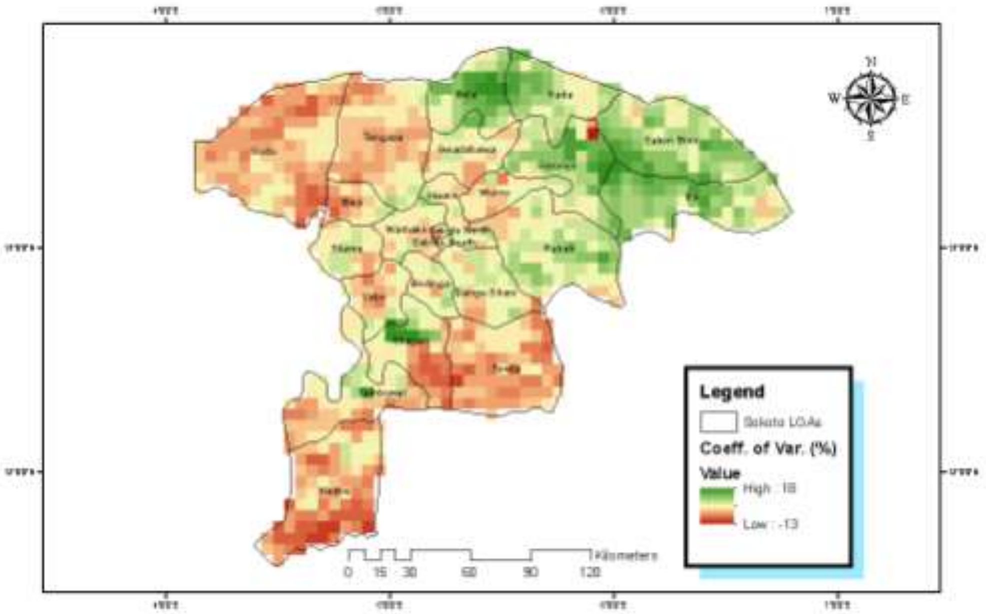

Figure 4.22 Coefficient of variation pentad image of the study area 2005/2009

Classified coefficient of variation pentad covering the study area is presented in Figure 4.23.

Figure 4.23 displays the areas with high, moderate, moderately and low coefficient of variation within the study area. The results indicate areas like Gwadabawa from the northern part to have slight change than the southern part of the state in 2005/2009. However, areas like Sobon Birni, Isa, Goronyo, Illela and Gada shows neither high, moderate or nor change and this might be attributed to the human activities in the area.

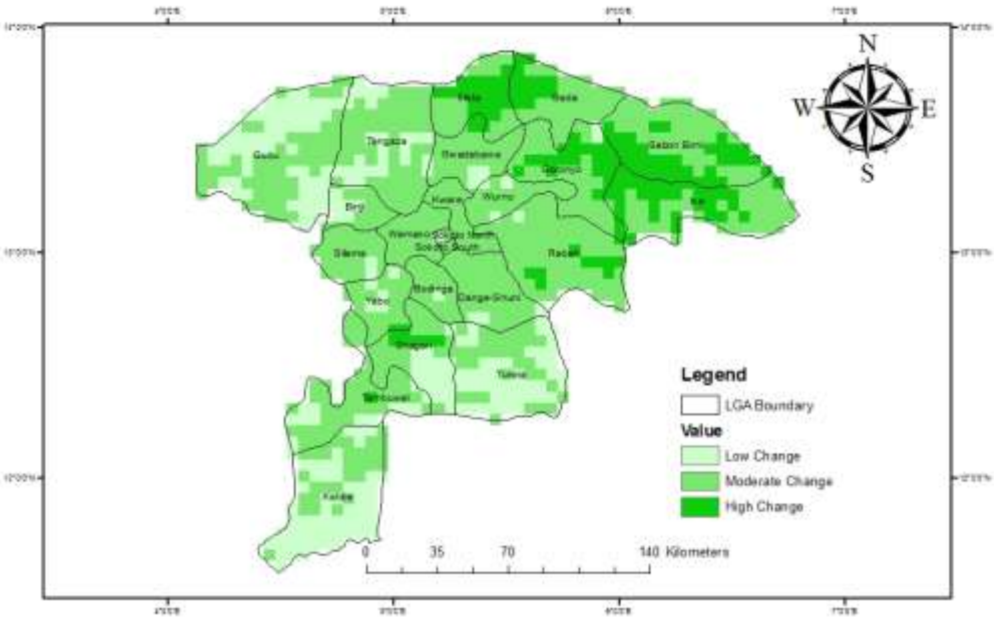

Figure 4.23 Classified coefficient of variation pentad image 2005/2009

4.3.9 Coefficient of variation pentad image 1990/2009

The coefficient of variation pentad image covering the study area 1990/2009 is presented in Figure 4.24.

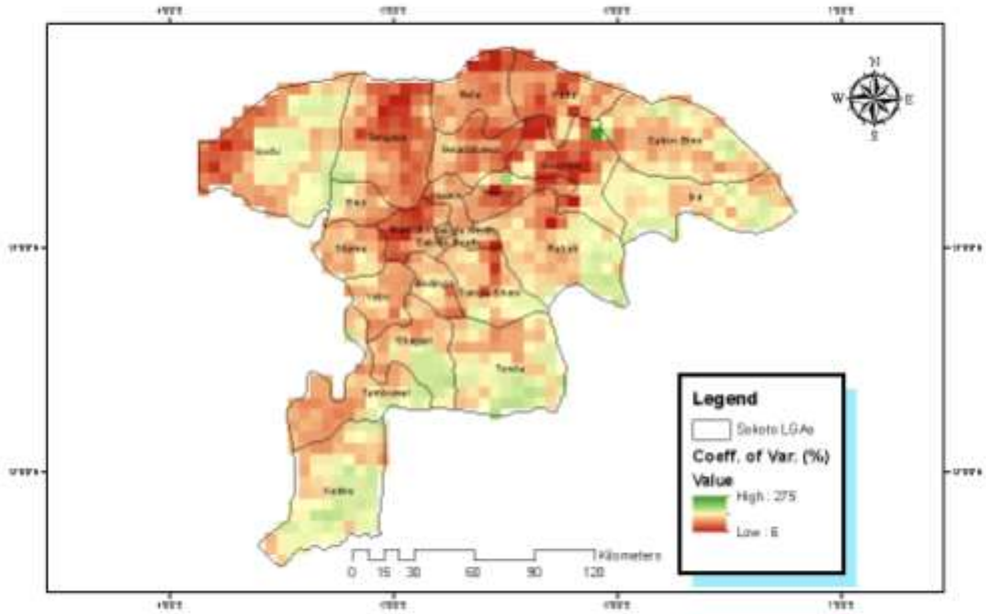

Figure 4.24 Coefficient of variation image 1990/2009

Figure 4.24 shows a range between 6% and 275. Areas like Sabon birni, ILlela and Tangaza are found to be with high coefficient of variation followed by moderate around Gudu, Tambuwal, and Yabo while Wurno is with low change.

