AN INTEGRATED APPROACH TO DELINEATION OF ECO - CLIMATIC ZONES IN NORTHERN NIGERIA

BY

ABDULKADIR, Aishetu

(Ph.D/SSSE/2006/162)

DEPARTMENT OF GEOGRAPHY
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA
NIGERIA.

MAY, 2011

AN INTEGRATED APPROACH TO DELINEATION OF ECO- CLIMATIC ZONES IN NORTHERN NIGERIA

BY

ABDULKADIR, Aishetu

(PhD/SSSE/2006/162)

A THESIS SUBMITTED TO POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN ENVIRONMENTAL MANAGEMENT

MAY, 2011

DECLARATION

I hereby declare that this thesis titled: An Integrated Approach to Delineation of Eco-climatic Zones in Northern Nigeria: is an authentic study carried out by me and has not been presented elsewhere for any form of academic award.

ABDULKADIR, Aishetu 28/06/11

(PhD/SSSE/2006/162) Signature & Date

CERTIFICATION

This thesis titled: An Integrated Approach to Delineation of Eco-climatic Zones in Northern Nigeria by: ABDULKADIR, Aishetu (Ph.D/SSSE/2006/162) meets the regulations governing the award of degree of Doctor of Philosophy (Ph.D) of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literary presentation.

Dr. M.T. Usman
Major Supervisor
29/06/11
Signature & Date

Dr.A. H. Shaba
Co-supervisor I
29/06/2011
Signature & Date

Dr. A.S. Abubakar
Co-supervisor II
Abubakar 29/06/2011
Signature & Date

Dr. A.S. Abubakar
Head of Department
Abubakar 29/06/2011
Signature & Date

Prof. M. Galadima
Dean, School of Science and Science Education
8/7/2011
Signature & Date

Prof. (Mrs) S.N. Zubairu
Dean, Postgraduate School
1/8/2011
Signature & Date

ACKNOWLEDGEMENTS

All my praise is due to the Almighty Allah for granting me guidance, wisdom and strength to accomplish this Ph.D. My special thanks and appreciation goes to my major supervisor, Dr. M.T. Usman for his unique supervision and mentorship that led to the success of this frontline piece of research. I appreciate the invaluable comments and contributions of my minor supervisors, Dr. H.A. Shaba and Dr A.S Abubakar that enhanced the quality of this research. I greatly appreciate the grandfathers of the Department of Geography, Prof. J. M. Baba, Prof. D.O. Adefolalu and Prof. G. N. Nsofor for their valuable contributions and encouragement. Immense appreciation and thanks go to Dr. A.A. Okhimamhe for her motherly advice and encouragement. I thank the Departmental Cartographer, Mr. J. Omotayo, all my colleagues in the department of Geography and Mallam Musa Huruna, Department of Urban and Regional Planning, FUT Minna, for their vital contributions. I also appreciate the Post Graduate School representatives at the various seminars, Dr. A.M. Jinadu and Dr. Sanusi as well as the External Examiner, Prof. A.S. Mashi, Umaru Musa Yar'Adua University, Katsina, for their enormous comments and contributions that enhanced the quality of this research.

I sincerely acknowledge the University Network for Disaster Risk Reduction in Africa (UNEDRA) for its effort towards capacity building in Africa and Harold John Annegarn, University of Johannesburg, for his unique counselling and stimulation. My appreciation also goes to the Nigeria Meteorological Agency (NIMET) and the National Centre for Remote Sensing, Jos, for providing the requisite data for this research. Particularly, I am grateful to Isiaiku N. A., National Landuse/ Landcover Project Manager, National Centre

for Remote Sensing, Jos, and Mrs Ukeje, J.E., Acting Director, Applied Meteorological Services, NIMET, Abuja, for their support and encouragement.

My sincere appreciation goes to my parents Mallam Muhammadu Abubakar and Mallama Abubakar Zuliakha (May their gentle souls rest in peace) for the love, care, support and all-round development given to me that served as the backbone for my educational achievement. My profound gratitude goes to my beloved husband Mallam Abdullahi Abdulkadir for his understanding, support and cooperation during the busy time of the study. Lastly, I am grateful to my students, brother, sisters, children and other members of the family for their cooperation. Once again, I say Thank you All.

ABSTRACT

The increasing cumulative effects of depletion of resources, variability in distribution of rainfall and fluctuation in agricultural productivity have had drastic consequences on livelihoods in Northern Nigeria through distortions in the quality of the biotic and abiotic components in the zone. Though this process has been apparent since the 1969 -1973 Sahelian drought, its extent and actual impact on eco-climatic zonation was left unascertained with obvious implications for general planning. To date, requisite data have not been collated and analysed to document the current changes taking place in the climatic characteristics in the belt. The present study was aimed at doing this for the first time. It used rainfall and temperature data (1950-2006) to measure rainfall effectiveness parameters; quality index, onset and cessation dates, hydrologic growing season (HGS) and Aridity Index (AI) in addition to using National Oceanographic Atmospheric Administration (NOAA) Advance Very High Resolution Radiometer (AVHRR) images to derive a Soil Adjusted Vegetation Index (SAVI). These derived parameters were summarized and ranked using numerical identifiers for the interpretation of the various moisture situations to assess the eco-climatic characteristics in the zone. A multi-temporal database was developed for the eco-climatic factors and classes were defined for each factor using quantitative definitions for the respective time series. The point data were transformed to spatial data X, Y, Z and a geo-reference base map for Northern Nigeria was digitized. These were then subjected to spatial analysis. The result reveals variability in the effect of each factor on eco-climatic zonation while confirming the long-held belief that progressive aridity is evident in this belt despite recent increases in total annual rainfall receipt. The results also confirm increased delay in rainfall onset, earlier cessation, shorter HGS, poorer moisture quality and higher aridity in the belt. The quantitatively derived eco-climatic index and related maps identified five eco-climatic zones; Wet, Humid, Sub-humid, Dry Sub-humid and Semi/Arid as against, the three classic regional climatic zones; Tropical Hinterland, Tropical Continental and High Plateaux zones. The eco-climatic maps further unveil progressive transformation or southwards shifts in the boundaries of the regional climatic zones; Tropical Continental North to Semi-arid/Arid and Dry Sub-humid eco-climatic condition, Tropical Hinterland shows diversified levels of humidity; Dry sub-humid, Sub-humid, Humid and Wet. By implication, the identified changes do suggest shifts in regional circulation system, super-imposed on global patterns of variability. This may point to the inevitability of episodic drought and crop failure in the belt. Thus, the accurate delineation of the current eco-climatic zones is essential for providing adequate information needed to achieve food security and sustainability of the physical environment. It is recommended that long term multi-temporal images should be used to develop composite data set for the identification of vegetation cover in the region and the study should be extended to cover the entire country.

