AN ASSESSMENT OF DROUGHT IN KADUNA STATE, NIGERIA BETWEEN 2000 AND 2014

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DECLARATION

I hereby declare that the work in this dissertation "An **Assessment Of Drought In Kaduna State, Nigeria Between 2000 and 2014**" was carried out by me in the Department of Geography under the supervision of Prof. S.A. Yelwa and Prof. I.J. Musa. The information derived from the literature have been duly acknowledged in the text and a list of references provided.

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Pius,Nnah Moses **Date**

P13SCGS8213

CERTIFICATION

This Dissertation titled **"AN ASSESSMENT OF DROUGHT IN KADUNA STATE, NIGERIA BETWEEN 2000 AND 2014**" by Moses Nnah PIUSmeets the regulations governing the award of degree of Masters of Science, (Remote Sensing and Geographic Information System) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literacy presentation.

Prof. S.A. Yelwa (Chairman, Supervisory Committee)	Signature	Date
Prof. I.J. Musa (Member, Supervisory Committee)	Signature	Date
Dr. A.K. Usman (Head of Department)	Signature	Date
Prof. K. Bala (Dean, SPGS)	Signature	Date

DEDICATION

This work is dedicated to the Most Precious Blood that pours out from the Sacred Head of my Lord Jesus Christ, the Temple of Divine Wisdom, Tabernacle of Divine Knowledge and Sunshine of Heaven and Earth.

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I give Glory to the Father, the Son and the Holy Spirit for making it possible for me to be among the living today.

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LIST OF ABBREVIATIONS

ACIS	Applied Climate Information System
ACSD	African Committee on Sustainable Development
APA	American Planning Association
ARTEMIS	Africa Real Time Environmental Monitoring Information System
AVHRR	Advanced Very High Resolution Radiometer
CMI	Crop Moisture Index
CPC	Climate Prediction Center
DEWS	Drought Early Warning System
DM	Drought Monitor
ENSO	El-Niño/Southern Oscillation
EROS	Earth Resources Observation and Science
EWSs	Early Warning Systems
FAO	Food and Agriculture Organization
HPRCC	High Plains Regional Climate Center
ICID-I	International Conference on Climate Sustainability and Development in Semiarid Regions
KRPC	Kaduna Refinery and Petrochemical Company
MODIS	Moderate-resolution Imaging Spectroradiometer
MTN	Mobile Telecommunication Network
NADSS	National Agricultural Decision Support System
NCAT	Nigerian College of Aviation Technology
NCDC	National Climatic Data Center

NDMC National Drought Mitigation Center

NDVI Normalized Difference Vegetation Index

NEMA National Emergency Management Agency

NIMET Nigeria Meteorology

NITEL Nigeria Telecommunications Limited

NOAA National Oceanic and Atmospheric Administration

NPC National Population Commission

OLR Outgoing Longwave Radiation

PDSI Palmer Drought Severity Index

RIM Regional Implementation Meeting

SCAN Soil Climate andAnalysis Network

SDO Seasonal Drought Outlook

SIDS Small Island Developing States

SNOTEL Snowpack Telemetry

SOI Southern Oscillation Index

SPI Standardized Precipitation Index

SPSS Statistical Package for Social Sciences

SST Sea Surface Temperature

SVI Standardized Vegetation Index

SWSI Surface Water Supply Index

TCI Temperature Condition Index

TFR Total Fertility Rate

TOGA Tropical Ocean Global Atmosphere

USDHHS United States Department of Health and Human Services

UNCCD United Nations Convention to Combat Desertification

UNECOSOC United State Nations Economic and Social Council

USDA United States Department of Agriculture

USGS United States Geological Survey

VCI Vegetation Condition Index

VegDRI Vegetation Drought Response Index

WMO World Meteorological Organization

WOCEWorld Ocean Circulation Experiment

ABSTRACT

Kaduna state is located within the Guinea Savannah of the African Continent. As a result, it is susceptible to desertification and the risks of drought abound. This study examined the three most important ways of monitoring drought in any locality: people's perception, precipitation data and satellite remote sensing. Simple statistical tables were used to present and analyse the data. Equally, Microsoft Office Excel, Statistical Package for Social Science (SPSS), and Idrisi software were used to analyse the data. The study revealed that there have been episodes of drought in Kaduna state within the period under review. The study also revealed that there is a positive relationship (0.72) between rainfall and vegetation vigour/biomas in the state. Similarly, vegetation condition index (VCI) revealed a value 10.2% indicating a severe drought in the state. Therefore, the study concluded that both rainfall and vegetation vigour/biomas are generally decreasing; indicating a strong positive correlation value of 0.71 (71%). The study therefore recommends that there should be public enlightenment campaign on drought as it is a very complex phenomenon and its effects very devastating. The study recommends that individuals be encouraged to develop the habit of tree planting to curtail the dilapidating vegetation in the state. Government should provide an effective municipal supply of water across the state for both domestic and industrial usage in a bid to protect underground water resources. In addition, research and extension services should be carried out in order to develop particular breeds of seeds that can survive the drought.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Drought is not a strange phenomenon to African continent especially in the Sahel region in which the northern part of Nigeria lies. Kogan (1997) defined drought as a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage and causing adverse impacts on vegetation, animals, and/or people. It is a normal, recurrent feature of climate that occurs in virtually all climatic zones, from very wet to very dry (Kogan, 1997). According to Redmond (2002), drought is an insidious hazard of nature. It originates from a deficiency of precipitation which results in a water shortage for some activities. The National Aeronautics and Space Administration (NASA) (2008) has defined drought as a creeping disaster, this is because of its slow mode of occurrence. Drought has typically been more ambiguous. Definitions of drought have varied, in part because it is a hazard event that lacks clear boundaries. It is difficult to define because it often develops slowly over months or years, and has different impacts depending on the location, time of year and sector of the community (Palmer, 1965). Addition, Folger, Cody and Carter (2012) posit that drought is relative to some long-term average condition, or balance, between precipitation, evaporation, and transpiration by plants.

Drought is different from aridity, which is a permanent feature of climate in regions where low precipitation is the norm, as in a desert (Folger, Cody and Carter, 2012). Similarly, droughts are the resultant effects of acute water shortage due to lack of rains over extended periods of time affecting various human activities and leading to problems like widespread crop failure, replenished ground water resources, depletion in lakes/reservoirs, shortage of drinking water and, reduced fodder availability etc (Folger, Cody and Carter, 2012). In general, drought means different things to different people; the meteorologist, the hydrologist, city managers, farmers etc. Human factors, such as water demand and water management can exacerbate the impact that drought has on a region (Edith, 2012). In practice, drought is defined in a number of ways that reflect various perspectives and interests. To the farmer, agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, soil water deficits, reduced ground water or reservoir levels needed for irrigation, and so forth (National Oceanic and Atmospheric Administration, NOAA, 2008).

To the meteorologist, drought is usually defined based on the degree of dryness (in comparison to some "normal" or average) and the duration of the dry period. Drought onset generally occurs with a meteorological drought (Buchanan and Davies, 1995). Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiency of precipitation are highly variable from region to region (Okorie, 2013). Similarly, hydrological drought is associated with the effects of period of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e. stream flow, reservoir and lake levels, ground water). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale (Dilley, 2000). Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system (Peters*et. al.*, 2002). It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream, stream flow, and ground water and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors. It is therefore in the light of the above that it becomes very unrealistic to expect a universal definition of drought for all fields of activity (Wilhite, and Glantz, 1985).

The dwindling pattern of rainfall over the past few decades as observed by meteorologists in Kaduna state calls for concerted efforts for reviewing its impact on vegetation and food security. Data from weather stations an observations from farmers indicates that food production and indeed vegetation growth is impacted negatively by the declining rainfall which could be as a result of changes in climatic phenomena.

Kaduna state is located within the Guinea Savanah of Africa, as a result it is susceptible to desertification and the risks of drought abound. In addition, several studies (McKee, Doesken, and Kleist 1994; Okorie, 2003 and NASA Earth Observatory, 2008) have revealed that drought is induced by several factors ranging from declining precipitation, wrong agricultural practices, wrong utilization of water resources among others vis-à-vis regional differences.

1.2 STATEMENT OF THE RESEARCH PROBLEM

Tadesse*et. al.* (2008) posited that owing to climate change and variability, drought has become a recurrent phenomenon in several countries across the globe. It is manifested in erratic and uncertain rainfall distribution in rainfall dependent farming areas, especially in arid and semi-arid ecosystems. Frequent and severe drought has become one of the most important natural disasters in sub-Saharan Africa and often results in serious economic, social, and environmental crises marked by the creation of uncertain agricultural economies (Kandji and Verchot 2006).

According to United Nations Economic and Social Council (ECOSOC) in their fifth meeting of African Committee for Sustainable Development (ACSD-5) Regional Implementation Meeting

(RIM of 2007); drought and desertification are at the core of serious challenges and threats facing sustainable development in Africa. These problems have far reaching adverse impacts on human health, food security, economic activity, physical infrastructure, natural resources and the environment, and national and global security. Although drought has several definitions, the central element in these definitions is water deficit.

This deficiency results in a water shortage for some activity, group, or environmental sector. Desertification which is defined as a process of land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activitieshas similar effects on the environment and the people (Kogan, 1998). Land degradation manifests itself through soil erosion, water scarcity, reduced agricultural productivity, loss of vegetation cover and biodiversity, drought and poverty (Liu and Kogan, 1996).

Droughts are natural hazards with varying patterns in space, time, and intensity. Their dynamic character challenges our ability in planning, predicting, monitoring and providing relief to affected areas (McKee, Doesken and Kleist, 1994). Because of the spatial and temporal variability and multiple impacts of droughts, we need to improve the tools and data available for mapping and monitoring this phenomenon on all scales. Previous studies have established significant relationships between climate variables and satellite-derived vegetation indices over non-irrigated croplands and grasslands (Viau, Vogt and Beudin, 2000). Therefore, the need to integrate information provided by satellite-derived metrics on seasonal vegetation performance and climate-based drought indicators to produce a timely and spatially-detailed drought monitoring product is the goal of this research.

Thus, a significant drawback of climate-based drought indicators is their lack of spatial detail. In addition, meteorologically-based indices are dependent on data collected at weather stations. Some areas have very sparsely distributed stations and this affects the reliability of the drought indices (Smith, 2000).

The underlying cause of most droughts can be related to changing weather patterns manifested through the excessive buildup of heat on the earth's surface, meteorological changes which result in a reduction of rainfall, and reduced cloud cover, all of which results in greater evaporation rates (NASA (Earth Observatory), 2008). The resultant effects of drought are exacerbated by human activities such as deforestation, overgrazing and poor cropping methods, which reduce water retention of the soil, which lead to soil degradation.

Agriculture has been noted to be most dominant occupation in most African countries (Broad and Agrawala, 2000), as a result, a greater proportion of the drought (and of course desertification) problems will impact vehemently on agriculture most especially in rural areas as 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 drought and desertification (Young, Jaspars, Brown, Frize, Khogali, (2001).

The consequence of this is felt on agriculture leading to fall in food production, crop failure, rise of unemployment, land degradation, desertification, loss of biodiversity etc. According to Yelwa (2012), the cumulative effect of drought is felt in other disasters such as desertification and famine, prominent in the Sahara and Sub-Sahara. Similarly, the American Planning Association (APA, 2005) agrees that drought can affect surface water and groundwater supplies.

No one is immune from the impacts of drought, and when drought is severe, it can affect nearly all typical daily activities. Bathing, food preparation, sanitation, healthcare, recreation, and a host of other activities that contribute to health and wellbeing can be negatively impacted by drought. Such effects particularly burden vulnerable populations, such as young children, older adults, disabled persons, individuals with compromised health, and those living at or below the poverty line (U.S. DHS 2012).

In this regard, to conduct a detailed study so as to know the periodicity and intensity of droughts in order to develop strategies for monitoring, controlling and mitigating the impacts is of paramount importance (Okorie, 2003). The Advanced Very High Resolution Radiometer (AVHRR) data have been explored for monitoring vegetation and Normalized difference vegetation index (NDVI) data being generated for the whole Africa. Similarly; the installation of the Africa Real Time Environmental Monitoring Using Imaging Satellites (ARTEMIS) by FAO has both proved useful in this regard. Furthermore, other remotely sensed data such as NDVI derived from MODIS and SPOT data are also being utilized in similar studies. Thus, employing remote sensing and GIS techniques in this study by using NDVI conforms to the present scientific method of research analysis.

Most of the researches carried out on environmental hazards such as drought, famine and desertification have mostly been conducted by multinational bodies such as United Nations, Food and Agriculture Organization; corporate bodies such NOAA, NASA etc.

However and EniolorundaYelwa (2012) simulated the movement of desertification in Sokoto and its environs using 1km SPOT-NDVI data and discovered that the cumulative effect of drought is felt in other disasters such as desertification and famine prominent in the Sahara and Sub-Sahara.

Dipanwnita, Arnab, Patel, Saha and Siddiqui (2015) assessed agricultural drought in India using remote sensing derived Vegetation Condition Index and Standardised Precipitation Index and found out that there was a significant agreement between VCI and SPI (r = 0.75).

Adewale and Aremu (2014) also examined the extent and intensity of extreme drought in some parts of the Savanna Region of Nigeria. They discovered that extreme droughts were confined to extreme northern states.

Similarly, Hurrell, (1995) agreed that drought can affect surface water and groundwater supplies.

One undisputable cause of 'famine' in northern Nigeria is the failure of crops resulting from insufficient or untimely rainfall. To ascertain this fact, Okorie (2013) carried out a research on drought in the Sub-Saharan Region of Nigeria using Satellite Remote Sensing and Precipitation Data and discovered that many years of drought episode were recorded in all the 14 states covered in the study (Kaduna state inclusive).

No specific attention has been paid to Kaduna state with respect to drought. In addition integrating the three datasets so as to achieve a coherent and more effective way of monitoring and mitigating drought has not been recorded.

1.3 RESEARCH QUESTIONS

Drought has not typically been a topic of concern to many individuals. In part, this may be due to a lack of clarity about what constitutes drought and therefore how it affects individuals. Events such as tornadoes and hurricanes have distinct beginnings and ends, demarcating bursts of meteorological activities that leave little doubt of when they are happening. When the earth starts to shake, we know an earthquake has begun. Beyond that, scientists largely focus on describing where an event falls along a spectrum of severity or probability. In view of this, this study has the following questions:

i. What is the magnitude of drought in Kaduna State?

ii. What is the extent of drought in Kaduna State?

iii. What are the most effective ways of controlling and mitigating drought for Kaduna State?

1.4 AIM AND OBJECTIVES

The aim of this study is to assess drought in Kaduna State Nigeria between 2000-2014. The aim will be achieved through the following objectives;

i. To assess the magnitude of drought in the study area

ii. To determine the extent of drought in the study area.

iii. To analyze respondents’ views on effective ways of controlling and mitigating the impacts of drought in the study area

1.5 SCOPE OF THE STUDY

The study covered the whole of Kaduna state, with specific reference to the years 2000 to 2014. This involved the use of 10 years decadal NDVI data from Aqua-Modis, 15 years precipitation data NIMET Zaria and Kaduna and a set of questionnaire. According to the World Meteorological Standard, a weather station covers a distance of 150km radius.

1.6 SIGNIFICANCE OF THE STUDY

In view of the fact that no one is immune from the impacts of drought, a study with this aim is highly important. The cumulative and resultant effects of drought as witnessed in other localities and other disasters such as famine, desertification calls for more researches in other to minimize the impacts of drought since it cannot be eliminated completely. With the availability of NDVI data provided by NOAA – AVHRR, SPOT, AQUA MODIS and ARTEMIS provided by FAO, it is very possible to monitor and assess drought conditions and other environmental issues within the African Continent (using satellite remotely sensed data).

In drought monitoring, ground points observations are associated with some limitations such as subjectivity, incompleteness, irregularity and unreliability, but satellite sensors provide spatial information on vegetation's stress caused by drought conditions, thus providing an effective method of drought assessment and monitoring. The study found out people's perception to drought in the study area, the contribution of rainfall variability to declining vegetation growth and agricultural activities aimed at reducing food insecurity in the study area.

With regard to the problem definitions of this study as highlighted, the results obtained will be very useful for drought monitoring and mitigating across the study area when properly implemented.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter focused on important relevant literatures. This includes a review of conceptual framework and a review of related literatures as observed by other researchers.

2.2 CONCEPTUAL FRAMEWORK

2.2.1 Droughts as Hazard: Concepts, Definition, and Types

Drought differs from other natural hazards in several ways. First, drought is a slow onset of natural hazard, often referred to as a creeping phenomenon (NASA (Earth Observatory), 2008). Because of the creeping nature of drought, its effects accumulate slowly over a substantial period of time. Therefore, the onset and end of drought are difficult to determine, and scientists and policy makers often disagree on the bases (i.e., criteria) for declaring an end to drought. Tannehill (1947) stated that:

> *"We may truthfully say that we scarcely know a drought when we see one. We welcome the first clear day after a rainy spell. Rainless days continue for some time and we are pleased to have a long spell of fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows how serious it will be*

until the last dry day is gone and the rains have come again ... we are not sure about it until the crops have withered and died."

In furtherance, theauthor asked; should drought's end be signaled by a return to normal precipitation and, if so, over what period of time does normal or above-normal precipitation need to be sustained for the drought to be declared officially over? Do precipitation deficits that emerged during the drought event need to be erased for the event to end? Do reservoirs and groundwater levels need to return to normal or average conditions? Impacts linger for a considerable time following the return of normal precipitation; so is the end of drought signaled by meteorological or climatological factors, or by the diminishing negative human impact?