Classified coefficient of variation image covering the study area is presented in Figure 4.25.

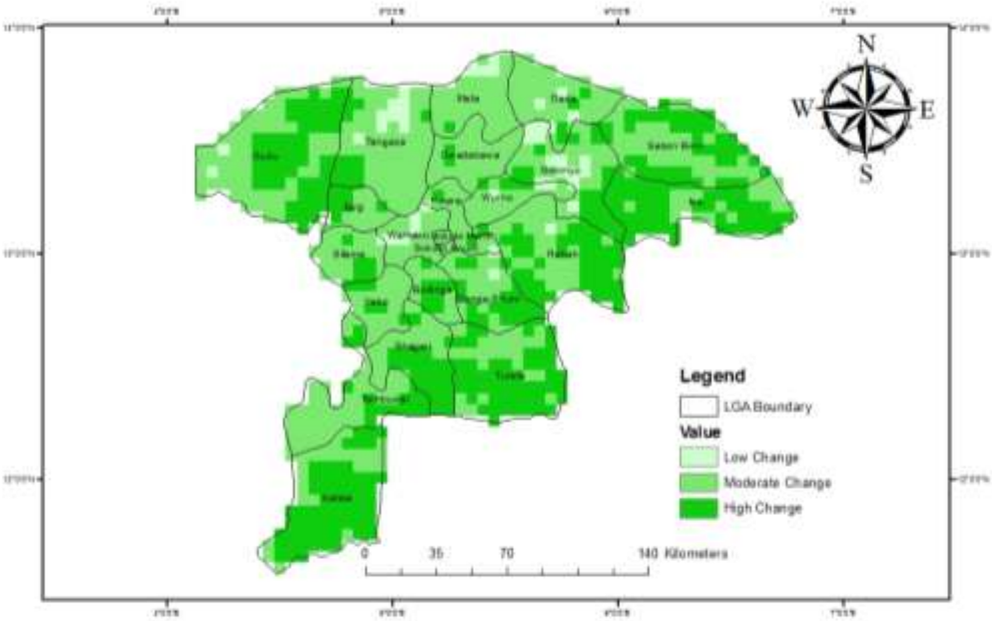

Figure 4.25 Classified coefficient of variation pentad image 1990/2009

Figure 4.25. It indicates that marginal part of the study area render positively high changes while the central part change very slightly or no change.

4.4 Characterization of rainfall of the study area 1990/2009

The characterization of rainfall of study area 1990/2009 is presented under the following subheadings:

4.4.1 Rainfall distribution of the study area

The monthly distribution of rainfall in the study area 1990 is presented in Figure 4.26.

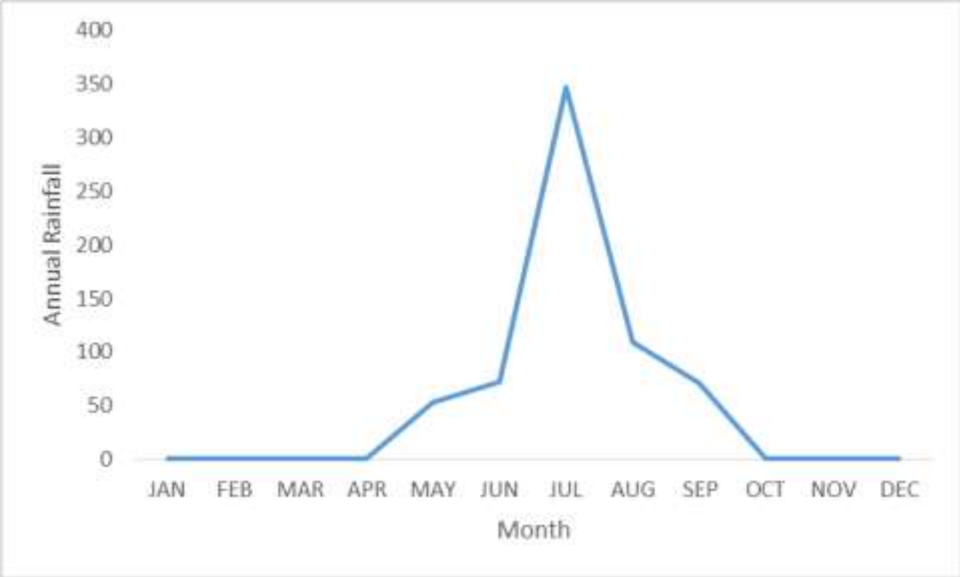

Figure 4.26 Monthly rainfall distribution of the study area 1990

Figure 4.26 shows theannual pattern of rainfall distribution and month of July, found to be the highest with 347.4mm, followed by August 109.6mm and June 72.2mm.

The pentad rainfall of the study area are presented in Figure 4.27, 4.28, 4.29 and 4.30.