TABLE OF CONTENTS

CHAPTER ONE

Page

CHAPTER TWO

CHAPTER THREE

Page

CHAPTER FOUR

Page

Page

Page

CHAPTER FIVE

LIST OF TABLES

LIST FIGURES

ABBREVIATION, GLOSSARY AND SYMBOLS

ADP	Agricultural Development Project
AI	Aridity Index
AVHRR	Advance Very High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BLC	Biome Level Characterization
C	Cessation dates
CBERS	China-Brazil earth Resource Satellite
CCCFR	Centre Climatic Change and Fresh Water Resources
CCD	Charge-Coupled Device Camera
Cpt	Cumulative Pentad Rainfall
DTM	Digital Terrain Model
ECI	Eco-climatic Index
ECZ	Eco-climatic Zone
ENSO	El-Nino-Southern Oscillation
EOFS	Empirical Orthogonal Functions
ETM	Enhanced Thematic Mapper Plus
ET_O	Reference Evapotranspiration
EWS	Early Warning System
FAO	Food and Agricultural Organization
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCT	Federal Capital Territory

FPAR	Fraction of Photosynthetically Active Radiation Absorbed by Vegetation
GCM	Global Circulation Models
GCPs	Ground Control Points
GEMI	Global Environmental Monitoring Index
GESAVI	Generalized Soil-adjusted Vegetation Index
GIS	Geographic Information System
GPS	Global Positioning System
HAPEX	Hydrologic Atmospheric Pilot Experiment
HG	Hargreaves
HGS	Hydrological Growing Season
HLZ	Hoiridge Life Zone
hpt	Highest Pentad Total Rainfall
IRMI	Intra-Seasonal Rainfall Monitoring Index
ISO	Intra Seasonal Oscillation
ITD	Inter-Tropical Discontinuity
L	Adjusted Factor
LAI	Leaf Area Index
MBE	Mean Bias Error
MEC	Moisture Effectiveness Classes
MEI	Moisture Effectiveness Index
MEM	Moisture Effectiveness Map
MEV	Moisture Effectiveness Variability
MEZ	Moisture Effectiveness Zones

MODIS	Moderate –Resolution Imaging Spectroradiameter
MQI	Monsoon Quality Index
MSAVI	Modified Soil Adjusted Vegetation Index
Nb	Number of ‘Breaks’ in Rainfall
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEMA	National Emergency Agency
NIMET	Nigerian Meteorological Agency
NIR	Near Infrared Reflectance
NOAA	National Oceanographic Atmospheric Administration
NPP	Net Primary Production
Ø	Onset
OLR	Outgoing Long Wave Radiation
OSAVI	Optimized Soil Adjusted Vegetation Index
PCA	Principal Component Analysis
PE	Potential Evaporation
PET	Potential Evapotranspiration
PM	Penman–Monteith
PVI	Perpendicular Vegetation Index
R	Red Reflectance
R_a	Extraterrestrial Radiation
R_i	Annual Rainfall Total
r_{mm}	Highest Monthly Rainfall Total
RMO	Real Monsoon Onset

RMSE	Root Mean Square Error
SAVI	Soil-Adjusted Vegetation Index
SMeX02	Soil Moisture Experiment
SPECNET	Spectral Network
SPSS	Statistical Packages for Social Sciences
SST	Sea Surface Temperature
TCI	Temperature Condition Index
TD	Temperature Range
TM	Thematic Mapper
UNEDRA	University Network for Disaster risk Reduction in Africa
UNEP	United Nations Environmental Programme
V	Wind Speed
VCI	Vegetation Condition Index
VI	Vegetation Index
VI_S	Vegetation Indices
WNP	West Northern Pacific
XUAR	Xhijiang Uygur Autonomous Region
ΔT	Daily Temperature Range
Φ	Latitude Converted to Radians
λ	Hydrologic Ratio

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Desertification and food security have become issues of global concern. They are important global issues because of their adverse impacts on the agricultural productivity, as well as food sustainability. Desertification is generally considered a global problem (Earth summit 1992), is highly complex in nature and depicts a lasting damage to the environment. The term desertification was first coined by a French scientist and explorer, Lovis Lawanden, in 1972. He affirmed desertification to be caused by a complex of-relationships involving human impact on arid, semi-arid and dry sub-humid areas (www.thehuman–race.com, 25 / 02 / 07). The last internationally negotiated definition of desertification is "land degradation of arid, semi-arid and dry sub-humid ecosystems resulting from variety of causes including human activities and climatic fluctuation" (UNEP. 1992). It is the vibrant degradation of dry and sub humid lands leading to loss of biodiversity and productive capacity across the globe.