The absence of a precise and universally accepted definition of drought adds to the confusion about whether a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. Definitions must be region specific because each climate regime has distinctive climate characteristics (i.e., the characteristics of drought differ significantly between regions such as the North American Great Plains, Australia, southern Africa, western Europe, and northwestern India). Definitions need to be application specific because drought, like beauty, is largely defined by the beholder and how it may affect his or her activity or enterprise. Thus, drought means some- thing different for a water manager, an agriculturalist, a hydro- electric power plant operator, and a wildlife biologist. Even within sectors there are many different perspectives of drought because impacts may differ markedly. For example, the impacts of drought on crop yield may differ greatly for maize, wheat, soybeans, and sorghum because each is planted at a different time during the growing season and has different sensitivities to water and temperature stress at various growth stages.

2.2.2 Types of Drought

2.2.2.1 Meteorological Drought

All types of drought originate from a deficiency of precipitation (Young *et al.*, 2001). When this deficiency spans an extended period of time, its existence is defined initially in terms of these natural characteristics. The natural event results from persistent large-scale disruptions in the global circulation pattern of the atmosphere. Exposure to drought varies spatially, and there is little, if anything, we can do to alter drought occurrence. However, the other common drought types (i.e., agricultural, hydrological, and socioeconomic,) place greater emphasis on human or social aspects of drought (figure 2.1), highlighting the interaction or interplay between the natural characteristics of the event and the human activities that depend on precipitation to provide adequate water supplies to meet societal and environmental demands.

2.2.2.2 Hydrological Drought

This is even further removed from the precipitation deficiency because it is normally defined in terms of the departure of surface and subsurface water supplies from some average condition at various points in time. Like agricultural drought, no direct relationship exists between precipitation amounts and the status of surface and subsurface water supplies in lakes, reservoirs, aquifers, and streams because these components of the hydrological system are used for multiple and competing purposes (e.g. irrigation, recreation, tourism, flood control, hydroelectric power production, domestic water supply, protection of endangered species, and environmental and ecosystem preservation). There is also considerable time lag between departures of precipitation and when these deficiencies become evident in these components of the hydrologic system. Recovery of these components is also slow because of long recharge periods for surface and subsurface water supplies. In areas where the primary source of water is snowpack, such as in the western United States, the determination of drought severity is further complicated by infrastructures, institutional arrangements, and legal constraints (Young et al., 2001).

2.2.2.3 Socioeconomic Drought

This differs markedly from the other types because it associates human activity with elements of meteorological, agricultural, and hydrological drought. This may result from factors affecting the supply of or demand for some commodity or economic good (e.g., water, grazing, and hydro-electric power) that is dependent on precipitation (Young e*t al.*, 2001). The author further observe that socioeconomic drought may also result from the differential impact of drought on different groups within the population, depending on their access or entitlement to particular resources, such as land, and/or their access or entitlement to relief resources. Drought may fuel conflict between different groups as they compete for limited resources. A classic example in Africa is the tension, which may become violent in drought years, between nomadic pastoralists in search of grazing and settled agriculturalists wishing to use the same land for cultivation(Young *et al*., 2001). The concept of socioeconomic drought is of primary concern to policy makers.

The interplay between drought and human activities raises a serious question with regard to attempts to define it in a meaningful way. It was previously stated that drought results from a deficiency of precipitation from expected or "normal" that is extended over a season or longer period of time and is insufficient to meet the demands of human activities and the environment (Kogan, 1997). Conceptually, this definition assumes that the demands of human activities are in balance or harmony with the availability of water supplies during periods of normal or mean precipitation. If development demands exceed the supply of water available, demand may exceed supply even in years of normal precipitation. This can result in human-induced drought. In this situation, development can be sustained only through mining of groundwater and/or the transfer of water into the region from other watersheds. Is this practice sustainable in the long term? Should this situation be defined as “drought” or unsustainable development?

In addition, Kogan (1997) suggested that drought severity can be aggravated by other climatic factors (such as high temperatures, high winds, and low relative humidity) that are often associated with its occurrence in many regions of the world. Drought also relates to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought event is unique in its climatic characteristics, spatial extent, and impacts (i.e., no two droughts are identical). The area affected by drought is rarely static during the course of the event. As drought emerges and intensifies, its core area or epicenter shifts and its spatial extent expands and contracts.

In technical terms, droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation short- fall and/or the severity of impacts associated with the shortfall (Taddei, 1997).It is generally measured by the departure of some climatic variables (e.g. precipitation), indicator (e.g., reservoir levels), or indices (e.g., Standardized Precipitation Indices) from normal and is closely linked to duration in the determination of impact.

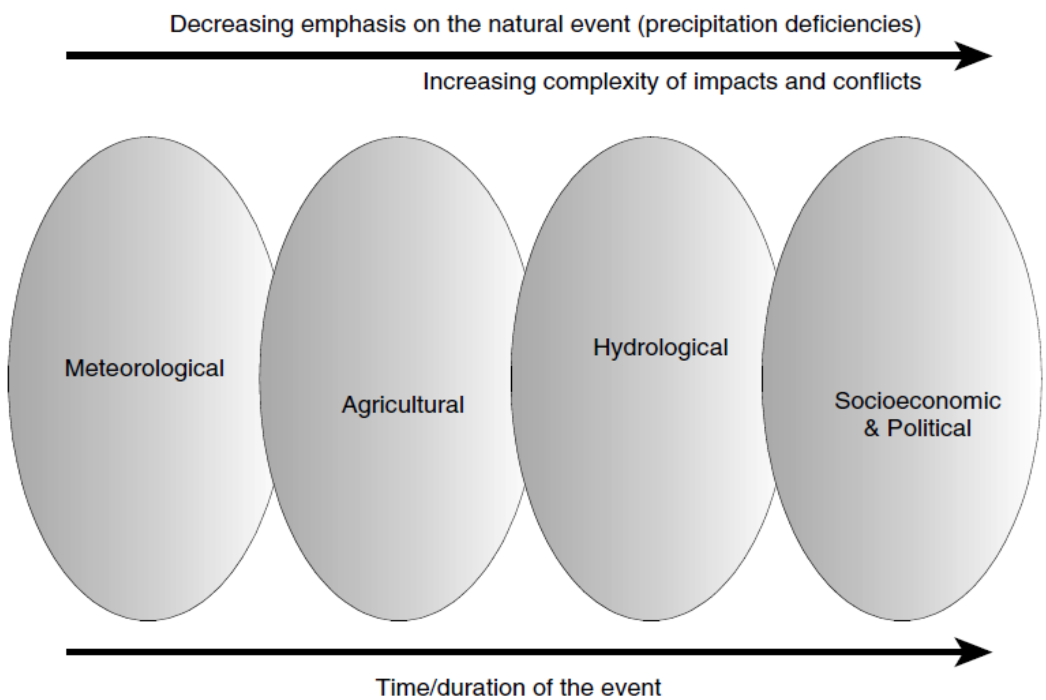


Figure 2.1 Natural and social dimensions of drought. (Source: National Drought Mitigation Center, University of Nebraska, Lincoln, Nebraska, USA.)

2.2.3 Characterizing Drought and Its Severity

Another distinguishing feature of drought is its duration. Droughts usually require a minimum of 2 to 3 months to become established but can continue for months or years (Heim, 2000). The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event.

Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity (i.e., epicenter) shift from season to season. In larger countries, such as Brazil, China, India, the United States, or Australia, drought rarely, if ever, affects the entire country. During the severe drought of the 1930s in the United States, for example, the area affected by severe and extreme drought reached 65% of the country in 1934 (Heim, 2000). From a planning perspective, the spatial characteristics of drought have serious implications. Nations should determine the probability that drought may simultaneously affect all or several major crop-producing regions or river basins within their borders and develop contingencies for such an event. Likewise, it is important for governments to calculate the chances of a regional drought simultaneously affecting agricultural productivity and water supplies in their country and adjacent or nearby nations on which they depend for food supplies. A drought mitigation strategy that relies on the importation of food from neighboring countries may not be viable if a regional-scale drought occurs (Cova, 1999).

2.2.4 The Challenge of Drought Early Warning

Drought has some unique characteristics that require different approaches to monitor its development and cessation and assess potential impacts on people and society at the local, regional, and national level. Common indicators of drought include meteorological variables such as precipitation and evaporation, as well as hydrological variables such as stream flow, ground water levels, reservoir and lake levels, snow pack, and soil moisture. Numerous climate and water supply indices are in widespread use to identify the severity of drought conditions, and to represent it in a probabilistic perspective. Each index has strengths and weaknesses, which need to be clearly understood as they are integrated into drought early warning systems (Heim, 2000).

In many countries, especially in Africa, early warning systems for drought are also coupled to those developed for early warning of famine and food shortages more generally. In these cases, many additional variables are monitored as indicators of stress on lives and livelihoods. Because of the slow-onset nature of drought, it is essential that early warning systems have the capacity to detect the early emergence of rainfall deficiencies, which will normally be the best indicator of an incipient drought period. There is a need for the application of climatic indices to evaluate the status of climate and water supply conditions and potential impacts in specific sectors (e.g., agriculture, wildfires) (Cova, 1999). This information should be supplemented by long range or seasonal forecasts whenever possible.

Although an understanding of underlying vulnerability is essential to understand the risk of drought in a particular location and for a particular group of people, a drought early warning system (DEWS) is designed to identify negative trends and thus to predict both the occurrence and the impact of a particular drought and to elicit an appropriate response (Buchanan-Smith and Davies, 1995). Numerous natural indicators of drought should be monitored routinely to determine drought onset, end, and spatial characteristics. Severity must also be evaluated continuously on frequent time steps. Although droughts originate from a deficiency of precipitation, it is insufficient to rely only on this climate element to assess severity and resultant impacts. An effective DEWS must integrate precipitation data with other data such as stream flow, snowpack, groundwater levels, reservoir and lake levels, and soil moisture in order to assess drought and water supply conditions.

These physical indicators and climate indices must then be combined with socioeconomic indicators in order to predict human impact. Socioeconomic indicators include market data—for example, grain prices and the changing terms of trade between staple grains and livestock as an indicator of purchasing power in many rural communities—and other measures of coping strategies. Poor people usually employ a sequence of strategies in response to drought. Early coping strategies rarely cause any lasting damage and are reversible. In many poor rural communities, examples of early coping strategies include the migration of household members to look for work, searching for wild foods, and selling nonproductive assets. If the impact of the drought intensifies, these early strategies become unviable and people are forced to adopt more damaging coping strategies, such as selling large numbers of livestock or choosing to go hungry in order to preserve some productive assets. Once all options are exhausted, people are faced with destitution and resort to crisis strategies such as mass migration or displacement (Corbett, 1988; Young et al., 2001). Monitoring these coping strategies provides a good indicator of the impact of drought on the local population, although by the time there is evidence of the later stages of coping, it is usually too late to launch a preventative response.

Similarly, Young *et al.,* (2001) suggested that effective DEWSsare an integral part of efforts world- wide to improve drought preparedness. (Many DEWSs are, in fact, a subset of an early warning system with a broader remit to warn of other natural disasters and sometimes also conflict and political instability.) Timely and reliable data and information must be the cornerstone of effective drought policies and plans. Monitoring drought presents some unique challenges because of the hazard's distinctive characteristics.

2.2.5 Explicit Computer Model Predictions

Between about 1970 and 1980, the basis for generating daily weather forecasts moved from sets of empirical, observationally based rules and procedures to explicit predictions made by computer models of the three-dimensional structure of the atmosphere. However, in order to make similar progress in computer-based forecasting on longer time scales, it was essential to incorporate the slower contributions to variability from ocean circulations and variations of the land surface (Stockdale *et al.*, 1998).

Similarly, tremendous success have been recorded in seasonal forecasting which have arisen from advances in knowledge made as a result of the careful analysis of data collected over time. The growth in knowledge about the circulation of the oceans and its modes of variability, which was stimulated in large measure during the 1980s with the implementation of the Tropical Ocean Global Atmosphere (TOGA) and World Ocean Circulation Experiment (WOCE) projects of the World Climate Research Program, has yielded rewards in the identification and understanding of even slower modes of variability than are at work on seasonal timescales. In particular, in the two ocean basins that extend to both polar regions, evidence exists in both oceanic and atmospheric records of quasi-rhythmic variations with timescales of a decade or so known as the North Atlantic Oscillation (Hurrell, 1995) and the Pacific Decadal Oscillation (Nigam et al., 1999).

The path to better prediction of droughts on the decadal scale involves identifying correlated patterns of variability in atmospheric and oceanic records, investigating the physical and dynamic processes at work, representing those processes within a hierarchy of computer models, and developing sets of statistics from a range of predictive models (Rajagopalan*et al*., 2000). Although research tends to focus on one scale or the other, implementation of the results at the practical level must integrate the outcomes of many complex processes across all timescales.

2.2.6 Climate Prediction and Drought Early Warning Systems

Early warning systems (EWSs) have become increasingly successful at recognizing the development of potential famines and droughts. Loveland, Merchant, Ohlen and Brown (1991) observed that in 1992 EWSs were successful in sounding the alarms about the drought emergence. Although some warnings, such as those given in southern Africa during 1997–1998 were not followed by full- blown droughts and famines, such events are not necessarily forecast failures because most, if not all, seasonal forecasts are issued as probabilities for dry, near-normal, or wet conditions. There has been increasingfocus on economic and social indices to complement physical information, a seasonal forecast for drought potentially provides an early indication of impending conditions. Economic and social indices tend to follow the development of drought and are valuable to confirm the existence of drought conditions.

Food security will exist when all people, at all times, have access to sufficient, safe, and nutritious food for a healthy and active life (World Food Summit, 1996). However, certain parts of the globe have been observed to be more vulnerable to droughts and famines because of variable climate, marginal agriculture, high dependence on agriculture, and social and military conflict. The populations of many countries in sub- Saharan Africa suffer from chronic malnutrition, with frequent famine episodes. Achieving food and water security will remain a development priority for Africa for years to come. Even in a nation that is food secure at the national level, household food security is not guaranteed.

Before too much investment of time and effort is placed in drought or rainfall early warning (as a physical event), one needs to ask what the "drought early warning system" is intended to achieve. A drought early warning forecast must identify components of a drought that strongly affect food supply and the development of famine conditions, along with factors affecting water supply. Drought EWSs should incorporate a broad range of information in order to provide a balanced perspective of conditions. Although no particular kind of information is a unique indicator, a famine EWS cannot do without physical information such as rainfall (including forecasts) or drought early warning. In fact, these types of information are practically the only types that can provide a longer lead-time forecast to the development of a drought.

The first purpose of a drought EWS is to determine the probability of a drought event and to monitor its spatial extent, duration, severity, and those who may be potentially affected. This requires an appreciation of the climatology of the area and the crop calendars. As described by Walker (1989), a famine EWS should detect, evaluate, and predict the hazard. It uses monitoring tools such as remote sensing, market conditions, and climate forecasts, as well as geographical information systems to isolate the extent of the hazard area. Huss-Ashmore (1997) examined the question of what predictions are needed for a famine EWS. In order to pursue an increase in food imports at a national level, governments require a significantly earlier indicator of potential problems. However, information such as drought early warning indicates only the potential for problems, whereas output-related indicators show the emergence of actual problems. Delaying a response until this information is available would generally result in some level of food shortage.

A significant challenge in developing a drought EWS is the range of spatial and temporal scales of the information available. On one hand, market prices of staple crops on a week-to-week basis may be monitored. But this information needs to be integrated with global three-monthly (and even possibly longer) regional climate forecasts. Related to this problem is information that only partly reflects the real information requirement.

2.2.7 Impediments to Using Climate Predictions for Drought Mitigation

A survey of the scientific literature, and experience in operational seasonal climate prediction, reveals that a variety of impediments obstructs the optimal use of seasonal climate forecasts, especially in drought mitigation (Nicholls, 2000).

The limited skill obtainable with climate predictions is well known and is often cited as a reason for the limited use of climate predictions. Awareness of the existence of an El Niño episode in 1997 led to mitigation efforts in southern Africa in anticipation of a possible drought in 1998. A major drought did not materialize that year; so the forecast led to preparations that created negative impacts, such as reducing the amount of seed purchased by farmers because they feared their crops would fail (Dilley, 2000).

Glantz (1977) noted a variety of social, economic, environmental, political, and infrastructural constraints that would limit the value of even a perfect drought forecast. He concluded that a drought forecast might not be useful until adjustments to existing social, political, and economic practices had been made. Hulme*et al.* (1992), in a study of the potential use of climate forecasts in Africa, suggested that forecasts may be useful at the national and international level (e.g., in alerting food agencies to possible supply problems), but they also concluded that improvements in institutional efficiency and interaction are needed before the potential benefits of the forecasts could be realized. Broad and Agrawala (2000), discussing the 2000 food crisis in Ethiopia, concluded that "even good climate forecasts are not a panacea" to the country's food crisis. The short fall of these predictions wouldn't have occurred if remote sensing and GIS techniques were applied in view of its accuracy, wider coverage, real time information provision etc.

2.2.8 Causes of drought

The underlying causes of most droughts can be related to changing weather patterns manifested through the excessive buildup of heat on the earth's surface, meteorological changes which result in a reduction of rainfall, and reduced cloud cover, all of which results in greater evaporation rates. The resultant effects of drought are exacerbated by human activities such as deforestation, overgrazing and poor cropping methods, which reduce water retention of the soil, and improper soil conservation techniques, which lead to soil degradation (Okorie, 2003). Desertification is caused by multiple direct and indirect factors. It occurs because drylands ecosystems are extremely vulnerable to over-exploitation and inappropriate land use that result in underdevelopment of economies and in entranced poverty among the affected population. 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.