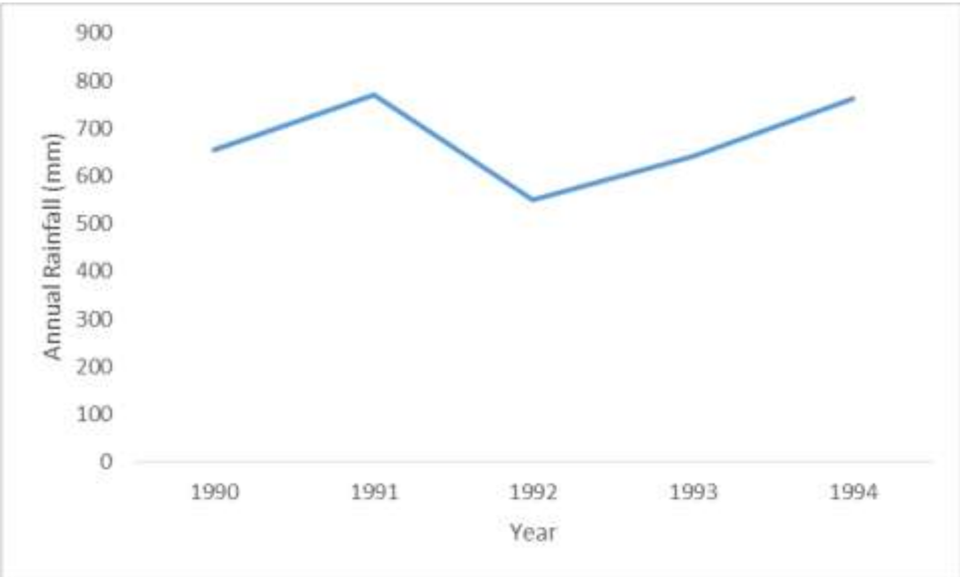

Figure 4.27 Rainfall Distribution Pentad of the study area 1990/1994

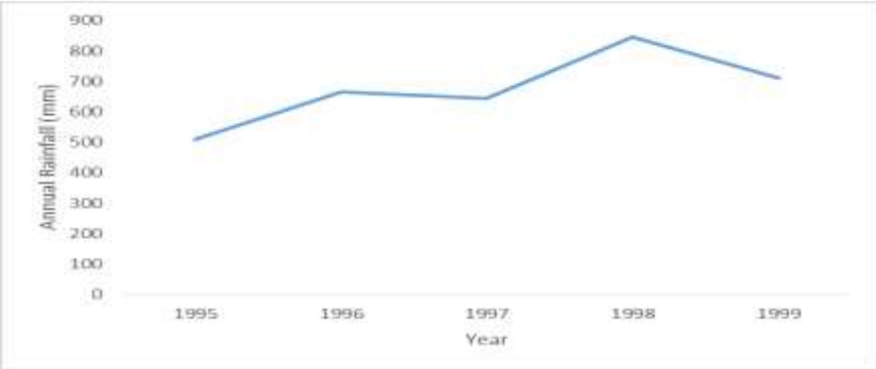

Figure 4.28 Rainfall Distribution Pentad of the study area 1995/1999

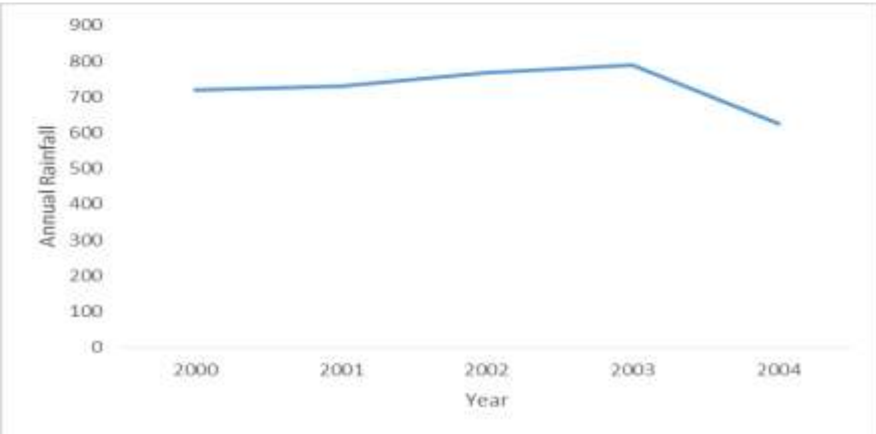

Figure 4.29 Rainfall Distribution Pentad of the study area 2000/2004

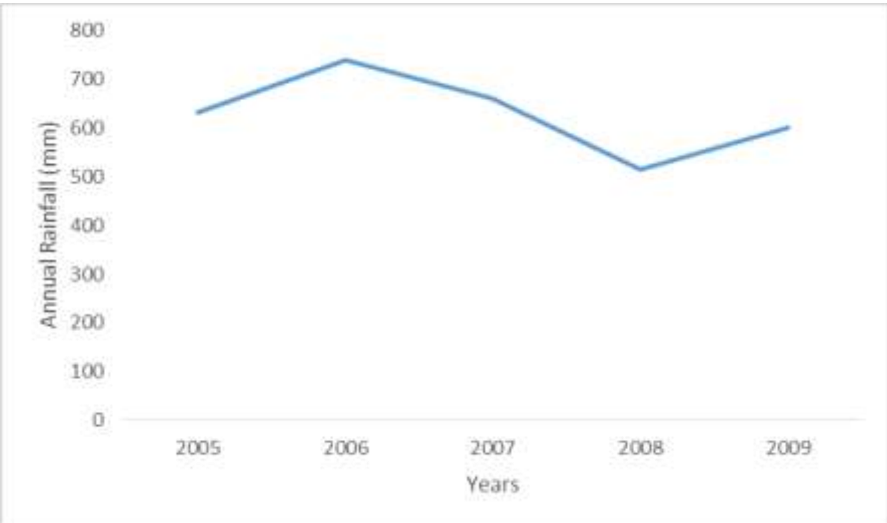

Figure 4.30 Rainfall Distribution Pentad of the study area 2000/2004

The distribution of rainfall using pentad of the study area describes the trend of rainfall in each pentad. Figure 4.27 been the first pentad has the highest rainfall in the year 1991 with 771.5mm, 1994 762.1mm, 1990 654.2mm, 1993 642.2mm and 1992 549mm. Figure 4.28 shows the trend from the highest in 1998, 1999, 1996, 1997 and 1995 with 845.9mm, 711.6mm, 666.9mm, 645.5mm and 509.8mm respectively. Figure 4.29 indicate the it highest rainfall in 2001 (790.2mm), 2002(76.7mm), 2003(731.6mm), 2005 (720mm) and 2000(626.7mm) and Figure 4.30 has 2008(739.5mm) as highest then 2007(660.3mm), 2009(632.6mm), 2005(601.3mm) and 2006(514.6mm).

Table 4.2 shows the rainfall distribution of the study area 1990/2009. Highest rainfall is in 1998 with an average rainfall of 845.9mm, 2003 with average rainfall of 790.2mm then 1991 with average rainfall of 771.5mm while the years with lowest average rainfall within the study time is 1995 with an average rainfall of 509.8mm, followed by the year 2008 with average rainfall of 514.6mm then 1992 with average rainfall of 549mm.

The long term pattern of rainfall in Sokoto state is presented in Figure 4.31.