Desertification is a problem of most areas across the globe particularly developing countries, such as in Africa, Middle East, India, Pakistan, China, Brazil, and some developed nations: Australia, U.S.A, Greece, Spain, and Portugal. In Africa, the rate of vegetation degradation is estimated at 21 million hectares per year, with 6 million hectares of land permanently lost to crop production; Africa is the most endangered, with a population estimated to reach 1.5 billion by 2025, despite being currently hardly able to feed 500 million (FAO). The West African Sahel has been described as the most affected region in the world, and that more than 100 million people are at risk from desertification and 80% of countries affected by desertification are developing countries (UNEP, 1984). A number of studies have also shown that desertification is a serious problem for millions of Nigeria's population and has caused much sickness, food insecurity, hunger, poverty, famine and even migration (Adefolalu 1986a &b; Usman, 2000; Adefolalu, 2003;and Nicholson,2003;).The effect is already obvious in the repeated drought and crop failure that had characterized Northern Nigeria in the recent past. In addition, projections suggest that if the negative trends were to continue, the future food Security of poor countries is threatened (El-Beltagy 1997; Eswaran et al. 1998a). Hence, there is need for immediate, comprehensive and meaningful response.

Land degradation is a broad term used to denote diminution in land quality resulting from biological, chemical and physical alteration in land conditions following series of events such as vegetation clearance, cropping, industrial activities, mining, climate change etc. Desertification is thus an aspect of land degradation and it is a well-known fact that in developing countries, environmental resources are the backbone of livelihood, hence the need to understand and develop, quantitatively, the knowledge of environments and their problems. Delineation of current eco – climatic zones using modern geospatial techniques will provide accurate information on the state of the environment and could enhance agricultural productivity, quality of life and boost food security.

Since 1960s, Northern Nigeria, particularly the Sudano-Sahelian belt which lies approximately north of latitude 12^0N in Nigeria, has been characterized by repeated droughts due to variability, and distribution pattern of rainfall. The 1969 -1973 and 1980 - 1983 droughts have been the most disastrous to the agricultural sector in this zone. In addition, increased pressure on natural resources has led to continuous degradation of the natural environment. Adefolalu (1986a) confirmed this by giving a simplified relationship representing a summary of desertification as: *Drought + Man = Desertification.* In other words, desertification can lead to changes in the natural climate, consequently shifting the eco–climatic zones in the belt.

The geographical location of Northern Nigeria is generally prone to drought, wind and water erosion, thereby promoting geo- environmental degradation. The Sudano-sahelian belt is particularly a marginal land where crops experience moisture stress and often fail mainly as a result of the effect of the repeated prolonged drought. Specifically, this region has suffered from severe droughts and floods in the last four decades; the disappearance of the famous groundnut pyramids of Kano has been a direct effect of the 1969-1973 droughts for example.

The north (Sudano – Sahelian belt) of Nigeria is a marginal land, signifying that the climate can easily be modified due to the effect of climate change, deforestation, degradation and desertification, consequently shifting the eco-climatic zones. This drought-prone belt adjacent to the existing Sahara desert may become part of the desert in no distant time thereby, causing a shift in agro- eco-climatic zones. Decision-makers recognize food insecurity as a primary problem in Nigeria, but show little concern for the effect and impact of climate change and prolonged repeated drought in the region. Therefore, Northern Nigeria (especially its extreme part) is tending towards greater aridity whereas no feasible effort is placed on identify changes in classic eco-climatic belts. This is promoting geo-environmental degradation leading to diminishing agricultural production already apparent in the zone.

Despite these apparent changes across the region and country in general, North/South climatic description and other broad regional climatic designation still dominate decision-making. The two sub-climatic zones in Northern Nigeria are tropical continental north, tropical hinterland and the third zone is in response to relief; high plateaux. In addition, the eco-climatic parameter (rainfall amount, onset, cessation, length of the rainy season, humidity, temperature and vegetation) maps produced independently are used in place of eco-climatic maps. Furthermore, climatic classifications in Nigeria are highly related to vegetation zones since they are tied to rainfall values; areas of abundant rainfall have tropical rainforest or rainforest climate and to the middle belt, savanna (tropical hinterland climate). There are uncertainties defining climatic zones based on vegetation (Olu and Bogda, 2002). The location and latitudinal spread of the region necessitate the need to identify and delineation of the micro-sub eco-climatic zones in the region. Consequently, the integration of derived ecological and climatic parameters using Geographic Information System (GIS) to derive the eco-climatic map that will depict the eco-climatic condition in quantitative terms is crucial for sustainability of natural resources.

The universal increasing effect of these degradation processes in the region result in hydrologic and climatologic changes thus advancing aridity in the belt and making the environment less productive. If the future must be guaranteed there is an urgent need to protect the fragile environmental resources such as water, soil and vegetation (Kufoniyi et al, 2003). As a result, for improved quality of life and environmental sustainability, there is the need to quantify desertification, identify and delineate the current eco-regional climatic zones using modern geospatial tools. By and large, sustainability of land productivity and quality of vegetation is highly a function of environmental quality. These dictate the use of appropriate information for delineating the current eco-climatic zones and identifying crop suitability for enhanced food security, and the general security of the physical environment.

1.2 Statement of Problem

Globally, researches have confirmed increased rate of desertification (Eswaran *et al*., 1998; Zhao *et al.,* 2005; Huang and Siegert, 2006; Susana and Keller, 2006; Sonia *et.al.,* 2007; Sivakumar, 2007 & Hanafi and Jauffret 2008). Adefolalu (1986b) has shown that trends in rainfall between 1911- 1980 can be associated with a long-term multiplier effect of land surface (ecological) changes- a reflection of feedback processes induced by human activities. Adefolalu (1986a) also confirm that the dry condition in the northern Nigeria between the drought years of 1969-1973 and 1979-1983 showed that the vegetal cover never recovered despite the surplus rainfall of 1974-1976; signifying an irreversible change is taking place in the region. In addition, Adefolalu (1988) attest that the extreme northern vegetation savanna is declining to the steppe-type of Koppen's B-Climate or desert. Thus, the drying condition in the Northern region is increasing as such that the ecological changes are irreversible

The existing climatic and eco-climatic parameter maps have been mapped on the basis of vegetation and annual rainfall patterns using traditional vector maps overlay. With time since they were first mapped over 40years ago, changes have been occurring as a result of various land degradation processes resulting to likely shifts in boundaries and conditions of the mapped zones. Several studies have suggested that land-cover changes alter the weather (Shukla, 1993; Meehi, 1994; Cotton and Pielke, 1995).With the power of GIS technology and the need to track such changes, studies are now required that employ GIS tools in mapping eco-climatic zones in northern Nigeria.