Consequently, the causes of desertification are more complex to unravel. Desertification is driven by a group of core variables, most prominently climatic factors (Hulme and Kelly 1993) that lead to reduced rainfall (Rowell *et al.* 1992) and human activities involving technological factors, institutional and policy factors, and economic factors (UNCCD 2004) 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

.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 mostly 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. These factors prevail in many parts of the region (Okorie, 2003).

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. 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 11-fold increase. The forage needs of livestock exceed the carrying capacity of its grasslands. It is reported that overgrazing and over-cultivating are converting 351,000 hectares of land into desert each year. 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.

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

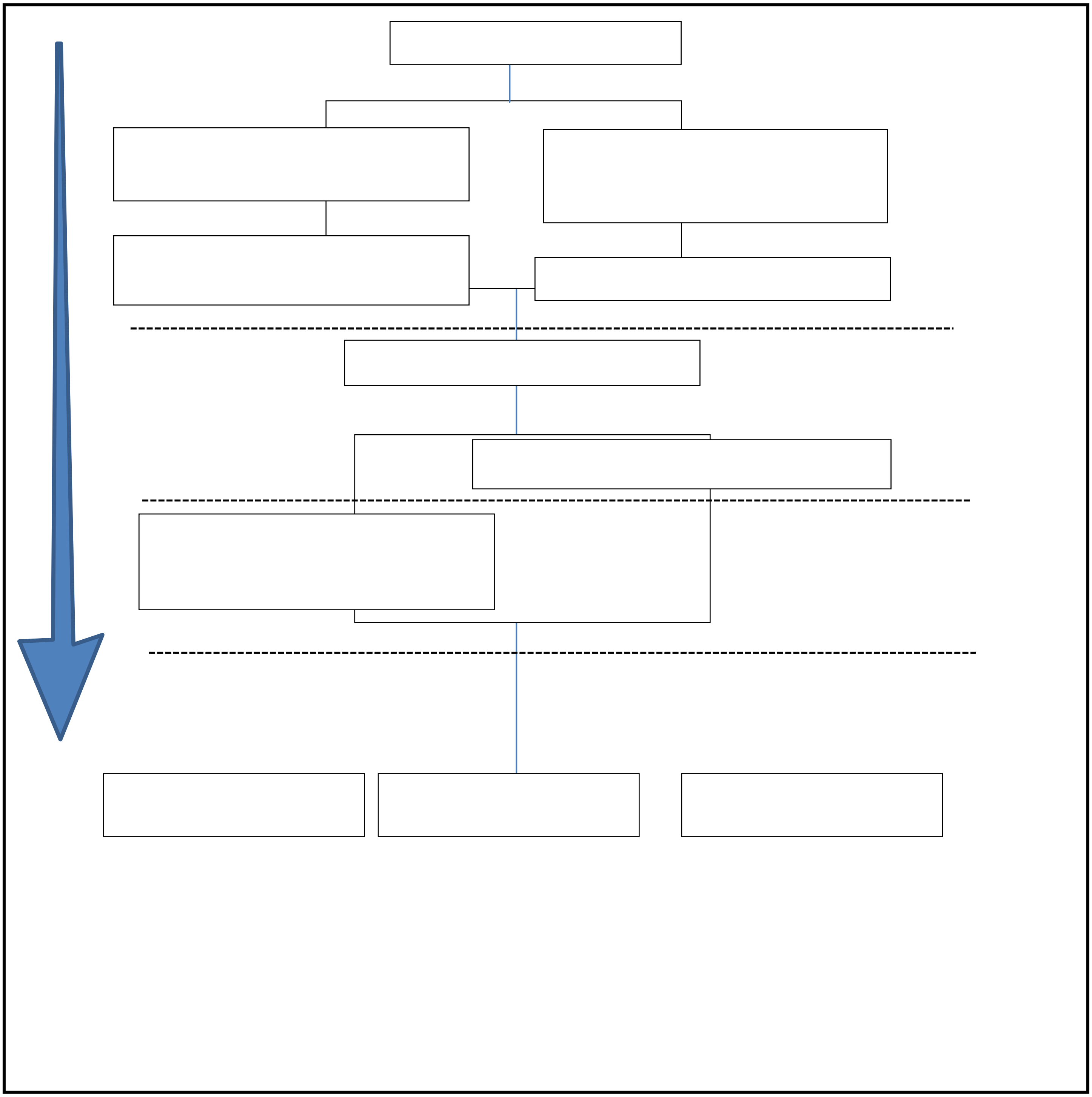
485 million people or sixty-five percent of the entire African population. Desertification especially around the Sahara has been pointed out as one the potent symbols in Africa of the global environment crisis. Climate change is set to increase the area susceptible to drought, land degradation and desertification 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 according to (Lester, 2006) is threatened by desertification. Nigeria is reported to be losing 992 square kilometers of rangeland and cropland to desertification each year (Mohammed, 2009). This affects each of the 10 northern states of Nigeria.

The continent has witnessed a high frequency of occurrence and severity of drought. Drought is one of the most important climate related disasters in Africa. Climate change is set to exacerbate occurrence of climate related disasters including drought. Current climate scenarios predict that the driest regions of the world will become even drier, signaling a risk of persistence of drought in many parts of Africa (arid, semi-arid and dry sub humid areas) which will therefore bear greater and sustained negative impacts.

2.2.9 Impacts of Drought and Desertification

Land degradation and desertification constitutes major causes of forced human migration and environmental refugees, deadly conflicts over the use of dwindling natural resources, food insecurity and starvation, destruction of critical habitats and loss of biological diversity, socio-economic instability and poverty and climatic variability through reduced carbon sequestration potential (Lester, 2006). The impacts of drought and desertification are among the costliest events and processes in Africa evident broadly on the economy, agriculture, water supply, biodiversity, energy and migration.

The widespread poverty, the fact that a large share of Africa's economies depend 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. The consequences are mostly borne by the poorest people and the Small Island Developing States (SIDS). In the region, women and children in particular, bear the greatest burden when land resources are degraded and when drought sets in. As result of the frequent droughts and desertification, Africa has continued to witness food insecurity including devastating famines, water scarcity, poor health, economic hardship and social and political unrest. Figure 2.2 illustrates the gravity of drought and desertification impacts in the African region.



2.3 LITERATURE REVIEW

This section reviews related literatures base on the following themes; satellite metrics in drought monitoring, forecasting drought, the need for drought monitoring, climate delivery systems, remote sensing for droughts monitoring, and drought and desertification in Africa.

2.3.1 Satellite Metrics in Drought Monitoring

Water according to Hulme*et al.* (1992) is central to the world's development challenges. Whether it is food security, poverty reduction, economic growth, energy production, human health, water is the common denominator. Climate change is the spoiler. The increase in catastrophic events such as droughts and floods will impact lives, livelihoods, land values, and investment incentives, especially in vulnerable areas inhabited by poorer populations, (Hulme*et al.* 1992).

Droughts are natural hazards with varying patterns in space, time, and intensity. Their dynamic character challenges our ability in planning, predicting, monitoring, and providing relief to affected areas (Wilhite, 2000). Because of the spatial and temporal variability and multiple impacts of droughts, we need to improve the tools and data available for mapping and monitoring this phenomenon on all scales. Previous studies have established significant relationships between climate variables and satellite-derived vegetation indices over non-irrigated croplands and grasslands. The need to integrating information provided by satellite-derived metrics on seasonal vegetation performance and climate-based drought indicators to produce a timely and spatially-detailed drought monitoring product is the goal of this research, (Wilhite, 2000).

Drought is an insidious natural hazard that results from a deficiency of precipitation from expected or "normal" that, when extended over a season or longer, is insufficient to meet the demands of human activities and the environment. Drought by itself is not a disaster. Whether it becomes a disaster depends on its impact on local people and the environment. Therefore, the key to understanding drought is to understand both its natural and social dimensions (Wilhite, 2000). Drought is a normal part of climate, rather than a departure from normal climate (Nicholls, 2004). The latter view of drought has often led policy and other decision makers to treat this complex phenomenon as a rare and random event. This perception has typically resulted in little effort being targeted toward those individuals, population groups, economic sectors, regions, and ecosystems most at risk (Wilhite, 2000). Improved drought policies and preparedness plans that are proactive rather than reactive and that aim at reducing risk rather than responding to crisis are more cost-effective and can lead to more sustainable resource management and reduced interventions by government (Wilhite et al., 2000).

Mohammad (2008) reports that desert, which now covers about 35 percent of Nigeria's land mass, is advancing at an estimated 0.6 km per annum while deforestation is taking place at 3.5 percent per annum. The desert belt has moved from Kebbi, Kano, Maiduguri to new Bussa, Kaduna, Jos, Sheleng while Savannah now interfaces between desert and forest along Oyo, Osun, Kogi and Benue states. Moreover, the Sudan Sahel region of Nigeria has suffered decrease in rainfall in the range of 3-4 percent per decade since the beginning of the nineteenth century (Mohammad, 2008). In the Daily Trust, (2008), the Director General, Nigerian Meteorological Agency analyzed rainfall data (1911 -2000) in three-30 year intervals - 1911-1940; 1941-1970; 1971-2000 showed that many more places are recording late onset, early cessation, shortened length of the rainy season and reduced annual amount of rain especially in the northern part of the country.

Mohammad (2009) also observed more frequencies of drought, more persistent harmattan haze and increasing temperature trends. According to him, over 80% of Nigeria's population depends on rain-fed agriculture and fishing as their primary occupation. Thus food production system being adversely affected by the variability in timing and amount of rainfall, frequent outbreaks of crop pests and diseases and heat stress. Food shortages will increase and many farmers could lose their sources of livelihood due to climate change.

Closely related to deforestation is desertification (a drought induced hazard), which is the long-term transformation of forestland into desert, a phenomenon that occurs in the arid regions in northern Nigeria, when land is neglected after trees are felled without replacement, (Mbano 2005). According to Ekpoh (2011), two third of 11 northern states could turn into desert or semi-desert during the 21st century. As a result, conditions are already evident on the northeast border of Nigeria, where Lake Chad has shrunk by 90%, and the Sahara is swallowing 351,000 hectares of potential farmland each year (Ekpoh, 2011).

The effects of drought are being exacerbated by desertification and the threat of the Sahara desert spreading southwards is considered a major challenge that no single country can tackle alone (Ekpoh, 2011). Land resources underpin the livelihoods of billions of people worldwide, and are central to sustainable national development. This is especially true in dry land areas which are experiencing severe pressure from increasing socio-economic impacts of land use and broader global changes.

There is no universal definition of drought. Definitions have been classified as conceptual and operational. Operational definitions are important because they attempt to determine the onset, severity, spatial extent, and end of drought conditions. Many indicators and indices of drought exist and these may disagree as to the severity of drought conditions. Commonly used drought indices in the U.S. include the Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), and Standardized Precipitation Index (SPI) (McKee *et al.*, 1994). Each of these indices has recognized strengths and weaknesses. Indices are often used to trigger both response and mitigation programs by local, state, and federal government. The PDSI, a meteorological drought index, was the first comprehensive drought index developed in the United States (Palmer, 1965). The PDSI provides a measure of the departure from normal of the moisture supply. The CMI is an indicator of soil moisture in the topsoil. The SPI is a simple calculation solely based on rainfall with a temporal flexibility that is theoretically much better suited to the quicker responses in vegetation detected by satellite imagery. It is a statistical measure on the surplus or lack of precipitation during a given period as a function of the long-term average precipitation (McKee *et al.,* 1993; McKee *et al.*, 1994).

Whereas drought indicators may assimilate information on rainfall, stored soil moisture, or water supply, typically they do not express much local spatial detail (that is, one value may be used to indicate climate conditions over an entire county) (McKee *et al.*, 1994). Alternatively, drought indices may also be calculated at one location where the input data are collected (that is, a climate station). This information is spatially discrete but only valid for a single location. Thus, a significant drawback of climate-based drought indicators is their lack of spatial detail. In addition, meteorologically-based indices are dependent on data collected at weather stations. Some areas have very sparsely distributed stations and this affects the reliability of the drought indices. Recently, it has become clear that no one indicator or index is adequate for monitoring drought on a regional scale; instead, a combination of monitoring tools integrated together is preferable for producing regional or national drought maps.

The various phenological stages of plant growth are linked to important biotic processes such as net primary production and water balance (Goetz and Prince, 1996; Lechowicz and Koike, 1995; Schwartz, 1992; Running and Nemani, 1991). In addition, lower atmosphere energy and carbon budgets are rapidly modified during the early stages of the growing season. Traditionally, phenology studies have been largely ground-based, with observations mainly providing information concerning specific plants over a limited spatial area. Satellite data analysis, however, provides a means to measure broad scale changes at the ecosystem level by making numerous, repeatable observations. Multi-temporal satellite observations have allowed researchers to quantify seasonal events and to characterize vegetation according to its seasonal patterns (Lloyd, 1990; Folger, *et al.* 2012, Redmond, 2002, 1993; DeFries*et al.*, 1995; Reed *et al.*, 1996). Environmental factors that appear to cause changes in the phenologic patterns exhibited in satellite data include drought, flood, disease, fire, and human-induced land cover change (such as clearing land for forest harvest or conversion to cropland).

Kogan (1995) has analyzed droughts in the United States using AVHRR data. One index, the Vegetation Condition Index (VCI), is a ratio of the NDVI collected in a given period compared to its historical range (maximum minus minimum) derived over several years of record. Possible VCI values range from 1 to 100. Kogan (1995) stated that VCI values of 35 and below indicate drought. Long-term changes in NDVI data have also been evaluated in several studies but results have not been conclusive. This according to Yelwa (2012) is as a result of differences in the tools used, data processing techniques and the length and time of the analysed time series. Similarly, Eklundh (1998) and Yelwa (2013) have shown that NDVIis closely related to biophysical parameters such as photosynthetically active radiation, leaf area index, biomass vegetation etc. Olsson and Eklundh (1994) also confirmed that seasonal and sub-seasonal signals of vegetation can be detected from NDVI data and consequently climatic variability related to El Nino – Southern Oscillation (ENSO).

Liu and Kogan (1996), Kogan, (1997) Unganai and Kogan (1998) among others have demonstrated the utility of the VCI in Africa, South America and Asia. The studies also developed an index from the thermal data (channel 4) from AVHRR known as the Temperature Condition Index (TCI). The satellite index data are compared to other measures, such as precipitation, atmospheric anomaly fields, and agricultural crop yield for validation purposes. The authors were able to predict corn yields from 6 to 13 weeks prior to harvest with reasonable accuracy by applying the VCI and TCI data. These studies were conducted at a spatial resolution of 16 km^2 based on NOAA Global Vegetation Index product.

Viau (2000) have compared the previously mentioned VCI and the NDVI (extracted from AVHRR data) to measurements of the SPI over less than 20 weather stations in Spain. In addition, Peters *et al.*, (2002) developed a Standardized Vegetation Index (SVI) for the central United States based on 1km^2 resolution AVHRR data. Several studies have investigated relationships between satellite-derived metrics and climate variables. In a recent study based in the Great Plains, Olsson (1993) demonstrated the relationships between NDVI-based seasonal metrics and climate variables for 68 stations in the central United States. Using a stepwise linear regression approach, the authors demonstrated that variables associated with moisture availability and thermal conditions were found to exert control on the performance of both grassland and cropland areas.

Another study (Olsson, 1993) shows moderate to strong relationships (R^2 =0.39-0.94) between annual integrated NDVI and several precipitation measures for specific grassland classes in the U.S. The authors suggest an integrated approach involving numerical models, remote sensing, and field observations to monitor grassland dynamics.

2.3.2 Forecasting Drought

Examination of the long-term climate records in some regions around the globe reveals persistent trends and periods of below-average rainfall extending over years to a decade or more, while other regions exhibit episodic, shorter droughts (Olsson (1993). Hence it is useful to consider the prediction of droughts on seasonal to interannual timescales and, separately, on longer decadal timescales. Our theoretical ability to make an explicit, reliable prediction of an individual weather event reduces to very low levels by about 10–15 days (this is called the "weather predictability barrier"), so forecasts with lead times longer than this should be couched in probabilistic terms. Consequently, a forecast with a lead time of a month or more requires a statistical basis for arriving at a set of probability estimates for the ensuing seasonal to interannual conditions. Two approaches allow us to derive these estimates. The first is based on statistical analyses of the climatic record and assumptions about the degree to which the statistics of the future record will differ from the past record. The second, and more recent, approach is based on the generation of statistics from multiple, explicit predictions of weather conditions using computer models of the climate system (Olsson (1993).

One of the earliest identified and most powerful rhythms, apart from the annual cycle itself, is the El Niño/Southern Oscillation phenomenon, often referred to as ENSO. The robustness of ENSO-related patterns over time in the distribution of rainfall, air and sea temperatures, and other climatic variables, and the fact that the phenomenon is caused by slowly varying components of the ocean–atmosphere system, renders it useful as a predictor, (Yelwa and Dangulla, 2012). ENSO-based indices are the dominant predictors for statistically based seasonal prediction schemes over many parts of the globe, although other indices are now being combined with ENSO for different regions.

One of the simplest of the statistical prediction methods is based on the underlying premise that the behavior of a dominant pattern in the future climate will continue to replicate the behavior observed in the past record. A systematic scan of the record of the Southern Oscillation Index (SOI), for example, can reveal occurrences, or “analogs,” when the track of the index over recent months was “similar” to the track in corresponding months in several past years (Stone and Auliciems, 1992).