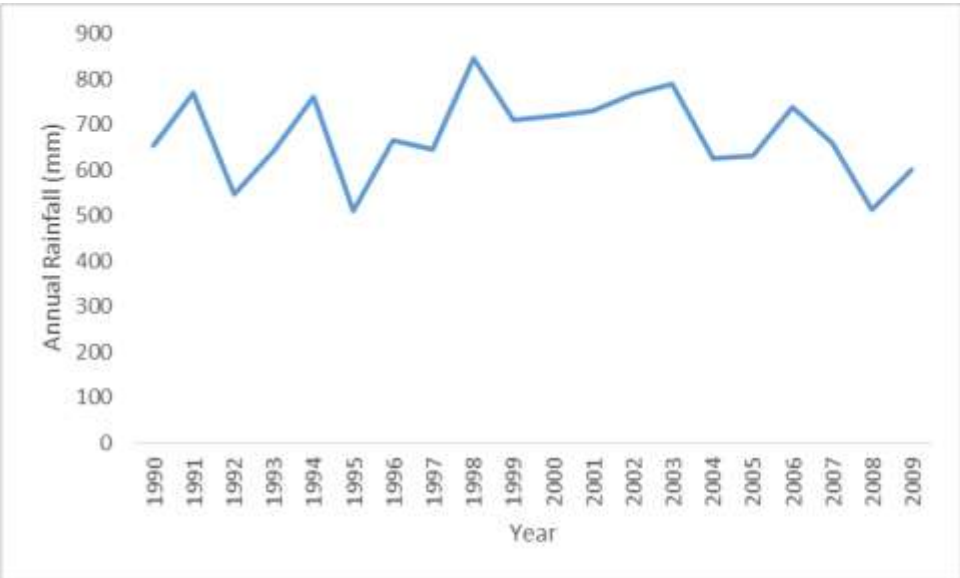

Figure 4.31 Pattern of annual rainfall of the study area 1990/2009

Table 4.2: Monthly Rainfall Distribution of the Study Area 1990/2009

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Rainfall (mm)
1990	0	0	0	0	53.2	72.7	347.4	109.6	71.3	0	0	0	654.2
1991	0	2.8	10.2	18.3	141.4	117	172.6	211.3	85.8	12.1	0	0	771.5
1992	0	0	0	0	38.9	61.9	150.9	132.5	164.8	0	0	0	549
1993	0	0	0	5	54.8	39.7	204.7	238.2	99.8	0	0	0	642.2
1994	0	0	0	0	0	51.8	163.7	355.6	185.5	5.5	0	0	762.1
1995	0	0	0	2.7	17.8	23.7	200.5	170.4	92.3	2.4	0	0	509.8
1996	0	0	0	0	49	194.4	160.5	240.9	7	15.1	0	0	666.9
1997	0	0	2.8	1.8	141.3	152.8	112.8	175.7	42	16.3	0	0	645.5
1998	0	0	0	10	6.9	88.7	180.6	183.1	374.9	1.7	0	0	845.9
1999	0	0	0	0	45	42.6	162.9	304.3	126.4	30.4	0	0	711.6
2000	0	0	0	0	26.5	59.7	361.6	159.8	63.8	48.6	0	0	720
2001	0	0	0	24.1	60.5	36.8	360.8	141.9	107.5	0	0	0	731.6
2002	0	0	33.3	30.8	67.4	231.6	183.1	179.2	43.3	0	0	0	768.7
2003	0	0	9.2	17.5	71.3	287.9	288.7	108.2	7.4	0	0	0	790.2
2004	0	0	0	11.1	114.1	128.9	296.5	67.2	0	8.9	0	0	626.7
2005	0	0	0	0	104.5	82.5	146.7	171.1	124.3	3.5	0	0	632.6
2006	0	0	0	0	19.4	40.6	153.7	314.7	181.3	29.8	0	0	739.5
2007	0	0	0	6.6	45.6	65.9	183.4	235.6	99.1	24.1	0	0	660.3
2008	0	0	0	0.7	41.3	94.7	152.2	130.2	93.9	1.6	0	0	514.6
2009	0	0	0	0	24.8	64.1	114.6	179.9	98	119.9	0	0	601.3

Source: NIMET, Sokoto Station

Figure 4.31 shows the rainfall trend in Sokoto for 20 years (1990-2009). The trend indicates a variation of annual precipitation in the study area. The highest peak in annual precipitation was in the year 1998 (845.9mm), this was followed by 2003, 1991, 2002, 1994, and 2006, with annual means of 790.2mm, 771.5mm, 768.6mm, 762.1mm, and 739.5mm in that order. However, the lowest annual mean was recorded in the year 1995 with annual mean total of 509.8mm thereby making it the driest year within the period under review (1990-2009). Similarly, the years 2008, 1992, 2009, 2005 and 2004 recorded low annual mean rainfalls of 514.6mm 549mm and 601.3mm, 626.7mm and 632.6mm respectively. Figure 4.31 further indicates that the study area annual mean precipitation of 676.13mm for the 20 years (i.e. 1999-2009). This accounts for the very low vegetation vigor/biomass recorded in the state as confirmed by (Yelwa and Isa, 2010). The fluctuating trend of the graph shows unequal pattern of rainfall in 20 years.

4.5 Relationship between rainfall and vegetation

The correlation between rainfall and EVI data of the study area b1990/2009 is presented graphically in Figure 4.32.

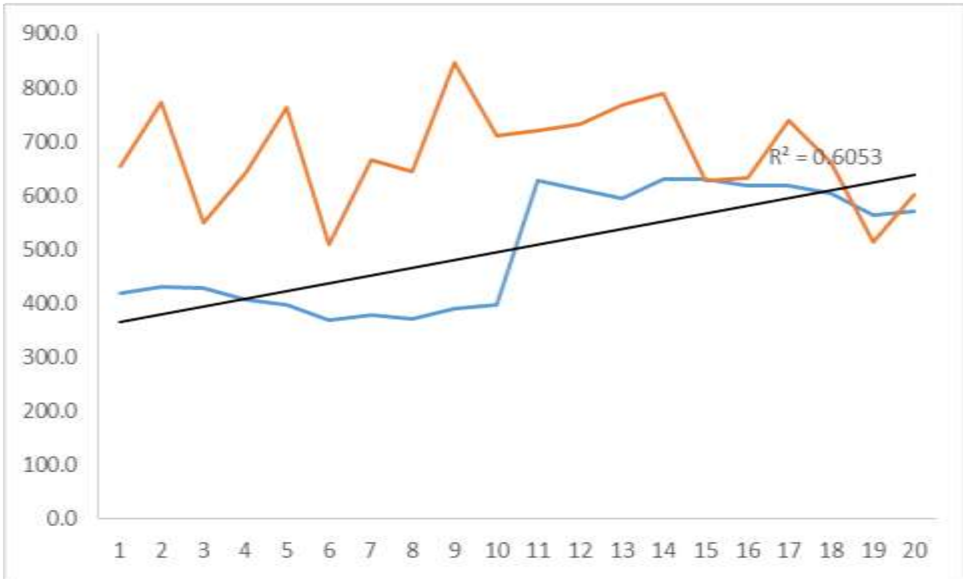

Figure 4.32 The relationship between rainfall and EVI of the study area 1990/2009

Figure 4.40 shows the relationship between EVI and rainfall data of Sokoto state and the result indicates a strong relationship between the variables because looking at the graph as rainfall increase so also the EVI value also increase and vice versa. Time series graph shows the pattern of rainfall in the study area across a period of twenty years from 1990-2009 and how it correlates with vegetation greenness of the area. It shows a positive correlation between amount of rainfall and vegetation, R^2=0.6053, and the relationship is significant. By implication, it suggests that the more the rainfall the more the vegetation of an area or simply put, the dense vegetation of an area is largely reliant on the amount of rainfall. The up and downward trend of the graph shows an unequal pattern of rainfall in 20 years. The highest rainfall on average was in the year 1998 (45.9mm), 2003 (790.2mm), and 1991 (771.5mm) and the least amount of rainfall was in the year 1995 (509.8mm), 2008 (514.6mm) and 1992 (549mm). However, from the year 2002 up to 2006, the rainfall pattern maintained an upward trend.