Generally, documentation on the deterioration of vegetation cover is dominant in literature; the obvious environmental problems and effects include higher albedo, lowering of water table, reduced surface water, increased soil erosion and, on the whole, increased aridity. Secondly, there is the politics of the actual land area that is desertified; is it the Sudan/Sahel/Sudano-sahelian or the sub-humid zone? Thirdly, the recurring crop failures experienced in this zone may be a response to inadequate information inherent in the use of the classic eco-climatic zones.

The increasing cumulative effects of depletion of resources, variability in distribution of rainfall and fluctuation in agricultural produce have drastic consequences. In Northern Nigeria, the socio-economic impacts over the years have been evident; repeated crop failures, sharp rises in prices of agricultural products, hunger, sickness, malnutrition, starvation and livestock death in extreme cases. This has given rise to a number of questions such as; what is the extent of degradation of natural resource such as vegetation, land and water? What extent of land is now suitable for agriculture and for which crops is it most suitable? Have eco-climatic zones changed and do they need to be redefined and re-delineated? If the zones have changed, how are they related to agriculture, farmland productivity and improved food security?

Generally, drought occurrence, erratic rainfall distribution and shift in economic fortunes, all combine to impact on the environment. Apparently, desertification of the northern region has been drastically altering the traditional eco-climatic zones resulting to recurring crop failure. Conversely, lack of information on the existing eco-climatic zone and changes that have taken place is an apparent problem. No researches have been carried out to investigate and map changes in the spatial extent of the traditional eco-climatic zones to establish new zones. These are gaps in the achievement of food security and sustainability of the physical environment that the study intends to fill.

1.3 Aims and Objectives of the Research

The study is aimed at delineating eco-climatic zones for enhanced food productivity and environmental sustainability in Northern Nigeria, using GIS techniques.

The specific objectives of the study were to:

i. Define and assess data on eco -climatic characteristics of northern Nigeria
ii. Classify the belt into appropriate GIS – based set of eco-climatic micro sub-sets for decision-making.
iii. Generate spatial data to depict changes that have taken place and account for their occurrences.
iv. Provide sustainable development solutions to the identified changes in trends.

1.4 Justification of the Research work

The classic eco-climatic zones were classified more than a century ago while researches have shown that forest zones have changed; rainfall patterns and the general hydrologic regimes are not static. Generally, if all these have changed, it is imperative that the broad eco-climatic zones have changed. These classic zones were defined using Koppen's method of classification based on quantitative values of temperature and precipitation that are horribly inadequate. Adefolalu, (1986a), Usman, (2000b) & Tennant and Hewitson, (2002) affirmed the need for additional rainfall characteristics in identifying plant moisture stress other than rainfall amount. Therefore, defining moisture condition using total annual rainfall amount may be grossly inadequate and inefficient to capture the effect on eco-climatic zonation as might be expected using other characteristics of rainfall; onset, cessation dates, hydrological growing season, moisture quality and hydrologic ratio.

The escalating variability in rainfall distribution, deforestation and degradation of natural resources in the Sudano- Sahelian belt has significant eco-climatic and socio economic impacts. In addition, the recurring prolonged drought in this belt has drastically altered the classic eco-climatic zones. Consequently, the agro-climatic zones we have always known might have been affected and this may be responsible for the recurrent crop failures which, slowly but surely, has induced a southward migration of Man and his livestock typical of the late nineteenth and early twentieth century's. It is noteworthy that the effects of these migrations have created socio-cultural and political tensions across the country especially in the central geo-political zone.

These subtle but undocumented processes of change have made it difficult in differentiating between the Sudan and Sahel, thus the name Sudano-Sahelian belt signifying an absence of a defined boundary between the two. Furthermore, it is not impossible that the generic eco-climatic zones have changed. This is possibly true of other zonal boundaries in the semi-arid and dry sub-humid areas. Vegetation change is known to have occurred alongside changes in hydrologic regimes, soil productivity levels and attendant shifts in socio-economic practices and fortunes. First to ascertain this is important for general planning. To date, requisite data has not been collated and analyzed to document the current changes taking place in eco-climatic conditions. Secondly, the zones were classified using conventional data (rainfall total and temperature) and traditional methods (vector maps overlay). These traditional techniques can be improved upon on the basis of innovative advanced technologies (GIS) yet to be exploited in Nigeria for accurate determination of eco-climatic zones.

In reality, we cannot continue to use old data to address these environmental problems. The issue needs to be tackled, and cannot be done without proper planning and information; data must be collected and analyzed to identify changes that are taking place. The present study is important in generating empirical data which will quantify some of the enumerated effects, quantify aridity rate and redefine the eco-climatic zones for increased food security, using a combination of climatic, remotely sensed data, field data and GIS techniques. This is necessary for planning, early warning and mitigation purposes.

1.5 Study Area

This section describes the unique features of the Sudano-sahelian belt.