2.3.3 The Need for Drought Monitoring

A key component of drought risk management and breaking the hydrological cycle is drought monitoring. Decision makers need timely and accurate information about the development of drought conditions in effect, an early warning system so they can anticipate the onset of drought and be prepared (Zwiers*et al.* 2011). They also need accurate and timely assessments of drought severity so appropriate responses can be coupled with current or anticipated drought impacts. In addition, during drought recovery, decision makers need information that can document the status of recovery and identify if and when the event is over. Drought monitoring must be a continuous process so the hazard and its impacts do not creep up on a region. Decision makers would also benefit from short- and long-term drought forecasting tools that allow them to anticipate and respond to a drought episode with greater precision.

One constraint to effective drought monitoring has always been the lack of a universally accepted definition of the concept. Scientists and decision makers must accept that the search for a single definition of drought is a hopeless exercise. Drought definitions must be specific to the region, application, or impact. Drought must be characterized by many different climate and water supply indicators. Impacts are complex and vary regionally and on temporal timescales. Moreover, drought monitoring indicators, ideally, should be tied directly to triggers that assist decision makers with timely and effective responses before and during drought events (Zwiers*et al.* 2011).

The need for improved drought monitoring is highlighted by recent widespread and severe droughts that have resulted in serious economic, social, and environmental impacts in many countries. In the United States, these droughts have fostered development of improved drought monitoring data and tools and collaborations between scientists. Drought has had a significant impact on civilization throughout history, but it is one of the most difficult phenomena to measure and even to define. Numerous drought indices and indicators have been developed in the last two centuries, based on the sector and location affected, the particular application, and the availability of data, among other factors (Glantz, 1997).

Drought can take multiple forms, including meteorological drought (lack of precipitation), agricultural (or soil moisture) drought, and hydrological drought (runoff or streamflow) (Nicholls, 2004). The complexity of drought often results in a definition that is couched in general terms, such as a marked deficiency of precipitation that results in a water shortage or hydrological imbalance that affects some activity or group. It is best represented by indicators that quantitatively appraise the total environmental moisture status or imbalance between water supply and water demand (Pfaff, Broad and Glantz, 1999). Civilization has struggled to develop early warning and other response systems to address the drought problem, but the diversity of climates, range of sectors impacted, and inconsistency in available resources and data make even drought assessment on a continental scale, let alone on a global scale difficult (Olsson (1993).

However, in most of the rest of the world, drought-induced crop failure and famine can create severe hardship. In 1992, an International Conference on Climate, Sustainability and Development in Semiarid Regions (ICID-I) focused the world's attention on the plight of drylands peoples and was influential in the negotiation of the United Nations (UN) Convention to Combat Desertification (UNCCD) (Glantz, 1997). With 193 country parties to the convention, the UNCCD is a global mechanism to combat desertification and mitigate the effects of drought through national action programmes that incorporate long-term strategies supported by international cooperation and partnership arrangements. Since ICID-I, increasing attention has been paid to how a changing climate may affect the frequency and intensity of drought.

Global warming can intensify hydrological droughts and alter runoff timing from snowmelt, affecting water management decisions (Glantz, 1997), and drought-affected areas will likely increase in extent and the vulnerability of semiarid regions to drought will also likely increase. Some countries have made efforts to adapt to the recent and projected changing climate conditions, particularly through conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for flood drought and coastal management, and disease surveillance systems.

According to Heim (2000), several drought indicators have been used to monitor and assess drought conditions. The fact that the Palmer Drought Severity Index (PDSI) gained so much attention and acceptance in the years following its development (Palmer, 1965), particularly in the United States, indicated that decision makers needed tools to monitor and respond to drought events. Before thePDSI, most drought monitoring efforts used some representation of precipitation, but these were largely applicable to specific locations and not appropriate for many applications (Palmer, 1965).

The PDSI and its assortment of companion indices were quickly accepted because they considered both supply and demand, even if (in retrospect) imperfectly. Palmer had attempted to develop a drought index that included a simplified two-layer soil model and a demand component affected by temperature (Heim, 2000). The index also attempted to standardize for location and time, so that the values could be compared between different climate regimes. Historical calculations could easily be made, so comparisons through time at one spatial point were possible. The index provided a simple scale that decision makers and the public could associate with various levels of drought severity.

Unfortunately, the PDSI's many weaknesses and limitations have been identified over the years (Alley, 1984; Guttman, 1998; Guttman, 1991; Guttman*et al.,* 1992; Hayes *et al.*, 1999). Other indices and techniques have been developed in the United States to sidestep some of the weaknesses. The Surface Water Supply Index (SWSI) was developed to account for the snowmelt-based water resource characteristics of the western United States (Shafer and Dezman, 1982). The statistical and temporal properties of SWSI are not well characterized or understood, and the method is yet to be thoroughly critiqued in the manner of Carlo, Giancarlo and Alessandra (1999). Garen (1993) modified the originalSWSI procedure to incorporate water supply forecasts during the winter season.

In 1993, a group of scientists at Colorado State University (McKee *et al.*, 1993) developed a new drought index, the Standardized Precipitation Index (SPI). Extensive studies showed that the PDSIwas highly correlated (typically r >0.90) with precipitation at certain timescales (almost always 6–12 months), and therefore temperature added little supplementary information. Although based on precipitation alone, the SPI was designed to address many of the weaknesses associated with the PDSI and intended to provide a direct answer to the questions most commonly posed by water managers. The SPI "suite" provides information on absolute and relative precipitation deficits and excesses on a variety of timescales and on the frequency or likelihood of occurrence. The SPI can clearly show situations that are simultaneously in excess and deficit on different timescales (e.g., short wet episodes within long dry periods, or vice versa) and highlights rather than overlooks such common behavior.

Even with the development of the SPI and SWSI, four major limitations to drought monitoring remain: (McKee *et al.*, 1993);

i. Temporal frequency of data collection. Most changes are slow, but drought status can change appreciably in the course of a day (e.g., with heavy rain or snow), or over a few days to a week (e.g., spells of high heat, low humidity, high winds, significant evaporation or sublimation of snowpack, sensitive phenologic stages, shallow soil moisture depletion by high evapotranspiration demand, and so forth). Thus, daily updates represent about the right frequency of new information. In many instances, data are measured and collected only on monthly or sometimes weekly timetables and are often unavailable for several days or weeks because of manually intensive processing methods. Concerns about the quality of near-real time data and the quality control process involved in providing usable recent data have also contributed to these temporal limitations.

ii. Spatial resolution.In most cases spatial resolution has been at a coarse, regional scale. In the United States, much of the climate information has been organized by climate divisions. These divisions fail to provide the required spatial detail of drought conditions needed by decision makers, especially in the West, where topographic gradients predominate.

iii. Use of a single indicator or index to represent the diversity and complexity of drought conditions and impacts. Decision makers need multiple indicators to understand the spatial pattern and temporal timescales within and between regions.

iv. Lack of reliable drought forecasting products. To respond effectively, decision makers need to anticipate the development and cessation of a drought event and its progression.

The U.S. Drought Monitor (http://drought.unl.edu/dm) is a more recent development. The National Drought Mitigation Center (NDMC), U.S. Department of Agriculture (USDA), and National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center (CPC) and National Climatic Data Center (NCDC) author the weekly Drought Monitor (DM) map, which was first released in 1999. The DM is not a forecast; rather, it was designed as a comprehensive drought assessment that reflects the existing drought situation across the country. Because multiple physical conditions may be present at once and no preferred scale exists for assessing drought, the DM also incorporates and heavily weights human expertise and judgment in the assessment of associated impacts (McKee *et al.,* 1993).

The DM defines four categories of drought severity based on increasing intensity (D1–D4), with a fifth category (D0) indicating an abnormally dry area (possible emerging drought conditions or an area that is recovering from drought but may still be seeing lingering impacts). The drought categories represented by this scale are moderate (D1), severe (D2), extreme (D3), and exceptional (D4). Several characteristics of the DM product make it unique and successful. One of its strengths is that the five categories are based on a percentile approach, where D0 is approximately equal to the 30th percentile; D1, the 20th; D2, the 10th; D3, the 5th; and D4, the 2nd (Svoboda *et al.,* 2002).

A second key strength of the DM product is that it is based on multiple indicators. One indicator is not adequate to represent the complex characteristics of drought across a region. The key indicators used in creating the weekly DM map include streamflow, measures of recent precipitation, drought indices, remotely sensed products, and modeled soil moisture. Many other ancillary indicators are also used, depending on the region and the season. For example, in the western United States, indicators such as snow water content, reservoir information, and water supply indices are important for evaluating the current and future availability of water. These indicators inherently incorporate the effects of hydrological lag and relationships across space and time between climate and the surface or groundwater system. The Drought Monitor also incorporates information from approximately 150 scientists and local experts around the country. The DM seeks corroborative impact information to provide added confidence in the initial assessments gained from purely quantitative information describing the physical environment. This kind of "ground truth" is important and increases broad-based credibility of the product with users.

An overall short coming of all these drought monitoring strategies is obvious in the multiplicity of different climatic zones across the globe (McKee *et al.*, 1993). Hence much emphasis was laid on the local climatic scenarios and variables during the time of developing these strategies without an in depth and sufficient information on other micro climates across the globe. This undermines the effectives of the entire above reviewed drought monitoring procedures. Seemingly, the effectiveness of these collaborative drought monitoring efforts is outweighed by lack of basic information, observation, and monitoring systems; lack of capacity building and appropriate political, institutional, and technological frameworks; low income; and settlements in vulnerable areas, among others.

2.3.4 Climate Delivery Systems

According to Pasteris*et al*. (1997), the development of new tools that provide timely, detailed-spatial-resolution drought information (involving the use of remote sensing and GIS techniques) is essential for improving drought preparedness and response. Moreover, incorporating the use of remote sensing and GIS technologies expands more effective ways for monitoring drought-induced vegetation stress such as Normalize Difference Vegetation Index (NDVI), and Vegetation Drought Response Index (VegDRI). Integrating traditional climate-based drought indicators and satellite-derived vegetation index metrics with other biophysical information to develop drought conditions in near-real time (National Weather Service, 2003). VegDRI is a new 'hybrid' drought index that integrates: satellite-based observations of vegetation conditions, climate-based drought index data, biophysical characteristics of the environment to produce 1-kilometre resolution maps that depict 'drought-related' vegetation stress.

New tools and technologies have improved the capacity to monitor real-time precipitation measurements around the United States, largely resulting from the development of the Applied Climate Information System (ACIS) (Pasteris*et al.*,1997). The primary goals of ACIS are to integrate data from several unique networks into one transparent database maintained by the six NOAA regional climate centers and provide software tools to create a wide variety of climate-related products. A web-based interface provides access to near-real-time National Weather Service (NWS) Cooperative Observer Network data, NCDC preliminary and historical datasets, and regional climate center network datasets. ACIS will eventually include information from a variety of federal networks (i.e., SNOTEL [Snowpack Telemetry], SCAN [Soil Climate and Analysis Network], the Remote Automated Weather Stations network) and other regional and state Mesonet data from around the United States.

A related tool is currently being developed as part of a collaborative project between USDA's Risk Management Agency and the Department of Computer Science and Engineering, the NDMC, and the High Plains Regional Climate Center (HPRCC), all located at the University of Nebraska. This project has led to the development of the National Agricultural Decision Support System (NADSS). The NADSS website (http://nadss.unl.edu) contains a collection of decision support tools designed to help agricultural producers assess a variety of climate-related risks. A national interface is being developed to enable a user to generate tabular or map products for the continental United States, or for any individual state or station. Calculations for the SPI, PDSI, a newly derived self-calibrated PDSI (Wells *et al.*, 2004), and a soil moisture model can all be generated and presented in map or table form. This operational tool is based on preliminary, quality-controlled, near-real-time data utilizing the ACIS interface.

2.3.5 Remote Sensing For Droughts Monitoring

Mitigation of natural disasters can be successful only when detailed knowledge is obtained about the expected frequency, character, and magnitude of hazardous events in an area (Krueger, *et al*. 1994). Many types of information that are needed in natural disaster management have an important spatial component.

One of the main advantages of the use of the powerful combination techniques of a GIS is the evaluation of several hazard and risk scenarios that can be used in the decision -making about the future development of an area, and the optimum way to protect it from natural disasters. Remote sensing data derived from satellites are excellent tools in the mapping of the spatial distribution of disaster related data within a relatively short period of time. Many different satellite based systems exist nowadays, with different characteristics related to their spatial, temporal and spectral resolution. Remote sensing data should generally be linked or calibrated with other types of data, derived from mapping, measurement networks or sampling points, to derive at parameters, which are useful in the study of disasters. The linkage is done in two ways, either via visual interpretation of the image or via classification.

Monitoring and assessment of drought through remote sensing and GIS depend on the factors that cause drought and the factors of drought impact. For a given region, the sequential NDVI observations can be plotted against time to quantify remotely sensed vegetation seasonality and dynamics. To summarise the phenological cycle of vegetation, many techniques have been applied with varying degrees of success. Some authors have used few simple parameters to evaluate the time-series of vegetation indices, like mean and standard deviation of NDVI profiles (Ramsey et al., 1995), the amplitude of the NDVI profiles, the onset and peak of greenness and the length of the growing season (Odenweller and Johnson, 1984; Lloyd, 1990; Loveland *et al*., 1991; Reed *et al*., 1994; Running *et al*., 1994). In addition, principal component analysis has been extensively used to characterise long sequence time-series of NDVI profiles (Townshend *et al*., 1985; Tucker *et al*., 1985; Eastman and Fulk, 1993; Benedetti *et al*., 1994; Anyamba and Eastman, 1996; Hirosawa*et al*., 1996, Yelwa and Isah, 2010, Badamasi, Yelwa, Abdulrahim and Noma, 2012). Other studies proposed some NDVI modeling based on logarithmic or exponential expressions (Badhwar and Henderson, 1985; Baret and Guyot, 1986. and Fourier transformation Menenti*et al*., 1993; Andres *et al*., 1994; Sellers *et al*., 1994; Taddei, 1997, Anyamba and Eastman, 1996).

To quantitatively describe the pattern of annual NDVI time-series, Samson (1993) proposed two additional indices, a skew index and a range index, based on the magnitude and shape of the NDVI profiles, respectively. Yelwa, Eniolorunda and Badamasi (2009) applied Remote Sensing and GIS to agricultural land encroachment analysis in the Sokoto-Rima Valley. Similarly, Eniolorunda, Abdulrahim and Yelwa (2008) applied Remote Sensing and GIS techniques to analyse change detection in the Upper River Niger Valley of the North-Western Nigeria. Lambin and Strahler (1994) and Lambin (1996) used the multitemporal change vector approach to compare the differences in the NDVI profiles for two successive hydrological years for a Sudanian–Sahelian region in Western Africa.

According to Eastman and Fulk (1993) the array of Normalized Difference Vegetation Index (NDVI) products now being derived from satellite imagery open up new opportunities for the study of short and long-term variability in climate. Using a time series analysis procedure based on the Principal Components transform, and a sequence of monthly Advanced Very High Resolution Radiometer (AVHRR)-derived NDVI imagery from 1986 through 1990, was used to examine trends in variability of vegetation greenness for Africa for evidence of climatic trends. It was shown that the temporal loadings for this component exhibit a very strong relationship with the El Nino/Southern Oscillation (ENSO) Index derived from atmospheric pressure patterns in the Pacific, Pacific Sea Surface Temperature (SST) anomalies, and with anomalous Outgoing Longwave Radiation (OLR). However, it was also detected that a second interannual variation, affecting most particularly East Africa and the Sahel, that does not exhibit a consistent ENSO relationship exists. The results show the teleconnection patterns between climatic conditions in the Pacific Ocean basin and vegetation conditions at specific regional locations over Africa. The comprehensive spatial character and high temporal resolution of these data offer exciting prospects for deriving a land surface index of ENSO and mapping the impacts of ENSO activity at continental scale.

2.3.6 Overview of Drought and Desertification Situations in Africa

The science of drought forecasting, however, is in its infancy in the African continent (Anyamba and Eastman, 1996). Drought is usually established by persisting high pressure that results in dryness because of subsidence of air, more sunshine and evaporation, and the deflection of precipitation-bearing storms. This is usually part of a persistent largescale disruption in the global circulation pattern. In March 2000, NOAA launched a new drought forecast tool for the United States called the Seasonal Drought Outlook (SDO). The authors further stated that the SDO tool is issued monthly at the same time as the traditional long-range seasonal temperature and precipitation forecasts. The SDO attempts to anticipate the pattern and trends for drought conditions across the country 3 months in advance.

The development of the SDO incorporates a mix of tools, including statistical techniques based on historical natural and "constructed" analogues, historical drought index probabilities based on the time of the year, and various dynamical and statistical precipitation and temperature outlooks spanning various time periods. The SDO forecasts have met with mixed success so far, a major stumbling block being the difficulty of forecasting rainfall, or lack thereof, during the summer (Anyamba and Eastman, 1996).

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 LOCATION

Kaduna state is located between latitudes $9^{o}02'$ and $11^{o}32'$ north of the equator and between longitude $6^{o}15'$ and $8^{o}50'$ east of the prime meridian. Kaduna state is bounded to the north by Katsina, Zamfara and Kano states; to the west by Niger state, to the East by Bauchi and to the south by Plateau, Nassarawa and the Federal Capital Territory, Abuja. The state has a land area of about 43,460 square kilometres which makes it the largest in the northwest geopolitical zone and has about 4.7 percent of the Nigerian land area (NPC, 2006). The longest distance by road from north to south is about 290 square kilometres and from East to West is about 286 square kilometres (Kaduna State Ministry of Finance and Economic Planning, 1996). It has three major urban areas; Kaduna, Zaria and Kafanchan which are accessible by different classes of roads, railway lines and airports.