The result was similar to studies carried out by Yelwa and Isa (2010), Abubakar and Eniolorunda (2016) which results showed that NDVI depends largely on precipitation. A study also carried out by Yelwa and Enilorunda (2012) showed that NDVI exhibits a saturation response to rainfall, leveling off as rainfall increases and remaining relatively constant after a certain threshold value is reached. According to the study, the most likely reason for this is found in the relationship between NDVI and vegetation growth which is exponential.

4.6 Desertification prone areas between 1990/2009

The extent of desertification in the study area between 1990/2009 is presented in Figure 4.33.

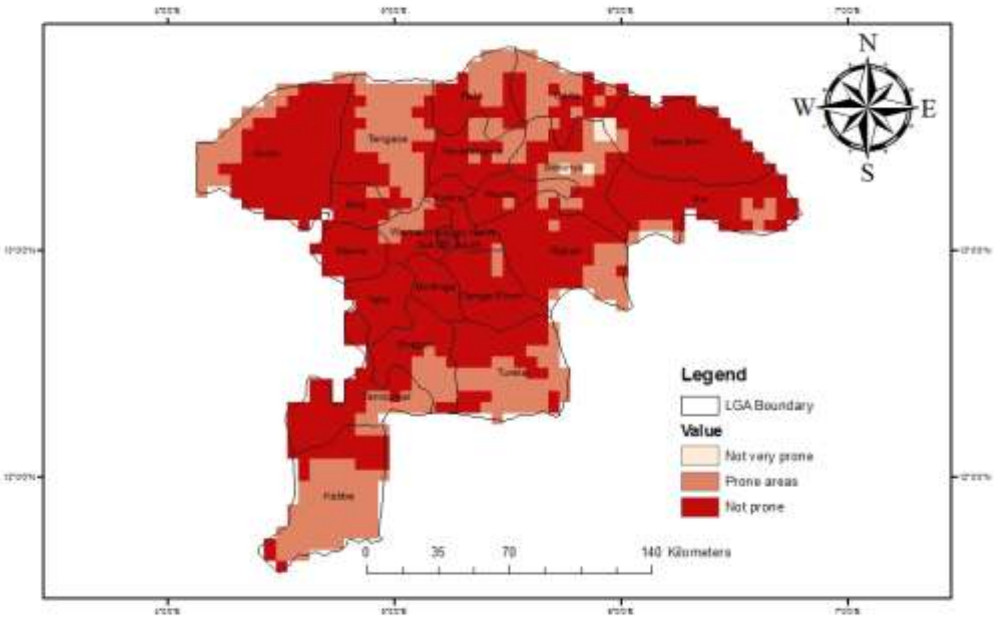

Figure 4.33 Desertification prone areas in the study area 1990/2009

Figure 4.33 shows the desertification prone areas within the study area 1990/2009. Bare areas are found at the marginal and the extreme northern part of the study area and were the desert prone areas while the dark reddish brown to light reddish brown colour, towards the south western part of the state around Sokoto Rima basin are the areas that were not prone to desertification.

The prone area can only be presented clearly using the overal image of the classified coefficient of variation not the pentad images.

4.7 Mapping the spatial extent of desertification 1990 to 2009

To map out the spatial extent of desertification in the study area, images developed in getting desertification prone areas were used to calculate the areas of each class using tabular format in unit of hectares.

The spatial extent of desertification covering the study area limited to 1990/2009 is presented in Figure 4.34.

Figure 4.34 shows the spatial extent of desertification in Sokoto state with the major areas at the northern part of the state coming down in a diagonal manner to the south western part of the state to the south eastern part of the state thereby supporting the previous results of the 4 pentad periods.

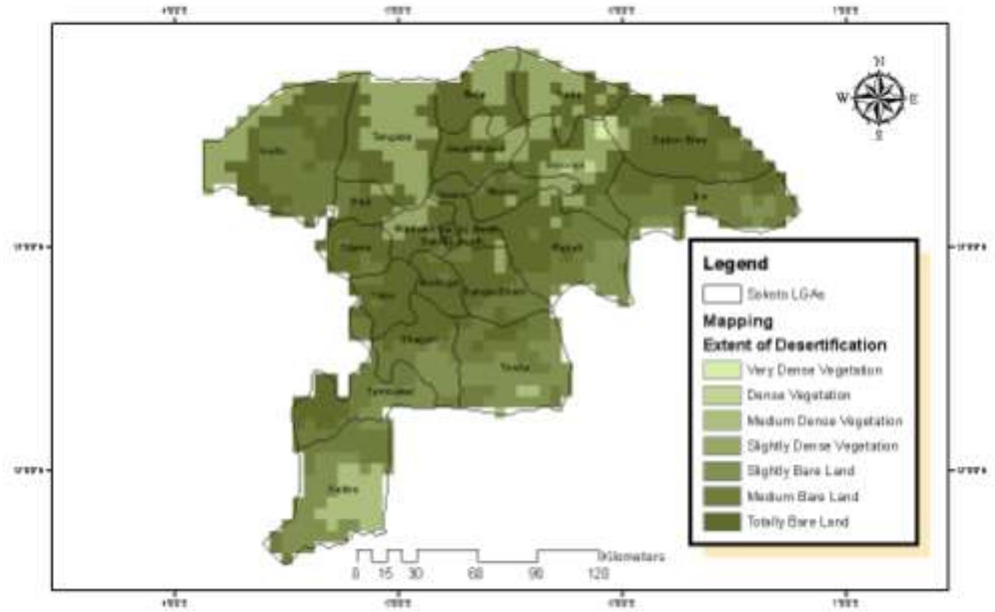

Figure 4.34 Desertification extent in the study area 1990 to 2009

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

This study assessed the encroachment of desertification into Sokoto State, Nigeria using remotely sensed data and Geographic Information System techniques. The study used two hundred and fourty (240) Enhanced Vegetation Index (EVI) imageries at 250m resolution from AQUA-MODIS satellite system as monthly synthesis sets, dating from January 1990 to December, 2009 the EVI images were used to assess the extent of desertification in the state. Annual rainfall records covering same years were sourced and used to determine the relationship between EVI and rainfall of the area.

Results indicate that in 1990 to 1994 the mean EVI was found to be 4163246, and 3808758 in 1995 to 1999, this indicated a slight decrease in contrast to the Coefficient of Variation that has about 3.9% and 4.2% respectively. The amount of rainfall received varied within these years as the periods had 675.8mm and 675. 94mm. However, in the year 2000 to 2004 EVI mean was 6187252 in 2005 to 2009, it was 5948497with the Coefficient of Variation of 4.4% and 5.5% and mean rainfall of 727.44mm and 629.66mm respectively.