1.5.1 Location of the Study Area

Northern Nigeria is located between Longitudes 3^0 to 15^0 East of the Greenwich meridian and Latitudes 9^0 and 14^0 North of the Equator (fig 1.1). Northern Nigeria is a political definition that covers all states that are fully located or partially located (middle belt) in the northern portion of the country. This zone stretches from the Sokoto plains through the northern section of Hausa land to the Chad Basin. The extreme Northern part of the belt approaches the desert fringes, particularly sharing boundaries with the semi-arid and arid zone of the Niger Republic. The States located in this zone are Sokoto, Kebbi, Zamfara, Kastina, Kano, Jigawa, Yobe, Borno, Gombe, Bauchi, Kwara, Plateau, Adamawa, Niger, federal Capital Territory (FCT), Nassarawa, Taraba, Kogi and Benue. The present study covers all the states with the exception of Kogi and Benue (See Figure 1.1).

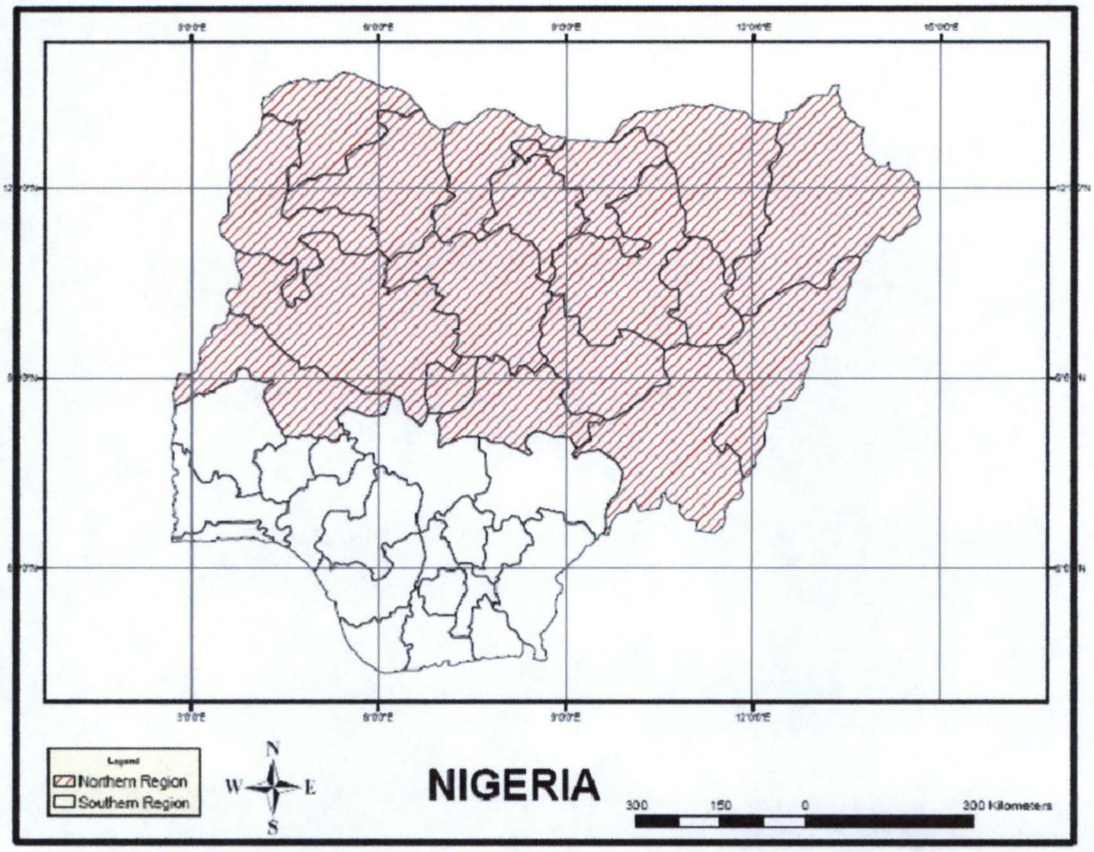


Fig1.1 Northern Nigeria

Source: Iloege, 1979

1.5.2 Climate

The northern region, due to its latitudinal location is characterized by tropical continental dry climate. The climate is characterized by alternate wet and dry season in response to the changes in pressure patterns. These give rise to two distinct prevailing air masses over the country at different times of the year. The dry tropical continental air mass originate from the Sahara desert (N.E Trades) and tropical marine time air mass (S.W. Trades) originate from a southern high pressure belt and flow across the Atlantic Ocean. By origin, the south west Westerly (summer monsoon) wind is moist and warm and the North Easterly (winter monsoon) is dry, dusty and cool. The changing pressure patterns in turn result from the apparent north-south movement of the sun (sun's zenith).

The two air masses, nearly opposite in direction, meet at a zone of discontinuity stretching east – west across West Africa known as the Inter Tropical Discontinuity (ITD). The zone where this air masses mix is called Inter-Tropical Convergence Zone (ITCZ), which moves north and south following the zenith of the sun; it reaches the southern limit at latitude 50N in January and its northern limit in the vicinity of latitude 14^0 North in May. By implication, the ITCZ reaches the study area latitude $9^0 - 14^0$ at different times of the year and recedes in September or October. Subsequently; there is variability in dates of onset and cessation of rains across the region. This can also be attributed to the migratory patterns of the ITD (Table: 1.1). The rainy season in this region is associated with late onset and earlier cessation, the onset and cessation are also characterized with destructive storms which destroy life and property.