3.3 PHYSICAL SETTING

3.3.1 Relief and drainage

Kaduna state possesses a striking variety of natural environment. The topography varies from the Kudaru ring complex hills in the East, to the wide valley plains of the River Kaduna in the West. The geology of the area consists of Precambrian rocks of the basement complex. The present topography constitutes of rolling lowland plain generally below 610 meters above sea level. This is not unconnected with the prolonged denudation of the basement complex rocks which underlie the area. The area consists of older granites, schist, and quartzite in different compositions. The land gradually slopes down towards the west and the southwest and is drained by two dominant rivers i.e. Rivers Kaduna and Gurara (www.wikiafrica/africa-nigeria/kaduna/physical/relief, September 2016).

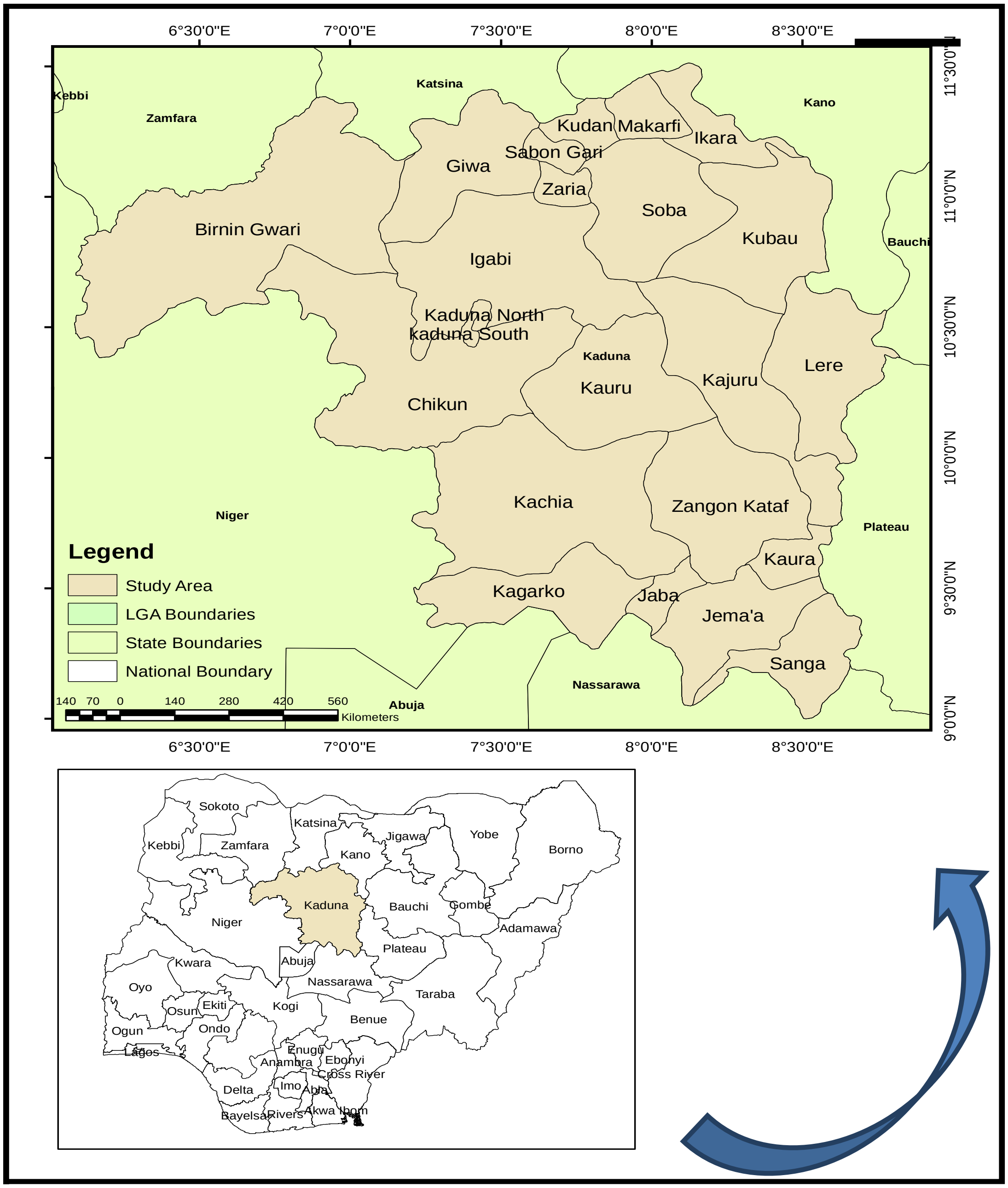


Figure 3.1: Map of the study area covering all the LGAs(Source: adopted and modified from Ministry of Lands and Survey, Kaduna State.)

The relief deeply influences the drainage pattern, most of the area lies within the Mada, Okawa and Gurara river systemin the southern parts of the state. The Okawa and Mada flows into the Benue, while the Gurara flows into the River Niger. There are other smaller rivers that drain the area, some of which include river Gwalake, Ninack, Anvuyeh, Abari, Akwa among others. These rivers are seasonal with low regime during dry season. In the northern part of the state, River Galma is the major drainage system. The Galma and its tributaries are largely ephemeral in character and their flow regimes are highly irregular, major tributaries of the Galma include Kubani, Saye, Tubo and Shika Rivers(www.wikiafrica/africa-nigeria/kaduna/physical/relief, September 2016).

3.3.2 Climate

Kaduna state has a tropical continental climate with marked seasonal variations(Laah, 2003).The area is influenced by two distinct air masses that have much effect on the climate. The northeast trade winds, which are usually dry and dusty, are pronounced between November and March. This period is referred to as Harmattan. The second type is the moisture laden tropical maritime air mass that originates from the Atlantic Ocean. The variations in the onset of rainfall are attributed to the fluctuations of the boundary between these two air masses. Rainfall is heavy in the southern part of the state and reaches an average of 500mm per month between April and September(www.wikiafrica/africa-nigeria/kaduna/physical/climate, September 2016). In the extreme north, the monthly average is 146mm, while Kaduna metropolis receives a monthly average of 361mm. The pattern of temperature and rainfall determines the types of crops, animals and food production. The first rain of the year is usually experienced in the state in March/April and usually falls in thunderstorm showers. The rain reaches its peak in August (Laah, 2003).

The air temperature varies with season. The highest 31^{o}C temperature is recorded in April while the minimum (16^{o}C) are usually recorded during the harmattan season that is between December and January. High evaporation during the dry season, however, creates water shortage problem especially in Igabi, Giwa, Soba, Makarfi, Ikara and Zaria Local Government Areas(www.wikiafrica/africa-nigeria/kaduna/physical/climate, September 2016).

3.3.3 Soil

The soil in most parts of Kaduna state falls under the ferruginous tropical soils. Most of the soils contain 30-40 percent clay at a reasonable depth, because of intensive leaching. The soils in the upland areas are rich in red clay and sand but poor in organic matter. The plains in Kaduna state have under gone considerable changes over the years due to combined actions of both physical and chemical weathering(www.wikiafrica/africa-nigeria/kaduna/physical/soils,September 2016).

3.3.4 Vegetation

Kaduna state lies within the northern Guinea Savanna ecological zone. The vegetation is typically of woodland type and deciduous in character. The dominant tree species include *isoberline, doka, bridelis, terminalia, acacia, vitrex* etc. grasses and shrubs occur in tussocks and the predominant family is the *androgenae*.

The southernmost part of the state has more rainfall, with an average of 1500-2000mm per annum(www.wikiafrica/africa-nigeria/kaduna/physical/climate, September 2016), thereby giving it more dense vegetation. However, human occupation and rapid increase in population have had significant impact on the natural vegetation. Efforts have been made by individuals and government to replenish the destroyed natural vegetation with trees like mango, cashew, guava, gmalina, among others.

3.4 POPULATION GROWTH AND DISTRIBUTION

The major ethnic groups that make up Kaduna population are Atyab, (Kataf), Bajju (Kaje), Gong, Hausa, Fulani, Gbagyi, Karni, Kong, Ikulu, Moro'a, Kagoro, Jaba, Kuturmi, Attakar, Fantsuam, Kadara, and Ninzon. The population as at 1991 was 3,935,618 (4.4 percent of the national total) and with a growth rate of 3.8 per annum. The 2006 population census shows Kaduna state to be 6,066,562.

A study by Mamman (1994)observed that the population of Kaduna has been expanding especially in the urban centres. Young able labourers in large numbers from rural villages migrate to towns to learn specific trades or acquire special training in masonry, carpentry, motor mechanics,etc. during the greater part of the year. The concentration of government employment opportunities and infrastructures in the towns attract a lot of people from other parts of the country to Kaduna. The changing economic and commercial status of the towns also attract investors and other professionals. As the cities grow either as a result of immigration or natural increase or combination of both, other very distinct forms of living and working structures emerge. There are bound to be development in commercial, social and industrial activities.

The relatively high growth rate of 3.8% implies that if present level of mortality and fertility remain constant and there is no serious disaster to either make people leave the state (as we observed during the religious crisis of 2000) or come into the state, the population of the state will double in 25 years (Mamman, 1994).

Birth rate is still very high and Total Fertility Rate (TFR) is 6.8 above the national of 5.8. (Laah, 2003). Although studies have shown that the total fertility rate is declining in Kaduna state, (Laah, 2003), population is still expected to increase. The age distribution shows that more than half of the population is in the age group of 0-19 years (over 65% is in the age group of 0-24). The pattern of age distribution in the state is consistent with past surveys and census. Indices show that Kaduna state is fast growing, but the concentration of the population is not evenly spaced. The three main towns i.e. Kaduna, Zaria and Kafanchan have over 60% of the total population of the state(NPC, 2006). Kaduna town is growing at about 10% per annum (NPC, 2006) which makes it one of the highest rates of urban growth in Nigeria.

3.5 SOCIOECONOMIC ACTIVITIES

Most of the inhabitants of the study area are agriculturalists. There are basically two systems of arable cropping. The first is the rain fed arable cropping which is dominant in the southern part of the state. It is labour intensive and cultivation is done manually by the use of crude implements. The major crops grown are mostly food crops like maize, yam, millet, cassava, cocoyam, sorghum, rice, acha and few cash crops like soyabeans, groundnut, cotton and ginger(Laah, 2003).

Irrigation agriculture the second system of cropping, which is also practiced along floodplains and wetlands (fadamas) in smaller quantities. This is due to variation in the seasons. Food crops such as maize, rice among other also grown through irrigation agriculture. Vegetables such as spinach, garden egg, okro, pepper, tomatoes among others also cultivated. Therefore it is envisaged that these agricultural activities are affected by the declining precipitation in the state. Food security can be undermined by this scenario indicating occurrence of drought(Laah, 2003).

Livestock farming is also another economic activity within the area. Animals reared include pigs, goat, sheep, chicken, cattle (owned mostly by the Fulanis) and dogs, among others.

The landscape of Kaduna state is dotted with several abandoned large and medium scale industrial enterprises especially in the main urban centers of Kaduna and Zaria. The location of industries in Kaduna is heavily lopsided in favour of two local governments namely Kaduna North and South LGAs. At least 65 percent of industrial establishment are located there.

Kaduna state is ranked among the states in Nigeria with the highest concentration of industries. The state has a dozen textile industries and the multipurpose Kaduna Refinery and Petrochemical Company (KRPC), International Brewery and Beverages Industries, Peugeot Automobile of Nigeria, Nigerian Brewery Plc, Sun seed Oil Industry and several others. These industries have stimulated the commercial activities of the state, thus making it a major player in commerce.

This has led to high influx of people into Zaria and Kaduna towns to engage in various economic activities like industrial, commercial, administrative, and educational and other tertiary activities. This has led to the growth of schools, hotels, banks, markets, roads networks, health centers, post offices, electricity etc. Minor economic activities such as weaving, blacksmithing, lumbering, mining, bee keeping, fishing etc. are also practiced in Kaduna state(Laah, 2003).

3.6 METHODOLOGY

3.6.1 Types and Sources of Data

The methodology of this research depends solely on primary and secondary data.

3.6.1.1 Primary Data

i. Satellite Imageries

The primary data will consist of a 15 years NDVI satellite imageries derived from Aqua-Modis (250m spatial resolution) satellite systems obtained from National Aeronautics and Space Administration (NASA) which was processed and analysed using the Idrisi GIS RS software.

ii. Questionnaire

In addition to this, questionnaire was administered to farmers, environmental managers, NIMET staff and the general public to find out their views based on the rainfall trends for the past 15 years.

3.6.1.2 Secondary data

Base on World Meteorological Organsation (WMO) standard, a weather station covers a radius of 100 kilometers; therefore, monthly rainfall data of 2000-2014 (15 years) was obtained from the Nigerian Meteorological Agency (NIMET) of the Nigerian College of Aviation Technology (NCAT) School Zaria and Kaduna Airport Kawo. This provided a reliable representation of the entire state rainfall. This was be complemented by texts, journals, thesis and dissertations from published and unpublished authors, also, internet materials on drought were utilized so as to widen the scope of literature review.

3.6.2 Population size

The entire population of the Kaduna state was utilized for the population of this research. According to the 2006 National Census, Kaduna state has a population of 6,066,526 (National Population Commission, 2006)

3.6.3 Sampling technique and sampling size

Purposive sampling method was used in this study. This was to ensure that information was derived from the most appropriate people within the population. The sampling frame of this study consisted of farmers, NIMET staff, National Emergency Management Agency (NEMA) staff and environmental managers. A number of models have been developed to estimate sample size. However, for this study, Yamane (1967) provides a simplified formula to calculate sample size with 95% confidence level and 5% sampling error assumption.

Thus;

$$n = \frac{N}{1+N(e)^2}$$

Where:
n = sample size,
N = Population size,
e = Level of significance (set at 0.05 for this study)

$$n = \frac{6{,}066526}{1+6{,}\,066526\,(0.05)^2}$$

$$= \frac{6{,}066526}{15165.6425}$$

$$= 400$$

n = 400

Therefore, the sample size used for this study is 400 respondents.

3.6.4 Image Preprocessing

The NDVI was acquired for the entire globe and needed to be reduced to the size of Kaduna state. Two major preprocessing operations were carried out to make the imageries fit for analysis; windowing and masking. Idrisi 32 Release 2 software was used to analyse the NDVI imageries in this research.

3.6.4.1 Windowing

To extract Nigeria from the global NDVI composites, the window operation of the reformat menu was used; using the minimum and maximum values for X and Y (Min X: 2.6, Max X: 14.7, Min Y: 4.15, Max Y: 14.1, number of pixels) and latlong (degrees) referencing system were used in preparing the imagery. This operation was carried out on all the monthly NDVI composites (with the exception of January 2000 which was not available from the Aqua-Modis Corporation).

Similarly, Kaduna state was extracted from the Nigerian composite for each month of the period under review. The window operation from the reformat menu was equally used to window out Kaduna state from Nigeria. Minimum and maximum values for X and Y (Min X: 6.0000001, Max X: 8.8500002, Min Y: 8.9000001, Max Y: 11.55, number of pixels) and latlong (degrees) were used in setting out the imageries. At the end of the windowing operation, 119 (i.e. with the exception of January 2000) NDVI images were obtained for the ten years.

3.6.4.2 Masking

The imageries contained negative values which could hamper the analysis, thus, the need to mask or cancel their effects. A Boolean map was created and used for changing the negative values of the imageries to zeroes while retaining the positive values. This operation was carried out on all the 119 NDVI imageries.

3.6.5 Data analysis

To achieve objectives i and ii, the NDVI images wereanalysed within the Idrisi 32 GIS-RS software using the GIS analysis tools. The magnitude of drought was calculated using he Vegetation Condition Index developed by Kogan. The extent of drought in the state was assessed using the extent tool in the GIS analysis menu in the Idrisi GIS-RS environment. Data was integrated with the rainfall data obtained from NIMET Zaria and Kaduna to show the correlation in the level of rainfall variability for the past 15 years. This was to determine the magnitude and extent of drought. It also showed the relationship between drought and other disasters. Data analysis was done using excel and other statistical software so as to carry out further analysis. This involved the use of Spatial Package for Social Sciences (SPSS) to carry out correlation test at 0.05 significant levels to show the relationship between precipitation and drought occurrence.

Objective iii was achieved using questionnaire administered to the respondents (see appendix 1). This brought out views of some effective ways of monitoring and mitigating the effects of drought peculiar to the study area.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 INTRODUCTION

Chapter four is concerned with the presentation and analysis of data. This is done in accordance with the objectives of the study.

4.2 DATA ANALYSIS

Objective 1: To assess the magnitude of drought in the study area

To assess the magnitude of drought in Kaduna state, responses from respondents were integrated with precipitation and NDVI data.

Table 4.1: Respondents' awareness of drought

Response	Frequency	Percentage
Yes	387	96.75
No	13	3.75
Total	**400**	**100**

Source: Author's Field Work, 2015

Table 4.1 indicates that 97% of the respondents have a clear-cut understanding of drought. Contrary to the 4% of the respondents who claimed not to understand drought, the remainder (3%) are able to provide credible answers to questions relating to drought and similar disasters as they affect their environments and generally their lives. A reliable understanding of the word drought is a very necessary condition for getting reliable information on the subject matter. This is because of its creepy nature and its large and adverse effects.