In terms of the spatial extent of desertification in the study area, in the 1990 to 1994 periods, areas with very dense vegetation were found to cover about 171525ha and this increased to 174892ha in the 1995 to 1999 periods which showed an increase of about 3367ha as against the 2000 to 2004 and 2005 to 2009 periods with about 3000ha that didn't change. Furthermore, areas covered with slightly bare land was 2159430ha, 2709445ha in 1990-1994 and 1995-1999 respectively and it showed an increase of about 550015ha. In 2000-2004, 2005-2009 it was 6012ha and 123109ha with an increase of 117088ha of land. In terms of areas that were bare the results showed an increase indicating that the desertification is encroaching the state.

5.2 Conclusion

In conclusion to the findings of this study, the study area is getting desertified and this effect to social, economic and the livelihood of the people living in the area. Status of vegetation was not in a very poor state. However, the mean images indicated a slight change of vegetation degradation within the time frame. Furthermore, there was a clear evidence of changes in vegetation trend particularly within the selected areas Gada, Illela and Tangaza. The results indicated that the EVI Coefficient of Variation values are small in some areas, it is because of the nature of the region being located in semi-arid region.

5.3 Recommendations

Based on the findings of this research, the following recommendations are suggested:

i. The appropriate government agencies in the state should map out policies that would address squarely this problem, devoid of political consideration so that it would go shoulder by shoulder with the federal government's resolve to contain soil erosion and desert encroachment for the benefit of entire citizen.

ii. State government should judiciously utilize the ecological fund as this will address to a great extent.

iii. The government should make kerosene available and affordable to the inhabitants of the area to reduce their dependence on fuel wood as a source of energy for cooking.

iv. Trees planting campaigns should be reviewed with a more realistic approach, not the tree planting by government officials captured on televisions. The people should be involved in every stage of such projects so that they can feel a sense of belonging. They should be made to see the environment as their own and not just for the government.

v. The youths who are leaving the villages to the cities in search of job opportunities can be employed to nurture the young trees planted during campaigns for sustainability of these projects.

vi. Sensitization campaigns on the consequences of climate change and cutting down of trees should be re-invigorated by both the state and federal government.

vii. GIS and Remote Sensing in desertification is a welcome development in technological breakthrough. It can be used effectively to monitor vegetation conditions and provide early warnings on drought and famine. I suggest that more studies should be carry out using different vegetation indexes not restricting to NDVI.

REFERENCES

Abubakar, S. D. and Eniolorunda, N. B. Effect of desertification on some selected soil properties in a semi-arid part of Northwestern - Nigeria. *Journal of Geoscience and Environmental Protection*. (4) 111 – 123.

Achim, S. (2007). Curbing climate change risks and opportunities for world's wildlife: Biological Diversity and Climate Change. Secretariat of the Convention on Biological Diversity. *Volume on Climate Change* (2) 133 – 145.

Acosta-Michlik, L., Klein, R.J.T. and Compe, K. (2005, June). *How vulnerable is India to climatic stress?* Measuring vulnerability to drought using the Security Diagrams concept; Human Security and Climate Change an International Workshop, Oslo, Norway, 21–23.

Africa Regional Review Report (2005). Energy for Sustainable Development. Retrieved on 14th November 2012 from www.arrresd.org

African Energy Policy Research Network (2005). Making the African Power Sector Sustainable. Final Regional Report

Akpata, T.G. (2011). Effects of global climate change on Nigeria agriculture: An Empirical Analysis. *CBN Journal of Applied Statistics*, 2(1), 1.

Amsel, S. (2009). *Deserts of the World*: The Sahara Desert of Africa. Exploring Nature Educational Resource. http://exploringnature.org/db/detail.php?dbID=44&=564.

Anderson, J. R. (1977). A Land Use and Land Cover Classification System for use with Remote Sensor data. *US geological survey professional paper*, 964, 28. Washington, DC.

Andreas R. (2005). Global Forest Management: What has been achieved, what comes next? Critical choices for structural, legal and financial options. Wissenschafts Zentrum Berlin (WZB)

Arnab K., Dipanwita D. (2011). Monitoring Desertification Risk Through Climate Change and Human Interference Using remote Sensing and GIS Technique. *International Journal of Geomatics and Geosciences*.India, vol (2), 21 – 33.

Audu, E.B. (2013). Fuelwood Consumption and Desertification in Nigeria. *International Journal of Science and Technology* 3 (1).

Ayuba, K.H and Dami, A. (2011). *Environmental Science: An Introductory Text.* A Revised and Enlarged Edition. Apani Publications Kaduna, PP 72, 73 and 76.

Ballad, T. and Brown, J (1982) One in six countries facing food shortage; in The *Guardian*;http://www.guardian.co.uk/climatechange/story/article_continue.

Bauer, M. E., Burk, T. E., Ek, A. R., Coppen, P. R., Lime, A. D. … and Heinzen, D. F. (1994). Satellite inventory of Minnesota forest resources. *Photogrammetric Engineering and Remote Sensing*. 60, 287–298.

Billy J., (2011). *An Assessment of the magnitude and rate of desertification in Yobe State, Nigeria* (1970 - 2005) using remote sensing and GIS approach. Unpublished Thesis. Department of Geography Ahmadu Bello University, Zaria.

Bryant, E. S., Birnie, R. W., and Kimball, K. D. (1993, April). A practical method of mapping forest change over time using Landsat MSS data: A case study from central Maine. *Proceedings of 25th International Symposium, Remote Sensing and Global Environmental Change*.Graz, Austria. pp. 469–480.

Byrne, G. F., Crapper, P. F., and Mayo, K. K., (1980). Monitoring land cover change by principal component analysis of multi-temporal Landsat data. *Remote Sensing of Environment*. 10, 175–184.

Climate Change Information Resource. (2005). *what causes global climate change?* New York Metropolitan region. Retrieved on April 2, 2013 from http://ccir.ciesin.columbia.edu/nyc

Climate Change Science Program and the Subcommittee on Global Change Research, (2003) Strategic Plan for the U.S. Climate Change Science Program: *A Report by the Climate Change Science Program and the Subcommittee on Global Change Research*, July 2003.

Chan, N. W. (1995). “Choice and Constraints in Floodplain Occupation: The Influence of Structural Factors on Residential Location in Peninsular Malaysia.” *Disasters*. 19(4):287-307.

Conserve Africa (2006). Breaking the vicious cycle of poverty and environmental degradation in Africa; Poverty and Environment in Africa: An Overview. http://www.conserveafrica.org.uk/desertification.html

Edris O.H.A., Dafalla M.S., Ibrahim M.M.M., Elhag A.M.H (2013). Desertification Monitoring and Assessment in Albutana Area, Sudan, Using Remote Sensing and GIS Technique. *International Journal of Scientific and Technology Research*. Khartum, Sudan.pp 34 – 56.

Ellis W. (1987). African Sahel: The Sticken Land. National Geographic August.