Table: 1.1Onset, Cessation and Length of the Growing Season

STATE	ONSET	CESSATION	SHORTEST LRS	LONGEST LRS
Kaduna	20th May	17th Oct.	<120	>180
Jigawa	19th June	27thSept.	<100	>150
Kano	9th June	27th Sept.	<100	>150
Katsina	7th June	7th Oct.	<110	>150
Kebbi	30th May	7th Oct.	<120	>150
Zamfara	30th May	7th Oct.	<130	>160
Sokoto	19th June	7th Oct.	<120	>140
Borno	15th June	7th Oct.	<100	>140
Yobe	15th June	7th Oct.	<100	>150
Bauchi	20th May	7thOct.	<100	>150
Taraba	10th May	17th Oct.	<120	>180
Adamawa	10th May	17th Oct.	<150	>190
Gombe	30th May	7th Oct.	<90	>150
Niger	25th April	27th Oct.	<150	>210

Source: CCCFR Eco-Climatic Atlas, 2005

The rainy season in this belt has high rainfall intensity concentrated within short period of time, thus increasing the rate and intensity of runoff. This varies from 34mm/hr in Kano, Katsina, Zamfara and Sokoto to 50mm/hr and above in Adamawa and Niger. The effects include increased and widespread flooding which is typical of the zone, thereby soil erosion is aggravated and consequently contribute to continuous land degradation which in addition to very low hydrologic ratio is a threat to socio –economic well being. The degree of wetness or dryness signifies the level of aridity which is less than 0.2 in Borno and Yobe, 0.2 in Sokoto, 0.25 in Zamfara and Gombe States. Hence, the Sudano –Sahelian zone is a moisture stress zone now seen to be tending toward increased degradation.

Table: 1. 2 Mean Rainfall Intensity

STATE	MEAN
Kaduna	36mm\hr
Jigawa	43mm/hr
Kano	34mm/hr
Katsina	34mm/hr
Kebbi	35mm/hr
Zamfara	34mm/hr
Sokoto	34mm/hr
Borno	39mm/hr
Yobe	45mm/hr
Bauchi	45mm/hr
Taraba	45mm/hr
Adamawa	50mm/hr
Gombe	45mm/hr
Niger	65mm/hr

Source: CCCFR Eco-Climatic Atlas, 2005

Table: 1.3 Mean Hydrologic Ratios

STATE	MEAN HYDROLOGIC RATIO
Kaduna	0.55
Jigawa	0.3
Kano	0.3
Katsina	0.3
Kebbi	0.4
Zamfara	0.25
Sokoto	0.2
Borno	0.15
Yobe	0.15
Bauchi	0.3
Taraba	0.6
Adamawa	0.4
Gombe	0.25
Niger	0.5

Source: CCCFR Eco-Climatic Atlas, 2005

Rainfall amount is low, erratic and characterized by spatial and temporal variations (Table: 1.4), duration and distribution are limited to few months within the growing season; rains do not come at expected times and when they come, they descend with vigour such that soils lose more nutrient than ever, rivers are filled with sediments and crop yield drops annually. Rainfall is of crucial importance for all life, not only because it is a resource for man and animals, but also because it is a major limiting factor in plant growth. In the study area, most of the agriculture is rain-fed and rainfall is highly variable particularly in terms of distribution. This is a threat to food supply both for human and livestock population

Table: 1.4 Total Maximum and Minimum Rainfall

STATE	Minimum	Maximum
Kaduna	<800	>1600
Jigawa	<400	>800
Kano	<600	>1000
Katsina	<600	>1200
Kebbi	<600	>1600
Zamfara	<600	>1400
Sokoto	<500	>1000
Borno	<400	>1000
Yobe	<400	>800
Bauchi	<600	>1200
Taraba	<1000	>1600
Adamawa	<800	>1400
Gombe	<600	>1000
Niger	<1000	>1600

Source: CCCFR Eco-Climatic Atlas, 2005

The latitudinal location of the belt also implies high temperature throughout the year, at about 27^0C. There are seasonal variations and latitudinal variations which affect diurnal and seasonal ranges. The highest maximum air temperature is recorded in the northern part usually areas North of lat 9^0 and occur in March /April and minimum temperatures are recorded in December/January North of lat 9^0N. The highest mean maximum temperature is above 40^0C in Maiduguri, Nguru, and Sokoto which are recorded in April and the least maximum is 30.7^0C recorded in Jos. The highest minimum temperature is 19.3^0C recorded in Minna and lowest minimum is about 12.5^0C recorded in Kastina, Jos, Potiskun and Maiduguri. These signals the fact that temperature ranges are higher in the extreme north than the middle belt (Table 1.5).

Table: 1.5 Maximum and Minimum Temperature (1950-2006)

STATION	MAXIMUM ^{0}C (MONTH)	MINIMUM ^{0}C (MONTH)
Yelwa	38.7 (March)	15.4 (December)
Sokoto	40.4 (April)	16.4 (January)
Gusau	38.7 (April)	14.5 (December))
Kaduna	35.5 (March)	15.4 (December)
Kastina	38.9 (April)	12.4 (January))
Zaria	35.7 (March)	14.1 (January)
Kano	38.8 (April)	13.4 (January)
Bauchi	37.3 (April)	13.4 (December)
Nguru	40.0 (April)	13.5 (January)
Potiskun	39.7 (April)	12.6 (January)
Maiduguri	40.6 (April)	12.6 (January)
Minna	37.2 (April)	19.3 (December)
Jos	30.9 (March)	12.5 (December)
Yola	39.5 (March)	16.6 (December)

Data Source: NIMET 2008

Generally, the highest temperatures in the country are recorded in this zone; usually the hottest are recorded before the onset of rains. In addition, temperature range is highest in the northwest & northeast above 10^{0}C and reduces southwards. The temperature of the zone exhibits similar characteristics except around Jos where the mean annual figures oscillate between 20^{0}C to 25^{0}C in view of the general principle of decreasing temperature with height in contrast to 30 ^{0}C and above in the surrounding lower land at the same latitude (Table :1.6)

Table: 1.6 Temperature Range (1950-2006)

STATION	RANGE (^{0}C)
Yelwa	29 ±7
Sokoto	29 ±9
Gusau	27±8
Kaduna	26 ±5
Kastina	26±10
Zaria	26±8
Kano	27±11
Bauchi	25±7
Nguru	27±10
Potiskun	27±10
Maiduguri	27±10
Minna	29±4
Jos	23±5
Yola	29±6

Data Source: NIMET 2008

The major factors that influence the distribution of temperature are the zenith of the sun and rainfall. Thus hottest months are March to April and not July as should be expected following the zenith of the sun mainly in response to the moderating effect of rainfall. The annual ranges of temperature are lower in mountainous areas and in the middle belt.