Table 4.2: Peoples' awareness of decrease in rainfall

Response	Frequency	Percentage
Yes	176	44.00
No	111	27.75
Not sure	113	28.25
Total	**400**	**100**

Source: Author's Field Work, 2015

From table 4.2, forty-four per cent of the respondents agreed that rainfall has been decreasing over the years in the study area. Contrary to this observation, 28% of the respondents said they rather observed increase in rainfall in the study area. Also, about 28% are not really sure of the general trend of precipitation in the study area. However, they are aware that some years may be characterized by late onset, early cessation, and light showers for most part of the year, crop failure as result of insufficient moisture, some years of prolonged rainfall in terms of early onset and late cessation but cannot actually quantify whether generally, total amount of precipitation received was on the increase or decrease.

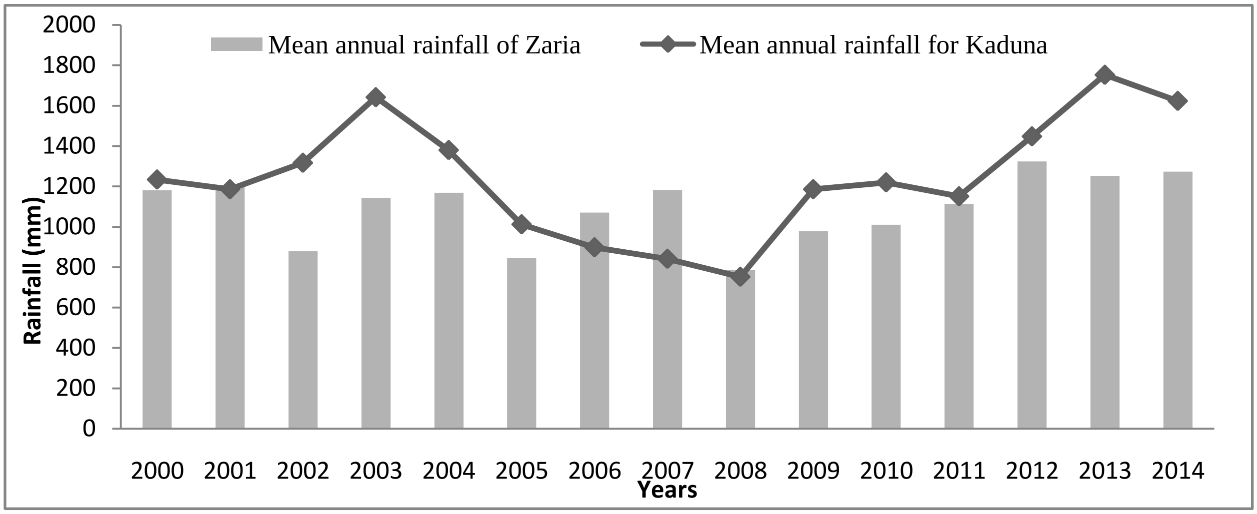


Figure 4.1: Comparative histogram showing annual rainfall for Zaria and Kaduna (2000-2014)

Figure 4.1 shows the rainfall variability in Kaduna state. The trend for Kaduna metropolis and environs show a little variability from the year 2000 to 2003 (1234mm, 1185.8mm, 1317mm, and 1642mm) from where it slide down continuously to its lowest in 2008 (752mm). From 2008 the pattern has been inconsistent with little increases and decreases until in 2013 where the highest amount of rainfall (1753mm) was recorded and then dropped again in 2014(1623.6mm). The level of consistency in the rainfall has been very minimal with a decreasing trend from 2003 to 2008.

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

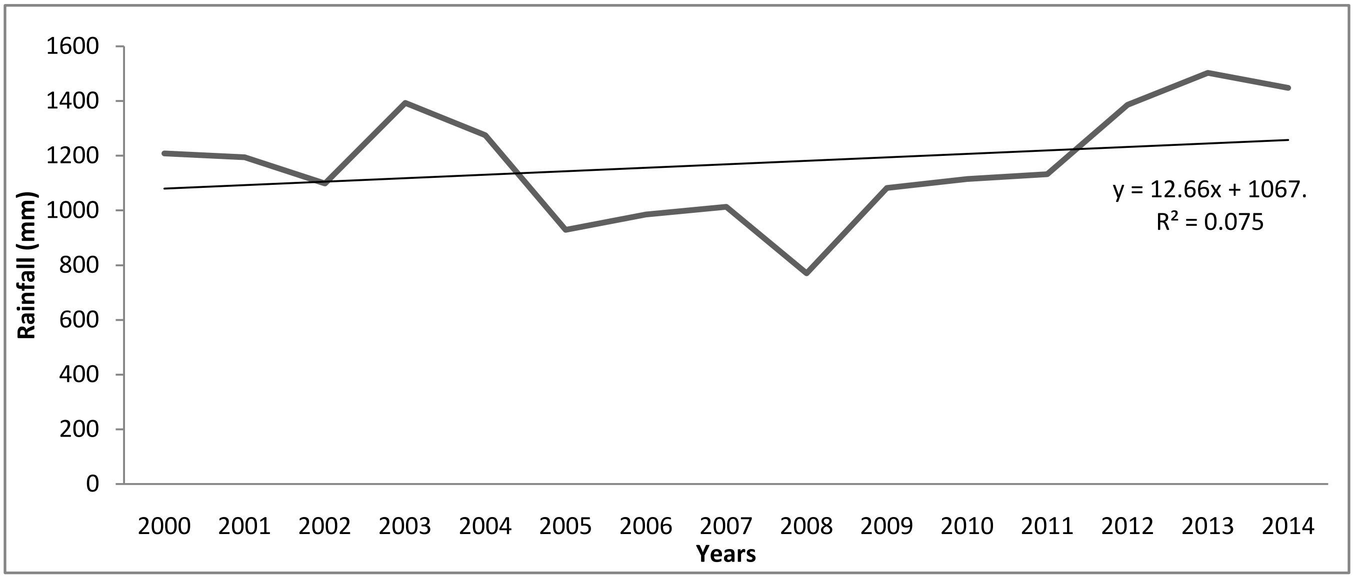


Figure 4.2: Annual rainfall for Kaduna State (2000 to 2014)

Figure 4.2 shows the derived annual rainfall pattern of Kaduna state. This was derived by computing the yearly total of Zaria and Kaduna rainfall recorded for the period under review (2000-2014). The pattern is similar to that of Kaduna metropolis and environs. This is because Kaduna metropolis and environs receives higher rainfall recorded than Zaria. Consequently, the lowest amount of rainfall recorded in Kaduna state as whole for the period under review was769.55mm (2008). Similarly, the highest amount of rainfall recorded for the same period in Kaduna state was 1502.9mm in the year (2013). Therefore, the pattern indicates that from 2003 to 2008 rainfall has decreased consistently in the state. However, from 2009 to 2013 (4 years), an inconsistent increase in rainfall was recorded followed by a decrease in 2014.

4.2.1 Classifications of Annual NDVI Mean Image

In order to further show the magnitude of drought, the mean annual NDVI was used to classify the vegetation into 6 clusters(unsupervised classification) using the cluster tool in GIS analysis menu of the Idrisi GIS-RS environment. The classification is broad covering all vegetation types in the state. The classification indicates that the most dominant vegetation type in Kaduna state is scanty vegetation with total area coverage of 4977432 hectares (54.25%) spread all over the state except in the North-Northeastern part of the state. This vegetation type consists mainly of grasses. This is followed by the medium vegetation type covering 2984018 hectares (32.52%) found mostly the South-Southeastern part of the state consisting of isolated pockets of trees and shrubs. Bare surfaces account for 1159816 hectares (12.64%). This vegetation type is found in the North-Northeastern (greater part of Zaria) part of the state and on isolated rocky ranges of southern part of Kaduna of Sanga Local Government Area and in Jema'a and Kaura Local Government Areas. Smaller vegetation groups include the high vegetation, moderate vegetation and water bodies with 27275, 15232 and 12146 hectares with 0.30%, 0.17% and 0.13% respectively. However, the water body is outside the state which is the Gurara water falls in Niger state which coincides with the area of high vegetation because of the availability of water. Similarly, the moderate vegetation belts occur in southern part of Kaduna mostly in Kaura Local Government comprising of isolated pockets of forests especially along GidanWaya and Sanga Local Government. The image is shown in Figure 4.3 and Table 4.3.

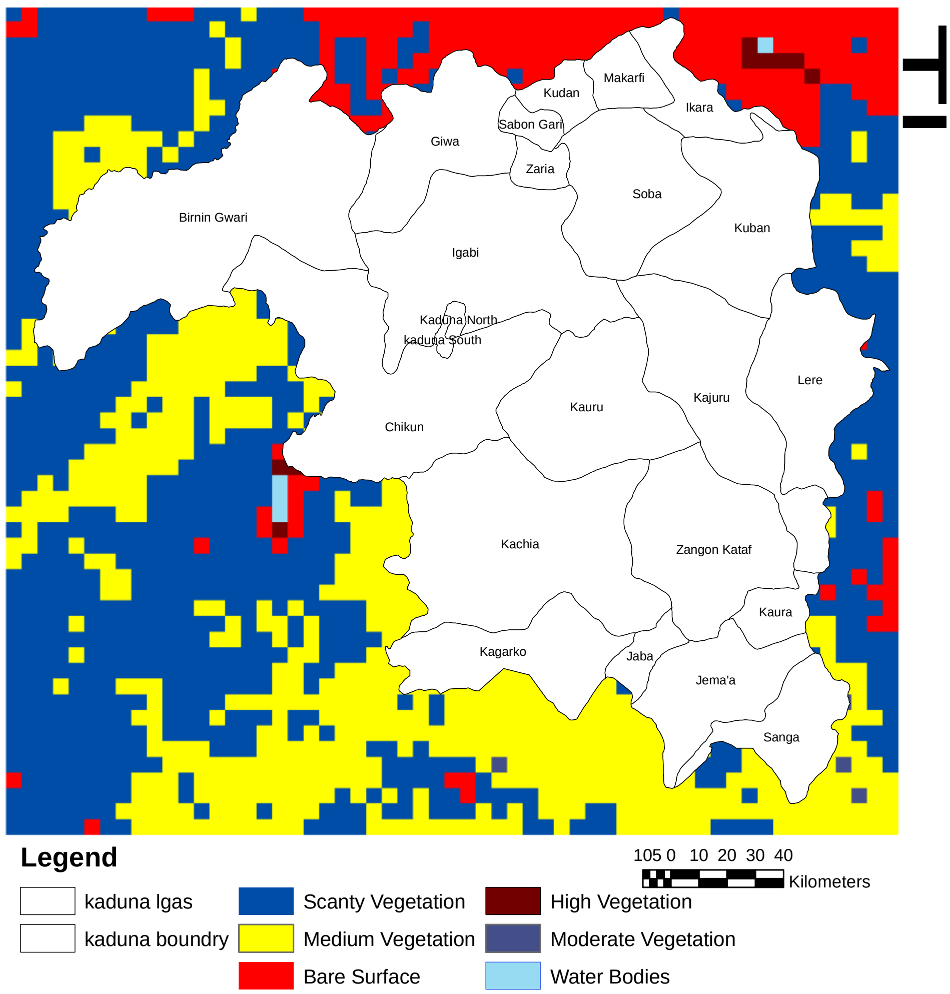


Figure 4.3 Classified Vegetation Image of the study area

Table 4.3: Classification of vegetation (NDVI)

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

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

The effects of climatic extremes and the likelihood of cloud contamination in the imagery are inevitable. Therefore, to reduce these contaminations, the mean NDVI of the end years of each comparison (the quasi time periods) was calculated (after Yelwa, 2008); this is illustrated in Table 4.4. Figure 4.4 shows the short term change (2000-2004) in vegetation growth in Kaduna state.

Table 4.4: Classification of end-point years, absolute and relative changes of the annual NDVI images

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

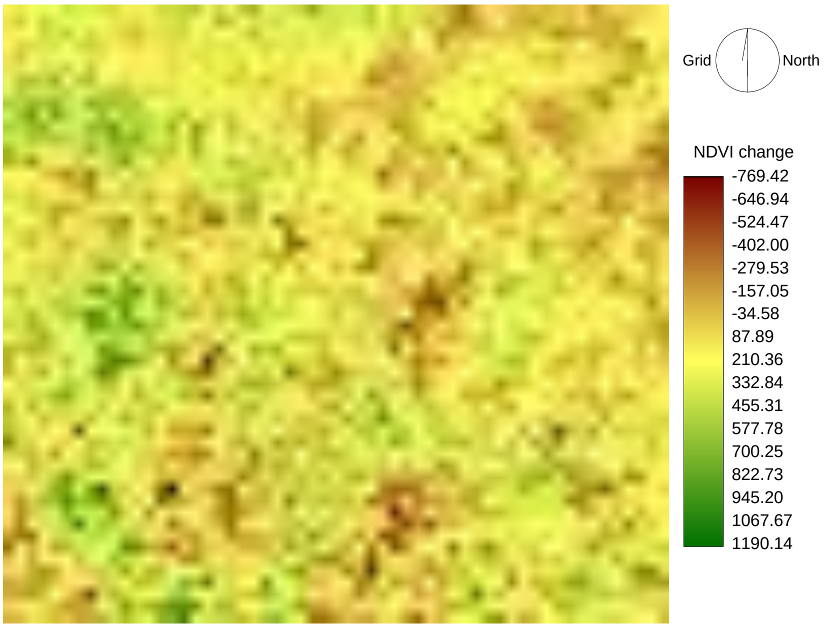


Figure 4.4: Quasi 5-years change image (2000/2001 to 2004/2005)

To enhance a more visual comparison of the images, the annual mean NDVI composites of the end point years were classified on an interval of three NDVI units using the information from the minimum and maximum value range (Table 4.5) obtained from the descriptive statistics of these images.

4.2.2 Determining Relative and Absolute Changes

To provide a picture of relative changes to the end point years (change of 5 years Table 4.5), NDVI units in northern Kaduna area of low biomass might represent a big change compared to the same NDVI units in southern Kaduna with more biomass. This can identify areas of significant changes. To derive the proportionate short term change, the original residual image for the quasi five year change (2004/2005) was divided by the 2000/2001 NDVI image to derive a 'per-pixel' (appropriate change) to show the relative changes between 2000 and 2004 (Figure 4.5). The same procedure was applied to the quasi 10 year period (Figure 4.6) to derived the appropriate long term changes from 2000 to 2009 (10 years change image) (Yelwa, 2008).

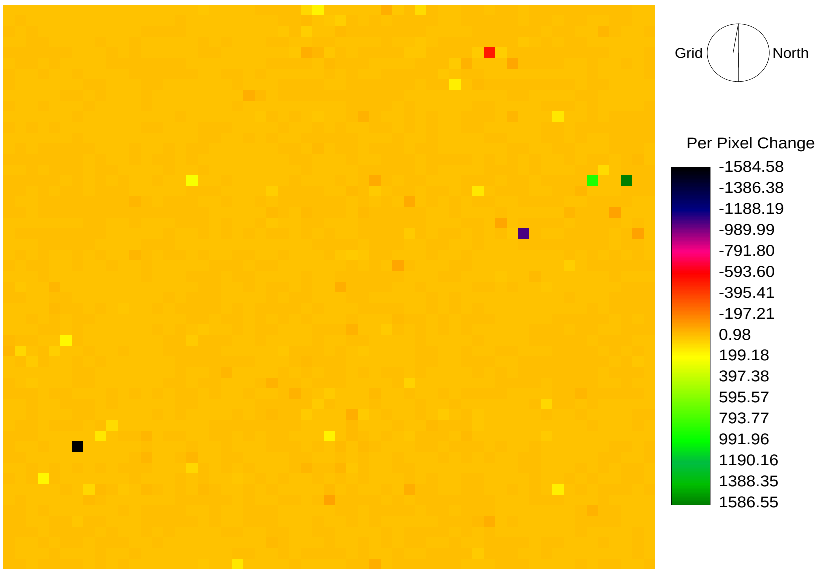


Figure 4.5: Per-pixel change image

Table 4.5: Descriptive statistics from the annual NDVI mean composite images

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

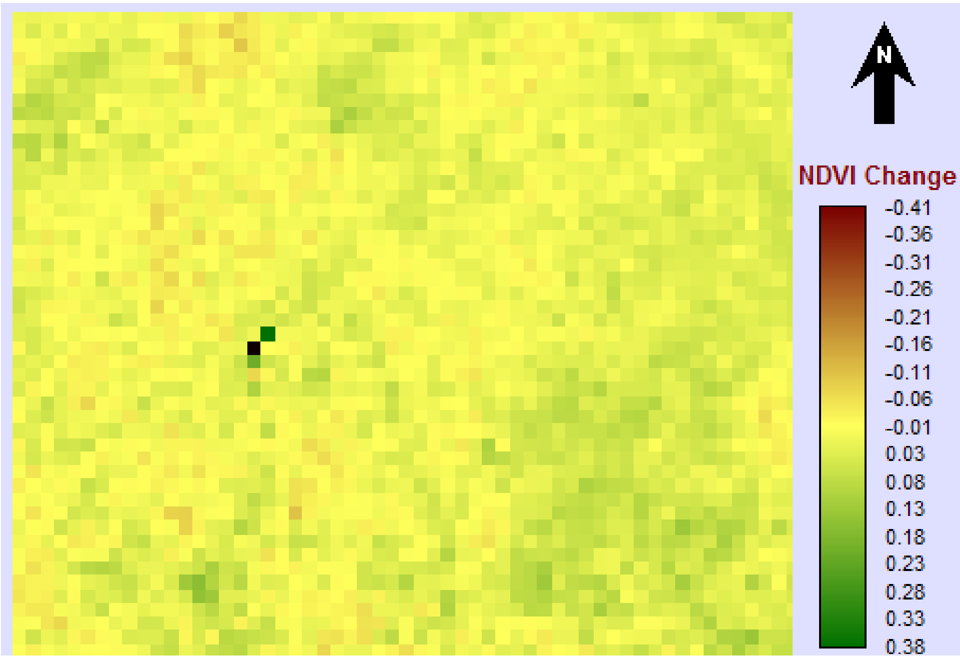


Figure 4.6: Proportionate long term change image

4.2.3 Analysis of Vegetation Condition Index

As an indicative of the magnitude of drought, the Vegetation Condition Index (VCI) was computed which is a ratio of the NDVI collected in a given period compared to its historical range (maximum minus minimum) derived over several years of record. Possible VCI values range from 1 to 100. Kogan (1995) stated that VCI values of 35% and under indicate drought. More so, long-term changes in NDVI data have been evaluated in several studies but results have not been conclusive, this according to Yelwa (2012), is as a result of differences in the tools used, data processing techniques and the length and time of the analysed time series. Table 4.6 shows the vegetation condition index of Kaduna state. According to Kogan

(1995)VCI ranges between 1 to 100%. A vegetation condition index of 70% indicates very luxuriant vegetation while that of 10 indicates a strong drought. Similarly, a VCI of 35% and less indicates drought. Therefore, the VCI for Kaduna state shows a value of 10.2% showing a strong drought in the state.