Eltahir, M.E. and Nagi, Z. (2010). Landscape change and sandy desertification monitoring and assessment: a case study in the northern Shaanxi Province, China. *Journal of American Science* .6(2):46-51.

Emodi, E.E (2013). Drought and Desertification as they affect Nigerian Environment.

Journal of Environmental Management and Safety 4(1):45-54. Retrieved 20th November, 2013 from www.cepajournal.com

Encyclopedia Britannica Student and Home Edition, (2010). Desert.Chicago: Encyclopedia Britannica

Farlex (2003), Free online dictionary, Canada.

Federal Government of Nigeria (FGN), (2004) *Combating Desertification and Mitigating the Effects of Drought in Nigeria* (Revised National Report on the Implementation of UNCCD).

Federal Ministry of Environment (2005). *National Erosion and Flood Control Policy*. FME, Abuja 41p.

Federal Ministry of Environment (2008). *State of Nigerian environment report*.

FENLearnig (2000), World Geography. Sandbox Networks inc. Infoplease Publishers.

Fuller, R. M., Groom, G. B., and Jones, A. R., (1994). The land cover map of Great Britain: an automated classification of Landsat Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing*. 60, 553–562.

Folaji, C. (2007). Climate Change and Adaptation: Empirical Situation and Policy Implication. African Technology Policy Studies Network. Nairobi, Kenya.

Ghribi M., (2005). GIS Applications for Monitoring Environmental Change and Supporting Decision-making in Developing Countries. United Nations Industrial Development Organization and the International Centres for Science and High technology. United nation.

Goldsmith, E. and Hildyard, N. (1990). *The Earth Report 2: monitoring the battle for our Environment.* Mitchell Beazley, London.

Green Earth Choice, (2011). Climate change and its adverse effects. Retrieved on April 23, 2013 from www.greenearthchoice.com/climate_change

Hall, F. G., Botkin, D. B., Strebel, D. E., Woods, K. D., and Goetz, S. J., (1991). Large-scale patterns of forest succession as determined by remote sensing. *Ecology*. (72) 628–640.

Haque, C.E. (2006). Coping with Riverbank erosion hazard and displacement in Bangladesh: Survival strategies and adjustments. *disasters*. 13(4): 300- 314.

Haruna, D.M. and Shaib, B. (2010). Integrated remote sensing approach to desertification monitoring in crop-rangeland area of Yobe State, Nigeria. *Journal of sustainable Development in Africa*, 12(5):236-249.

Hillel, D. and Rosenzweig, C. (2002). Desertification in relation to climate variation and change. *Advances in Agronomy*, 77: 1-38.

Huete A.R., Liu H.Q., Batchily K., YanLeeuwen W. (1997). A comparison of vegetation indices global set of TM images for EOS-MODIS. *Remote Sensing of Environment*.;59:440–451.

Hulme, M. (2014). Exploring the links between desertification and climate change. *Environment* 38: 4,39-11, 45.

International Fund for Agricultural Development, (2010). *Desertification* Retrieved March 15, 2013 from http://www.ifad.org/pub/factsheet/desert/e.pdf

International Fund for Agricultural Development (2007). Statement to the 61st session of the General Assembly. http://www.ruralpovertyportal. topics/desertification.

Intergovernmental Panel on Climate Change, (2007). Summary for policy makers of the Synthesis report of the IPCC fourth assessment report. Retrieved April 7th, 2013 from http://www.ipcc.ch/pdf/assessmentreport/ar4/syr4/ar4-syr-spm.pdf

Kelly, M. and Hulme, M. (1993). Desertification and Climate Change, *Tiempo*, 8:1-7.

Lester R. B. (2006). The earth is shrinking: Advancing deserts and rising seas squeezing civilization. Earth PolicyInstitute.http://www.earthpolicy.org/Updates

Levin, N. (1999). 1st Hydrographic Data Management Course, International Maritime Academy,Trieste, Italy.

Mamman, A. B. (2003). Sokoto State. in Mamman A. B., Oyebanji, J. O. and Patters, S.W. (Editors), Nigeria: A People United, A Future Assured, Volume 2., pp. 497 – 514, Federal Ministry of Information, Abuja, Nigeria, Gabumo Publishing Company Ltd, Calabar, Nigeria.

McHarry, J. Scott, F. and Green, J. (2002). Towards Global Food Security: Fighting against hunger. Towards Earth Summit 2002, Social Briefing 4 http://www.earthsummit2002.org/es/issues/foodsecurity/foodsecurity.rtf

Medugu, I. N. (2007). *A Comprehensive Approach to Addressing Drought and Desertification in Nigeria*. Master's Thesis, Faculty of Built Environment, University of Technolgy Malaysia.

Meier, P. and Bond, D. (2005). The Influence of Climate Variation on Pastoral Conflict in the Horn of Africa; *Human Security and Climate Change an International Workshop Oslo*, Norway, 21–23 June 2005.

Miller, A. B., Bryant, E. S., and Birnie, R. W. (1998). An analysis of land cover changes in the Northern Forest of New England using multi-temporal Landsat MSS data. *International Journal of Remote Sensing*. 19, 245–265.

Mutton, D. and Haque, C.E. (2004). Human Vulnerability, Dislocation and Resettlement: Adaptation processes of River-bank Erosion-induced Displaces in Bangladesh. *Disasters* 28: 41-62. Retrieved May 20, 2013 from www.onlinelibrary.wiley.com/doi/10.1111/j.0366. 2004.00242.x.

Nanyunja, R. K. (2004). How Does Water Scarcity Directly or Indirectly Influence Conflict or Cooperation? A Case Study in Uganda; *Human Security and Climate Change an International Workshop Oslo*, Norway, 21–23 June 2005.

National Population Commission, (2006). Legal notice on publication of 2006 census final Results. Retrieved May, 2012 from http://www.placng.org/legal/notice 200n%20publication%20of%2006%census20final %20resultpdf

Nelson, S.E. (1983). A Comparison of the Vegetation Response to Rainfall in the Sahel and East Africa using NDVI from AVHRR. *Climate Change 17:211-241.*

Nigerian Conservation Foundation (NCF). 2007: The Tide on Line, citing a statement by the President, Chief Philip Asiodu. http://www.thetidenews.com/article.aspx?

Nwafor, J.C. (2006). *Environmental Impact Assessment for Sustainable Development* EDPCA Publishers Enugu.

Ochi, S., Shibasaki, R. and Murai, S. (2000). *Modelling and assessement of NPP/Crop productivity in Asia by GIS combined with remote sensing data.* Conference Proceedings on GIS for Developing Countries International Rice Research Institute Los Banos,Phillippines. November, 2000. geo.uu.nl/gisdeco/gisdeco.html

Ojo EO, Adebayo P. F. (2012). Food Security in Nigeria: An Overview. *Eur. J. Sustain. Dev.* 1(2):199-222.