1.5.3 Vegetation

Northern Nigeria is dominated by savanna vegetation types; Guinea, Sudan and Sahel savanna, the density of trees and grasses decrease northwards responding to climatic conditions. The long dry season limits the growth of trees and periods of growth coincide with periods of rainfall. The tree species are generally scattered and deciduous to the south (Kwara, Niger, FCT and Nassarawa), and drought resistant species to the north (Kaduna, Kano, Katsina, Bauchi etc.). The tallest variety of grass is elephant grass which is found in the southern part of the region, shortest to the far north. Trees species include shea-butter, silk cotton, baobab, acacia, date palm and gum Arabic.

1.5.4 Land Use

Agriculture is the most dominant economic activity in northern Nigeria; crops like groundnuts, cotton, millets, beans, guinea corn, cassava, yam and maize are cultivated in the region which also has the highest concentration of cattle in the country. Hence, the vegetation has suffered great degradation from the hands of man and his livestock. The central towns are mainly the commercial and administrative centres, while the villages are mostly farming and animal-rearing communities.

1.5.5 Landforms

The central, west and part of eastern portion of the study area constitute extensive basement complex zones made up of the oldest rocks and mostly igneous like granites. These are moderately resistant hills and most widespread in the zone. The rocks may metamorphose to produce rocks such as Schist, gneiss and quartzite that mineralize to form metallic minerals like tin, columbite and gold which are also dominant in the basement complex zones. The northwest and northeast portions (Sokoto and Chad basins) and Niger- Benue Trough are made up of Sedimentary rocks underlain by basement complex and are mainly made up of young sands and clays due to increased erosion and deposition.

1.5.6 Relief and Drainage

The general relief of this belt is between 300 to 900 meters, except the Niger- Benue trough, Sokoto and Chad Basins that are below 300 meters. Jos plateau is the highest portion of the extensive north central plateau. The northern region is drained by Rivers Niger and Benue and their tributaries such as Rivers Kaduna, Gongola, Hadeija, Yobe and Gana. Others are Rima, Sokoto and Zamfara which take their source from the north central highlands and Ngoada and Yedseram which take source from the Eastern highland and empty into Lake Chad. Most rivers in the zone are characterized by rapids and falls, particularly Niger and Kaduna River thereby, providing favourable environment for construction of hydroelectric power while on the other hand a limitation to river transportation. Generally, both Niger and Benue rivers are the dominant catchment troughs for the zone.

The seasonality of rainfall determines amount and the flow of rivers and streams throughout the country. During the rainy season rivers are full and a lot of flooding is a common feature and this is usually disastrous to agriculture and property. Whereas, in the dry season a lot of the rivers are virtually without discharge and mostly become dry valleys filled with sediments, the abundant fresh water resources during the rainy season are usually not harvested for future use but lost as runoff into the ocean.

1.5.6 Geology

There two broad geological formations in northern Nigeria; the Precambrian basement complex and the sedimentary formation. The Precambrian basement complex rocks are very old crystalline basic material and they form bulk of the region's landmass. The common rocks are igneous and quartz, these often metamorphose to schist and quartzite and mineralized to form metallic mineral such as tin, columbite and gold. Sedimentary formations are dominant to northeast, northwest, along the Niger/Benue trough and other river valley in the region.

1.6 Scope and Limitation of the Study

The area covered by this study is northern Nigeria located at about longitudes 3^0 to 15^0 east of the Greenwich and latitudes 9^0 to 14^0 north of the equator. This area encompasses about 2/3 of the country and consists of about 17 states. The study is limited to the consideration of daily rainfall, temperature (maximum and minimum) data from 1950 to 2006 collected over thirteen synoptic stations. That the synoptic stations are globally referenced data collection points and spread fairly well as such, it's taken as sufficient basis for spatially interpolating for non-observed locations in the zone. In addition, the computation of VI is limited to SAVI due to its efficiency in depressing the influences of underlying soil on sensed vegetation. Similarly, the computation of SAVI is limited to the use of NOAA AVHRR data. This is based on the assumption that vegetation as mapped will bear footprint of human activities within the eco-system. Investigation of rainfall variability factors is beyond the scope of this research and the study is limited by unavailability of multi-temporal NOAA AVHRR data as only one day image set was use to derive the vegetation vigour for the region.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of related Literature

This chapter is a review of some existing literature on the following themes; rainfall variability, estimation of evapotranspiration, desertification, Vegetation Index and eco-climatic classifications.

2.2 Rainfall Variability

Rainfall variability has numerous effects on human activities, thus increasing climate change intensity and pressure on natural resource (water, land and vegetation). In addition to increased human pressure on the environment, this promotes geo environmental degradation. The extreme rainfall variability in this zone combined with fragile landscape, cause a high degree of environmental vulnerability thereby, complicating human activities in the belt. Since man generally strives constantly to exert control over the physical processes which he relies on for survival, the increased ecological imbalance and accelerated environmental problems may constitute disaster (El-Beltagy, 1997 and Eswaran and Reich 1998). Dregne and Chou (1992) estimated that 70% of the land in dry areas in the world was degraded in the 1990s.