Table 4.6: Vegetation Condition Index of Kaduna

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

Objective 2: To determine the extent of drought in the study area

The extent of drought in the study area is very important as this brings out a clear picture of the drought scenario in the state. Respondents' observation is very important in showing where drought has been witnessed.

Table 4.7: Areas of Decreasing Rainfall.

Response	Frequency	Percentage
Northern Kaduna	341	85.25
Central Kaduna	44	11.00
Southern Kaduna	15	3.75
Total	**400**	**100**

Source: Author's Field Work, 2015

Based on the locations where decreasing rainfall was observed, the entire study area was divided into Northern, Central and Southern Kaduna. This makes it easy for analysis. Table 4.7 indicates 85% of the respondents agreed that they observed the decreasing rainfall in the northern part of Kaduna state (i.e. from Jaji northwards to where the state meets with other neighbouring northern states such as Katsina, Kano, Zamfara, Kebbi, Bauchi. It is important to note here that during the distribution of the questionnaire, most respondents irrespective of their location in the state pointed to the northern part of the state as locations where decreasing rainfall was observed. This is in line with the desertification problem in the northern states which is ravaging the state.11 percent of the respondents however agreed that they observed decreasing rainfall in central Kaduna (i.e. Kaduna Metropolis). However, 4% agreed that they observed decreasing rainfall in Southern Kaduna. This means that larger part of the state has witnessed some significant episodes of decreasing rainfall largely beyond dry spells. As much of this observation was made in recent years (from 2005), it suggests then that the trend is on the increase as the earliest years of the study period recorded less decreasing rainfall than the recent years.

Table 4.8: Range of years when rainfall was observed declining

Response	Frequency	Percentage
2000-2004	54	13.50
2005-2009	241	60.25
2010-2014	105	26.25
Total	**400**	**100**

Source: Author's Field Work, 2015

When further asked which years respondents observed decreasing rainfall within the temporal scope of this study, 13% of the respondents agreed to 2000-2004 while about 26% of the respondents agreed to 2010-2014. However, 60% observed decreasing rainfall between the years 2005-2009 which was characterized by serious crop. According to them it occurred in the form of late onset, light showers and early cessation. Thus, respondents said price of food commodities in the markets skyrocketed especially in the study area and its neigbouring towns. Table 4.8 shows the result.

Table 4.9: Effects of yearly rains on crop production

Response	Frequency	Percentage
Yes	166	41.50
No	113	28.25
Not sure	121	30.25
Total	**400**	**100**

Source: Author's Field Work, 2015

Further asked whether the annual precipitation supports crop production or not, Table 4.9 indicates that 42% of the respondents agreed that the annual rain does not support crop production as before. They said that due to late onset and early cessation of the rains, the growing season of most stable crops have been reduced leading to low yield. Noting that they (farmers) spent so much of fertilizers, pesticide and herbicides to facilitate the quick growth of crops so as tomaximise output, they lamented that the insufficient rains render their efforts almost entirely unsuccessful. Contrary to this assertion, 28% of the respondents claimed that despite the decrease in the rains, they believe that the annual rainfall still supports crop production just like before. They claim that the reduction in annual rainfall is not sufficient to affect crop production. However, 30% of the respondents asserted that although there is a decrease in annual rainfall, they are not sure whether or not it actually affects crop production. This response comes mostly from non-farmers who however have observed the decrease in rainfall. They however are not sure of effects of decrease in rainfall on crop production. They may however, be aware of scarcity of farm produce, hike in price of food items, they attribute it to normal market conditions such as hoarding, perishable farm produce that quickly get out of season etc. without necessarily tying it to poor yield resulting from insufficient moisture.

4.2.4 Vegetation change vulvnerability base on Rainfall/NDVI cross-tabulation

To further show the extent of drought in the study area, change in vegetation was classified using the cluster (unsupervised classification) tool in the image processing menu of Idrisi GIS-RS environment while retaining all clusters.The result was three broad major categories; little change, moderate change and high change (Figures4.7Anad 4.8). The resultin agreement withFigure 4.8 where three major classes 0:3, 0:4 and 0:5 classes were classified as little, moderate and high/broad change respectively (Table 4.9). The little change class covers about 6.5 million hectares of land. This class is predominantly grasses and shrub whose growth (size/height) remains relatively low despite positive change in rainfall. Therefore, increase in rainfall will produce little observable growth in NDVI.

The moderate change class covers greater part of northern Kaduna with isolated parts to the west and eastern part of Kaduna covering about 2.1 million hectares. This class is covered by short grasses and well dispersed trees of average sizes and heights. This vegetation class is very sensitive to even a little amount of moistures such that a little rainfall will cause grasses to sprout up covering the entire area thereby significantly increasing the spectral signature recorded by satellite sensor; this is recorded as a significant increase in vegetation. The change in these parts is sharp and recognizable because the entire area was initially dry and bare. The broad/high change class exists in clusters found mostly in southern part of the study area. This covers just about 523,286 hectares of the entire Kaduna state. This class comprises of forests with tall trees and big sizes. These trees are deciduous, shedding their leaves during the dry seasons to conserve water; but as soon as the rains set in and within few days, are covered with dense leaves thereby increasing the chlorophyll content as such, the spectral signature recorded by satellite sensor. During the dry season, these areas are recorded with minimum NDVIor vice versa.

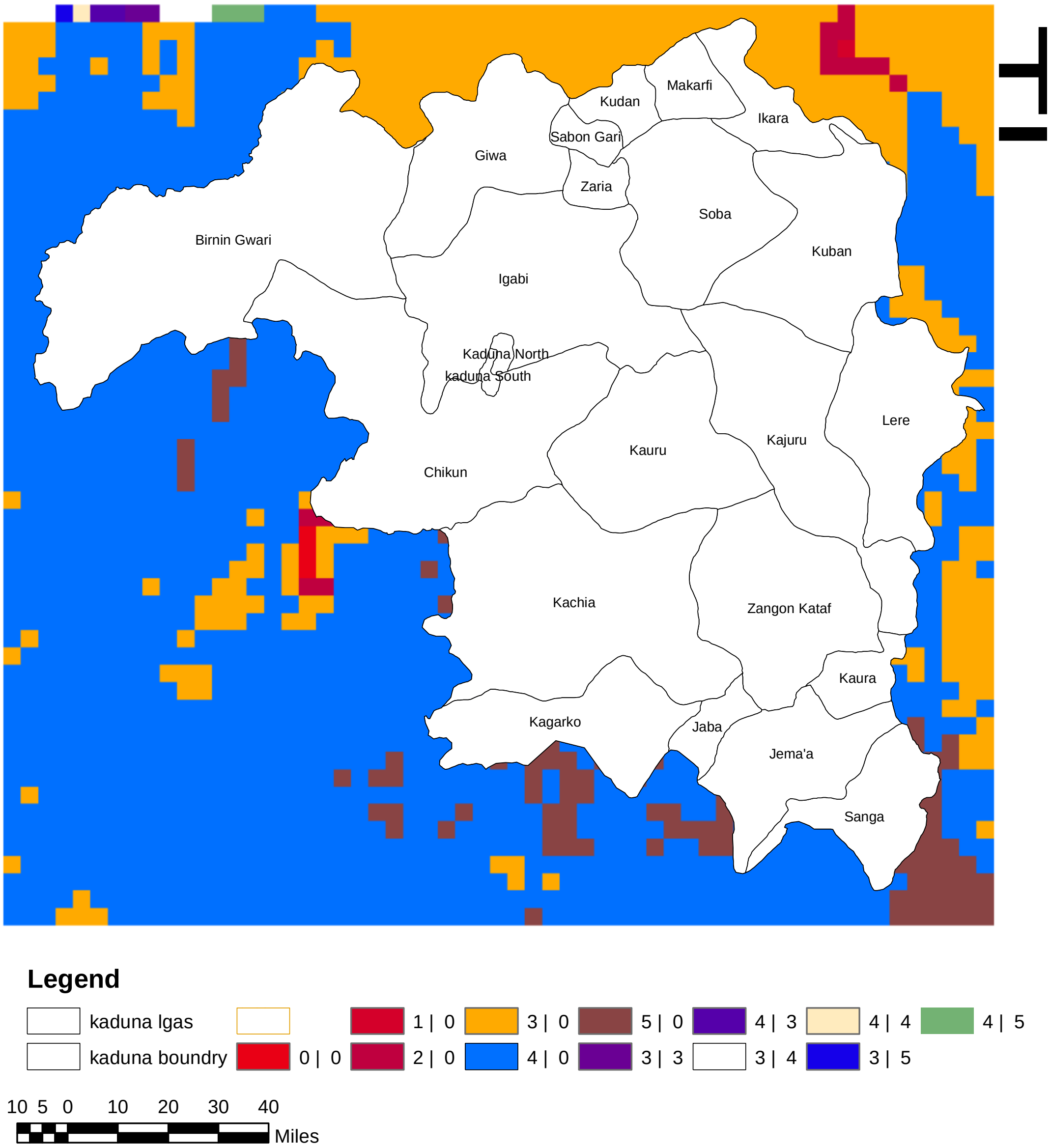


Figure 4.7: Cross-classified image of rainfall and NDVI

Based on the degree of susceptibility of vegetation to changes resulting from rainfall change, the little change class is the part of Kaduna state is mostly hit by episodes of drought. This area covers 6.5 million hectares of the study area, covering Zaria and its environments (Figure 4.7 and Table 4.10).

Figure 4.8: Classification of NDVI change image

Table 4.10: Classification of NDVI changes

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

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

To derive the absolute NDVIchange which further shows the extent of drought in the study area, the percentage of the mean NDVI change of the ten years (2000-2009) was computed. From the percentage, the successive yearly difference was calculated to arrive at the mean absolute NDVI change. The same procedure was applied to the rainfall to arrive at the mean absolute rainfall change. The result is presented in Figures 4.9 which shows the whether the NDVI is increasing or decreasing from the three broad NDVI change derived in Figure 4.7and 4.10 which shows the comparison between rainfall change and NDVI change.

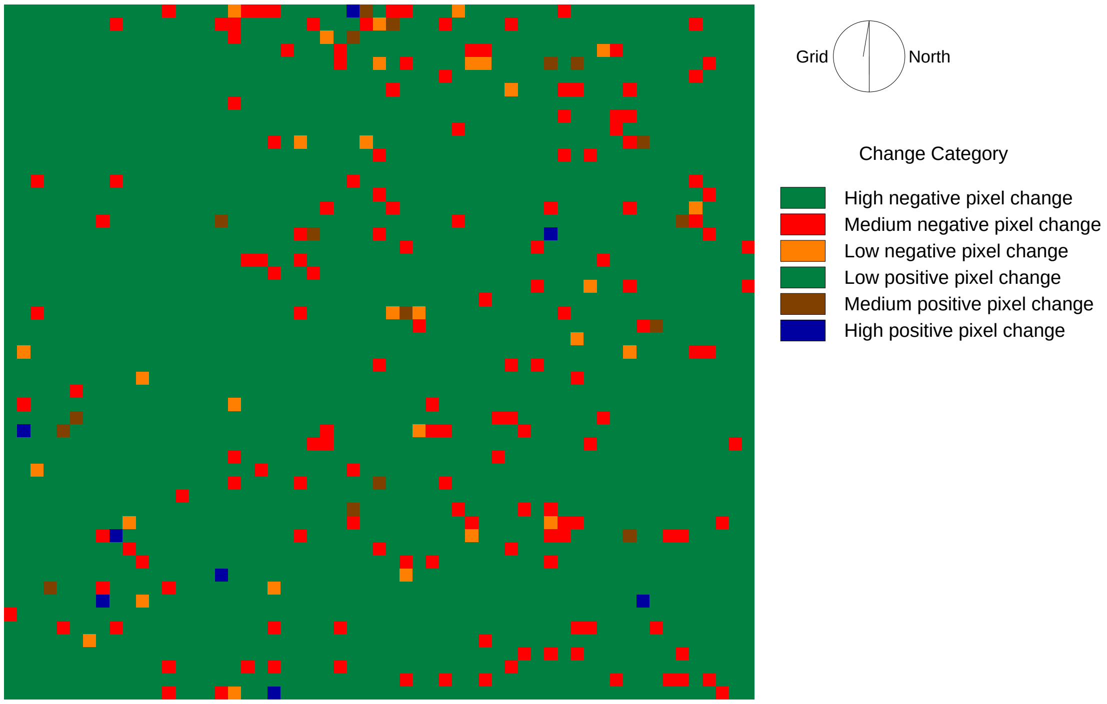


Figure 4.9: Classified pixel change image

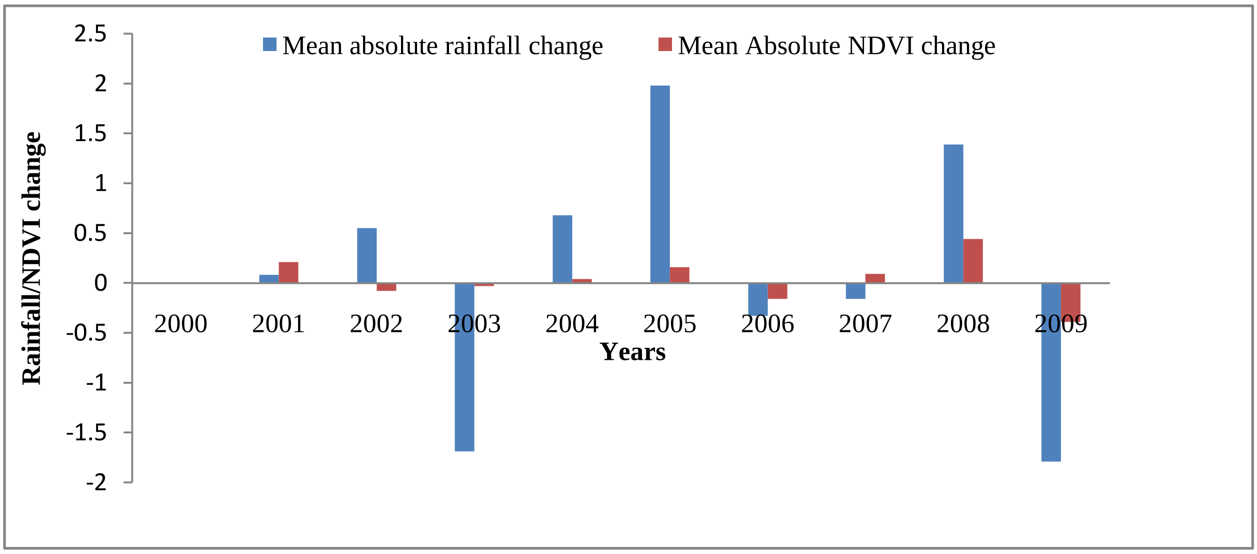


Figure 4.10: Means absolute rainfall and NDVI change histogram

Although the effect of rainfall on NDVI seems to be inconsistent (Figure 4.9), this is due to other climatic variables that act in conjunction with rainfall to affect the vegetation growth in Kaduna state. These climatic elements may include one or more of humidity, winds, sunshine duration and intensity, temperature etc. Dividing the total mean absolute NDVI change by the total mean absolute rainfall change gives a constant value by which a millimeter of rainfall can produce a change in NDVI. Thus, 1mm increase or decrease in rainfall will produce a 0.52 unit increase or decrease in NDVI respectively per annum. Therefore, since the total values of absolute change in both rainfall and NDVI are positive signifying decrease, this indicates that both rainfall and vegetation vigour are decreasing over time. Figure 4.16 also shows the inconsistency between rainfall and NDVI. Of particular interest are the years 2002 and 2007 with complete negative correlations between rainfall and NDVI changes. In 2002, while rainfall increased from the previous year (2001), the following year (2003) witnessed a decrease. This did not produce a corresponding change in NDVI; the NDVI decrease in 2002 and increased in 2003 contrary to the change in the rainfall. Similarly, in 2007, a little increase in rainfall produced a higher increase in NDVI.

4.2.6 Assessment of surface runoff using NDVI imageries

Runoff shows the relationship between the amounts of rainfall received and soil permeability/percolation. This further shows the extent of drought in the study area as it is indicative of precipitation received over time and space. A dry sandy soil will normally absorb more rain thereby reducing greatly surface overflow. Contrarily, a wet or hard baked soil absorbs very little amount of rainfall thereby increasing the amount of surface overflow thus accounting for a greater amount of runoff recorded by the satellite sensor.

From the NDVI images, the amount of runoff can be obtained. Figure 4.11 shows the amount of runoff (surface overflow) in the study for the year 2000. From the image, it is indicated that the runoff for the year was between 1mm –73mm from an annual rainfall of 1194.1mm.