Oladipo, E.O. (1993). Some aspects of the spatial characteristics of drought in northern Nigeria. *Natural Hazards,*8: 171-188.

Olasup F. (2014). History of Desertification in Nigeria. *Vanguard*, Wednesday, July 2

Oppong, E.O. (1993). Desertification Control Bulletin, number 23 UNEP.

Otegbeye, G.O. (2004). Drought and Desertification: Challenges for afforestation in Nigeria arid and semi-arid region. *Savanna,* 19(1):1-11.

Ozenda, N. (1991). Drought in the Sahel. *Science,* 202: 99-100.

Polgreen, L. (2007). In Niger, Trees and crops turn back the desert. In The New York Times published on February 11, 2007.

Rank J. (2015). *North West Region Guide.* Lagos: My Destination.

Reuters, (2007). Climate change to hit the poor worst, says U.N.'s Ban. http://www.alertnet.org/thenews/newsdesk/L0

Reynolds, J. F. and Stafford S. D. M. (2002). Global Desertification: Do humans cause Deserts? Vol 88, Dahlem University Press, Berlin.

Sabrino, T. and Raissouni, E. (2000) Expansion and Contraction of the Sahara Desert from 1980 - 1990. American Association for the Advancement of Science. Los Angelos.

Scapini, F., and Partners of MECO Project, (2002). Baseline for the Integrated Sustainable Management of Mediterranean Sensitive Coastal Ecosystems; a Manual for Managers, Scientists and all those Studying Coastal Processes and Management in the Mediterranean, Istituto Agronomico per l'Oltremare (IAO), Florence, Italy.

Simms, A. (2005). Africa – Up in smoke? The second report from the Working Group on Climate Change and Development. The New Economics foundation (nef).

Simon, M. and Allen, P.(1998). Public Perception of Risk Management in Environmental Controversie: A United Kingdom case study. *Journal of Risk, Health and Safety,* 309.

Singh, F. (1989). *Potential of a Post-classification Change Detection Analysis to identify land use and land cover Changes*. Unpublished B. Sc. project in physical geography and ecosystem analysis, University of Lund, Sweden.

Singh, M. (1986). Public Perception of Risk Management in Environmental Controversie: A United Kingdom case study. *Journal of Risk, Health and Safety,* 309.

Smith, P. M., Kalluri, S. N., Prince and Defries, R. (1997). The NOAA/NASA Pathfinder AVHRR 8-km land data set. *Photogram. Eng. Remote Sensing,* 63: 12 -32.

Suleiman, M. (2011). Nigeria: Desertification - Northerners Most Pressing Environmental Problem. Retrieved 25 January 2015 from allAfrica.com

Suleiman, S. (2005). *As Sahara Engulfs the Nigeria.* Sokoto: FMENV Nigeria

Tasihu, H. M. (2008). *Nigeria Environmental Issues.* Lagos, Nigeria: Ngenvirons.

Tell Magazine (2008). Food Security and Climate Change- Section on Desertification.

Thompson, M. and Warburton, M. (1984). 'Uncertainty on a Himalayan scale'. *Mountain Research and Development* 5(2): 115-35.

Tiffen, M. and Mortimore, M. (2002). Questioning desertification in dryland sub-Saharan Africa. *Natural Resources Forum* 26:218-233.*Transformation Blueprint*.

Tucker, C. J., (1979). Red and photographical infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, *Environmental Research Journal* 8, 127–150.

Tucker, C.J., Holben, B.N. and Goff, T.E. (1984). Intensive Forest Clearing in Randonia, Brazil as detected by Satellite Remote Sensing of Environment, 15, 255 – 261.

UNCCD (2004). Ten years on: UN marks World Day to Combat Desertification; Observances worldwide on June 17, 2004.

UNCCD (2006). Implementing the United Nations Convention to Combat Desertification in Africa: Ten African experiences. UNCCD Secretariat. Bonn, Germany.

UNEP, (1992). Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification. Report of the executive Director. Nairobi: United Nations Environment Program.

UNEP. (2013). *Fight Against Desert Enroachment.* United Nation: FADE, Africa.

United Nations Convention to Combat Desertification (UNCCD). (2004). a carrying pillar in the global combat against land degradation and food insecurity. Background paper for the San Rossore meeting ‘Climate change: a new global vision’ Pisa, Italy,15 - 16.

Van Crowder, L., Lindley, W.I., Bruening, T.H. and Doron, N. (1998). Agricultural Education for Sustainable Rural Development: Challenges for Developing Countries in the 21st Century; Extension, Education and Communication Service (SDRE); FAO Research; Rome, Italy

Van der Meulen, F. and Janssen, M., (1992). Towards a monitoring programme for European coastal environments, *Proceedings of the “Third European Dune Congress”,* 17-21 June 1992, Galway, Ireland.

Wang, J. Price, K.P. and Rich, P.M. (2001). Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains. *International Journal of Remote Sensing,* 222(18):3827-3844. Retrieved on August 5, 2012, from http://www.tandf.co.uk/journals

Weismiller, R. A., Kristof, S. J., Scholz, D. K., Anuta, P. E., and Momen, S. A. (1977). Change detection in coastal zone environments. *Photogrammetric Engineering and Remote Sensing*, 43, 1533–1539.

Wood, P and Yapi A.M. (Ed.) (2004). Rehabilitation of degraded lands in Sub-Saharan Africa: Lessons learned from selected case studies. International union of forest research organizations Special programme for developing countries (IUFRO-SPDC). *Forestry Research Network for Sub-Saharan Africa* (Fornessa).

World Meteorological Organization. (2005). Climate and Land Degradation. Retrieved March 25th, 2013 from http://www.wmo.int/pages/themes/wmoprod/documents

World Meteorological Organization. (2007). Climate and Desertification. Retrieved January 25th, 2013 from http://www.wmo.int/pages/prog/wcp/agm/publications/documents/wmo_cc_desert_

Yang, J. and Prince, S.D. (2000). Remote Sensing of Savanna Vegetation Changes in Eastern Zambia 1972-1989. *International Journal of Remote Sensing* 21: 301-332.

Yelwa, S. A. (2008). Broadscale Vegetation Change Assessment across Nigeria from Coarse Spatial and high Temporal Resolution AVHRR Data. (350 Pages). Cuvillier Verlag Gottingen Press, Germany, ISBN 978-3-86727-597-2.

Yelwa, S.A. and Isah, A.D. (2010). Analysis of Trend in Vegetation AVHRR-NDVI Data across Sokoto State 1982 – 1986 Using Remote Sensing and GIS *Nigerian Journal of Basic and Applied Sciences*. Vol. 18, No.1 pp9-96. ISSN No. 0794-5698.

Yelwa, S. A. and Eniolorunda, N. (2012). Simulating the Movement of Desertification in Sokoto and its Environs, Nigeria using 1km SPOT-NDVI data, *Environs Res. J.*, 6: 175-181.