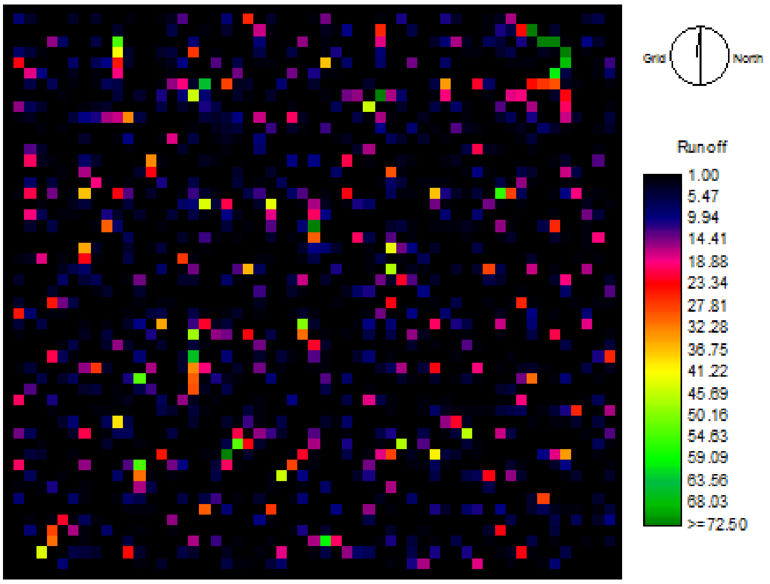


Figure 4.11: NDVI image showing the amount of runoff (2000)

Similarly, for the year 2004, runoff was computed to be between 1mm-62mm (Figure 4.12) with an annual rainfall of 1168.5mm, indicating a both a decline in rainfall and runoff.

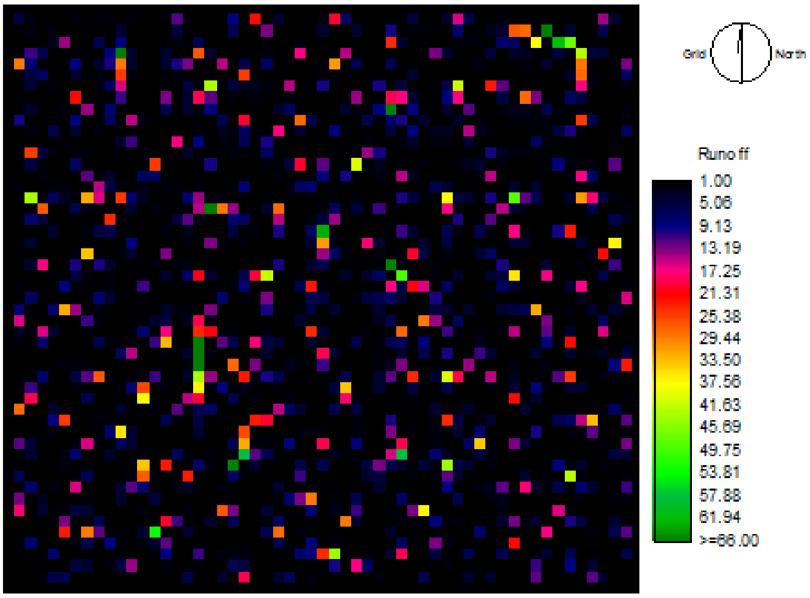


Figure 4.12: NDVI image showing the amount of runoff (2004)

In the year 2004 (5 years later) runoff decreased from 72.50mm (2000) to just about 62.00mm (2004) showing a decrease of 6.5mm accounting for a 9.4% change in runoff. By 2009runoff had decreased to its lowest value of just about 48.00mm compared to 2000 and 2004. Thus,from 2004 to 2009 runoff reduced by 18mm (i.e. from 66mm to 48mm respectively).This is higher compared to 2000 to 2004 with 6.5mm. Again from 2000 to 2009, runoff reduced from 72.50mm to 48.00mm (Figure 4.13); a difference of 24.5mm. However, of particular interest is the change from 2005 to 2009. This is more than twice the change witnessed from 2000 to 2004. This confirms with findings of both questionnaire and rainfall data in Table4.7 and Figure 4.2 where 60% of the respondents agreed that 2005 to 2010 were the years of decreased rainfall.

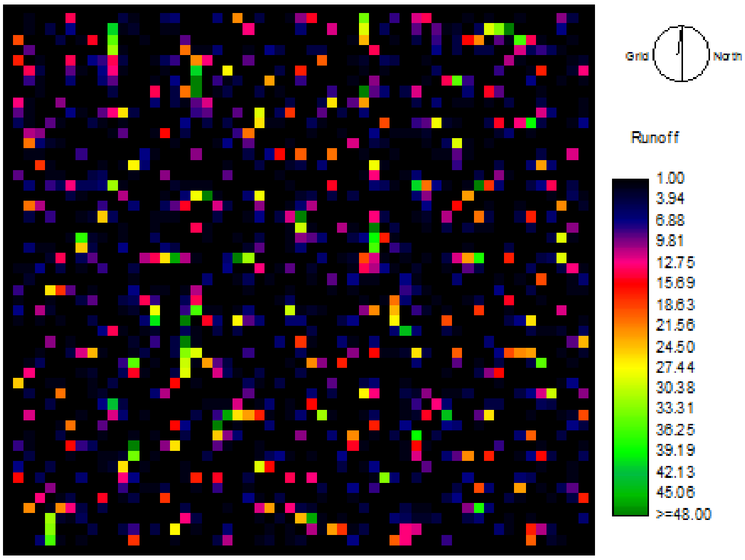


Figure 4.13: NDVI image showing the amount of runoff (2009)

To show the correlation between rainfall and NDVI, the rainfall change and NDVI changes for ten years (2000-2009) were used to run both Spearman and Pearson correlation at 0.05 significance levels using Statistical Package for Social Sciences (SPSS version 21). Pearson and Spearman were used to show level of agreement and consistency (appendix ii). Both Spearman and Pearson showed that correlation is significant at 0.05. However, Spearman correlation coefficient at 0.05 significant levels was 0.709 while Pearson was 0.707 at 0.05 significant levels.

Objective 3: To analyze respondents' views on effective ways of controlling and mitigating the impacts of drought in the study area.

Responses from respondents on ways of controlling and mitigating drought in the study area were grouped and presented as follows;

Early planting with the rains

Mass planting of trees

Construction of dams/water reservoirs

Increased irrigation

Controlled grazing and bush burning

Protection of underground water resources

Creating awareness on drought and its effects

Rainfall harvesting

Respondents' responses were presented as follows:

a. Early planting with the rains
b. Mass planting of trees
c. Construction of dams/water reservoirs
d. Rainfall harvesting
e. Increased irrigation
f. Controlled grazing and bush burning
g. Protection of underground water resources
h. Creating awareness on drought and its effects

Since the rainy season starts late and ends early, respondents agree that farmers should clear their farms, prepare for planting and wait for the rains to start. As soon as the rains start, farmers are advised to immediately plant their crops along with the rains. This will enable crops to utilise maximally the rains that fall within the short time. This category of respondents also advised that the research agencies should develop hybrids that require less moisture to grow and mature such that the short rainy season will just be sufficient for crop production.

Afforestation in the form of mass planting of trees (that are drought resistant) was suggested. This, if implemented, will help reclaim bare surfaces that are devoid of vegetation. This will improve the soil cover and moisture retention capacity both in the soil and the lower atmosphere thereby reducing the effects of drought.

Similarly, the construction of dams and water reservoirs was highly suggested. Activities towards this effort should be doubled when signs of drought are beginning to manifest thereby conserving enough water to reduce the effect of its scarcity. Also, dams, reservoirs, lakes, ponds should be dredged to reduce the amount of siltation thereby increasing the water retention capacity. Similarly, irrigation activities are highly recommended. This reduces overdependence on rainfed agricultural activities. Large and extensive irrigation schemes should be developed thereby ensuring crop production throughout the year. This will go a long way in reducing the effects of insufficient rainfall on agricultural activities. This can be further achieved by rainfall harvest. Runoff should bechannelled to reservoirs and dammed to avoid wastage through evaporation and misuse.

In addition, controlled grazing and bush burning were suggested. There should be well-equipped grazing reserves for the grazing animals. This reduces the labour of the nomads, activities of the animals, better nutrition for the animals, reduce over trampling of the earth crust and the extinction of certain plant species. In a bid to achieve this, bush burning should be outlawed. This goes a long way in ensuring more pasture for grazing animals, more cover for the soil and reduced susceptibility to both fluvial and aoleanerosion for optimal productivity.

Ground water resource may be the last resort in terms of serious drought. Therefore, they should be well protected. This can be achieved through an effective municipal water supply. Excess water during the rainy seasons should be dammed, treated and supplied for general community and industrial usage. Individual sinking of boreholes should be discouraged by providing portable water for all. By this, misuse of water resources is greatly reduced as everyone pays for any drop of water spilled, thereby preserving and controlling access to underground water resources. Also the entire environment should be covered with vegetation by planting large canopy threes to reduce evaporation thereby conserving the underground water bodies.

Finally, respondents recommended that awareness be created on drought and its effects. By this, people are enlightened on avoidance of any activities that could aggravate the effects of drought. Awareness will go a long way in sensitizing the people on the complexities of drought and its long term effects. This awareness could be through pamphlets, fliers, and pictures of ravaged areas, the radio, and television, the electronic and social media.

CHAPTER FIVE

SUMMARY, CONCLUSIONSAND RECOMMENDATIONS

5.1 INTRODUCTION

This study has revealed the magnitude and extent of drought in Kaduna state and the ways to moderate its effects. Peoples' perception, precipitation data and satellite remotely sensed data were integrated to assess various ways of assessing, monitoring and controlling drought. This integration is necessary because drought is a complex disaster and its occurrence and mitigation therefore need to be considered with utmost priority. Early studies on drought have made use of precipitation and other traditional data. Thus, major conclusions and recommendations are hereby presented to justify the need for this study and reveal its findings.

5.2 SUMMARY

The study has revealed that there is high rainfall variability in Kaduna state. However, this variability results in a significant decrease in rainfall. According to this affirmation, the environment is gradually becoming drier. The most important source of precipitation in the study area is rainfall. Therefore, food insecurity becomes obvious which could lead to hunger, malnutrition, starvation, force migration, dead of livestock etc. this is indicated in Tables 4.3, Table 4.4 Table 4.7, Table 4.12, Table 4.14 Figure 4.6 and Figure 4.7. Similarly, the research has revealed that both rainfall and vegetation are generally decreasing. This was indicated by the positive absolute mean values of 0.71 and 0.37 for rainfall and NDVI respectively (Table 4.17).

There is a positive relationship between rainfall and vegetation vigour/biomass (appendix ii).

The study also revealed that the magnitude of drought in Kaduna state is 10.2% indicating a strong drought (Table 4.6).

In addition, the extent of drought covers most of northern part of Kaduna state covering Zaria, SabonGari, Igabi, GiwaMakarfi, BirninGwari, Soba and Ikara Local Government Areas (Figures 4.3, 4.7 and 4.10).

The knowledge of remote sensing for monitoring and mitigating drought in Kaduna state is not adequate. This indicates that the knowledge of remote sensing and Geographic Information System is not wide as a result the preference for meteorological data. This poor knowledge of remote sensing can be eliminated by proper awareness and campaign, symposiums and sensitization on remote sensing and GIS.

5.3 CONCLUSIONS

In line with facts and figures from the findings of this study, the following conclusions are drawn;

- There is high rainfall variability in Kaduna state that consistently leads to a general decrease in annual precipitation. This was observed from the rainfall trend from 2000 to 2014 for the state.
- The decrease in annual precipitation was very significant in some years especially 2002, 2005 and 2008 to the extent of inducing a significant decrease in vegetation vigour/biomass.

- The decrease in rainfall is in the form of late onset and early cessation of the rainy season followed by prolonged dry spells.
- The magnitude of rainfall in Kaduna state is 10.2%
- The extent of drought covers greater part of the northern part of Kaduna state covering about 6.5 million hectares.
- There is a high positive correlation (0.7) between rainfall and vegetation in Kaduna state.
- The knowledge of remote sensing and Geographic Information System is not adequate in Kaduna state.
- Change in annual precipitation from 2005 - 2009 was unique. This is more than twice the change witnessed from 2000 to 2004confirming with results of questionnaire, rainfall and NDVI data

5.4 RECOMMENDATIONS

In view of the findings discovered during the study, recommendations are proffered to alleviate or eliminate prevailing drought challenges in Kaduna state. These recommendations are;

- There should be public awareness campaigns on drought and the way it affects people. This will go a long way in arousing peoples' consciousness on the disaster and its complexities as many have limited knowledge on drought.
- Government should embark and encourage mass planting of trees in the state to cope with the high rate of deforestation. Drought and fire resistant tree species such as *KhayaSenegalensis* (Mahogany) *termarindusindica (*Tsamiya*), perkiabiglobosa (*Doruwa*), isoblenadoka (*Kuka*),* etcshould be planted as this will provide cover for the earthcrust and reduce evaporation.

- Farmers should be encouraged to start cultivation as early as the rains set in so as to cope with dwindling rainy season. This is aimed at making maximum use of rainy season for optimum crop production.
- More research and extension services should be carried out in order to develop particular breeds of seeds that can survive the drought prone areas of the state. This will go a long way in reducing the effects of the drought.
- It is also recommended that Government should construct dams that could provide water throughout the dry season so as to ensure continued crop production throughout the year.
- Government should encourage the general public to participate in some form of agricultural practices. This will go a long way in ensuring that most of the land left redundant be put to use thereby providing cover for the earth crust.
- Government should ensure municipal supply of water for both domestic and industrial use as this will go a long way in ensuring sustainable utilization of ground water resources
- Nomadic herdsmen should be encouraged to be sedentary by providing them with range lands and the necessary equipment to support their livestock.
- Similar researches should be conducted in other drought prone states to ascertain rainfall variability in recent times and its corresponding effects on vegetation change.

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Appendix 1

Research Questionnaire

Department of Geography

Faculty of Science

Ahmadu Bello University, Zaria

Dear Sir/Ma,

I am a student of the above institution carrying out a research on **An Integrated Approach to monitoring drought in Kaduna state using remotely sensed data**. I am using this medium to collect ancillary data for my research. Please kindly contribute by providing credible and reliable answers to the under listed questions.

You are assured that your responses will be used only for academic purpose.

Thank you very much for your cooperation

Yours Faithfully,

Pius Moses Nnah

Questions:

1. For how many years have you lived in Kaduna State

a. 10-20 b. 21-30 c. 31-40 d. 41 and above

2. Were you raised in Kaduna?

a. Yes b. No

3. If no, specify……………………………………………………………………………

4. Please circle your gender

a. Male b. Female

5. Please circle your age bracket

a. 10-20 b. 21-30 c. 31-40 d. 41-50 e. 51 and above

6. Do you understand the word ‘drought’?

a. Yes b. No

7. If yes, how

Please specify ……………………………………………………………………………

8. Have you over the years observed decrease/increase of rainfall in your locality?

a. Yes b. No c. Not sure

9. If yes, do you agree that the weather is becoming drier every year?

a. Yes b. No c. Not sure

10. Where in your locality have you made such observation?

Please specify ……………………………………………………………………………………

11. Which year(s) have you observed declined rainfall in your locality?

Please specify ………………………………………………………………………………

12. Do believe that the yearly rains are not supporting crop production as before

a. Yes b No c. Not sure

13. What do you believe are the early signs of drought?

a. Increasing temperature b. Low relative humidity c. Drying environment

d. Deforestation

14. Do you believe the environment suffers from excessive deforestation due to decreasing rainfall?

a. Yes b. No c. Not sure

15. If yes, why do you think it is happening?

a. Cutting down of trees b. Declining rainfalls c. Not sure

16. Do you believe there is now fuel wood scarcity?

a. Yes b. No c. Not sure

17. If yes, what do thing is the reason (specify) …………………………………………….

18. Who are the people seriously affected by climate change?

a. The poor b.The rich c. Both

19. Which of these disasters do you think drought is related?

a. Desertification b. Erosion c. Deforestation d. wild fires e. all of the above

20. Do you think the climate is changing?

a. Yes b. No c. Not sure

21. If yes, does drought have a relationship with climate change

a. Yes b. No c. Not sure

22. If yes, how is drought related to climate change?

a. High temperatures b. Global worming c. Environmental Degradation

d. Declining amount of precipitation e. all of the above

23. Are you aware that global warming has led to very high torrential yet declining rainfalls?

a. Yes b. No c. Not sure

24. Which of these measures do you think will be most effective at monitoring drought?

a. The use of remotely sensed data b.The use of meteorological data c. All of the above

25. Suggest credible ways for combating the effect of drought in your locality……………………………………………………………………………………….

Appendix ii

Correlation table between rainfall and NDVI

Spearman's Correlation			Rainfall_Change	NDVI_Change
Spearman's rho	Rainfall_Change	Correlation Coefficient	1.000	.709*
		Sig. (2-tailed)	.	.022
		N	10	10
	NDVI_Change	Correlation Coefficient	.709*	1.000
		Sig. (2-tailed)	.022	.
		N	10	10
Pearson Correlation			**Rainfall_Change**	**NDVI_Change**
Rainfall_Change			1	.707*
	Sig. (2-tailed)			.022
	N		10	10
NDVI_Change	Pearson Correlation		.707*	1
	Sig. (2-tailed)		.022	
	N		10	10

*. Correlation is significant at the 0.05 level (2-tailed).