The current and widespread climate change and its effects on surface cover have been a major concern. Nicholson (2003) examined the question of land surface–atmosphere interactions in the West African Sahel and their role in the interannual variability of rainfall. The study illustrated that in the Sahel, mean rainfall decreased by 25– 40% between 1931–1960 and 1968–1997; every year in the 1950s was wet, and nearly every year since 1970 has been anomalously dry. The article presents arguments for the role of land surface feedback in producing these features and reviews research relevant to land surface processes in the region, such as results from the 1992 Hydrologic Atmospheric Pilot Experiment (HAPEX)-Sahel experiment and recent studies on aerosols and on the issue of desertification in the region. It included also summary of evidence of feedback on meteorological processes, presented from both model results and observations. In conclusion, each evaporative component of the surface water balance is argued to have its own timescale, with the presence of vegetation affecting the process both by delaying and prolonging the return of soil moisture to the atmosphere but at the same time accelerating the process through the evaporation of canopy-intercepted water. Hence the vegetation structure, including rooting depth, can modulate the land-atmosphere interaction. Such processes take on particular significance in the Sahel, where there is a high degree of recycling of atmospheric moisture and where the meteorological processes from the scale of boundary layer development to mesoscale disturbance generation are strongly influenced by moisture. Modelling rainfall variability is crucial to identification of vegetation cover.

The relationship between human activities and climate variability in causing environmental problems was examined. Stenphenne (2004) constructed past land-use and land-cover changes in the African Sahel over the last 30 years based on a dynamic simulation model. This simulated land use changes at two time frequencies; high frequency as driven by climate variability, and low frequency, as driven by demographic trends. Over the 1961 - 1996 period, the model simulations reveal distinct temporal patterns of land use change throughout the sudano –Sahelian Region. The study concluded that comparison between the land use model projections and remote sensing observations of land cover are very encouraging.

Furthermore, Usman (1999) developed an instability index for monsoon onset characterization over the Nigerian sahel using daily ambient and dew point temperature data for four level of the atmosphere (950,850,700 and 600hpa) over kano, Nigeria for 8-years period. The pentad mean values were used to ascertain mean Θ_e values which were then related to mean variability of rains using as index of distribution rather than annual rainfall totals. Results showed that steady convective instability within the middle troposphere lags behind that in the lower troposphere with two (fluctuating and steady) States in the former. The study stated that the onset period of the summer monsoons in West Africa especially over its Sahelian portion is very critical in its influence on agricultural productivity and convective weather phenomena that occur during this period are highly variable in frequency and strength.

Rainfall distribution is extremely uneven and has a major impact on climate. As a result; large quantities of reliable historic climatic data and powerful computational capabilities have been used to represent the degree of similarity or dissimilarity. Carl and Fredrick (2003) in their investigation on the variability of the climate of Eastern Africa in the recent decades used Empirical Orthogonal Functions (EOFs) of gauge rainfall data, and merged analysis of precipitation data derived from a combination of raingauge observations and satellite estimates between 1961-2001.It was discovered that ENSO mode is associated with wide spread positive rainfall anomaly conditions over the entire region of eastern Africa, except over Sudan. In addition, the global warming signals in precipitation over

East Africa were isolated and quantified. The finding indicates both inter-annual variability and increasing trend during the entire period.

Similarly effective rainfall onset dates have been used to visualize fluctuations in rainfall distribution in the Sudano- sahelian region. Wu and Wang (2000) used pentad and monthly outgoing long wave radiation (OLR) data on a 2.5^0 x 2.5^0 grid with global coverage constructed from daily means of the National Oceanic and Atmospheric Administration (NOAA) satellite observed data spanning from 1975 to 1995 with a nine month gap in 1978. Monson onset was determined by both the seasonal cycle and intra-seasonal oscillation (ISO). The result shows large onset variability in west northern pacific (WNP) which is attributed to large year to year changes of the seasonal cycle. The study concluded the warm sea surface temperature (SST) anomalies in the equatorial eastern central pacific play a major role in generation of large scale upper level convergence and descent anomalies over WNP and the cold SST anomalies in the WNP induce lower level anticyclonic wind anomalies and reduce convective instability.

Kiunsi and Meadows (2006) observed that one of the many contentious issues facing the appropriate and accurate assessment of land degradation is the varying emphasis placed on vegetation degradation and soil degradation processes. The study maintains that this has led to the compartmentalization of land degradation assessment methods, depending on the particular perspective adopted. Land degradation was assessed in southern part of the Monduli District of northeast Tanzania, an area typifying the so-called affected drylands of Africa. Three sets of land cover maps synchronized against long-term rainfall data (1960s, 1991 and 1999) were used to assess land degradation in the area. Utilizing these three sets of land cover maps as a basis for change detection, it is possible to distinguish areas that experienced changes in vegetation due to rainfall variability from those areas that were subject to changes consequent upon anthropological factors. All areas that displayed overall depletion of natural and semi-natural vegetation due to human factors were deemed to have undergone land degradation, whereas areas that experienced inter-annual land cover changes due to rainfall variability were classified as experiencing cover change due to ecosystem dynamics. This method provides a complete and appropriate assessment of land degradation in the study area and can be used to improve degradation assessment in other semiarid areas. Hence, rainfall trend are vital in assessment land degradation.

The variability and erratic moisture conditions in the Sudano-sahelian zone is often disastrous to the natural ecosystem. López *et al.,* (2008) observed that in arid and semi-arid ecosystems, water availability is discontinuous, highly variable, and characterized by discrete pulse events separated by long periods of limited resource availability. Plant growth in these ecosystems is also episodic and dependent on the water available during and after these discrete rainfall events. Precipitation thresholds for plant establishment have been estimated mainly for herbaceous plants and tree seedlings, but extrapolation of short-term results based on seedlings to natural tree populations is difficult. Nevertheless, estimations of water availability thresholds for tree recruitment are essential for successful policies on forest conservation and restoration. They proposed a methodology to estimate precipitation thresholds for adult tree populations using tree-ring series and precipitation data. This was used this with two Prosopis species from South America: Prosopis pallida and Prosopis chilensis. Results indicate a precipitation threshold of around 85 mm for the establishment of P. pallida trees, whereas the threshold for P. chilensis is likely to be much higher. Precipitation data are fundamental for tree concentration in regions of the world.

Thomas and Julio (1998) using Multicentury, tree-ring reconstructions of drought, disturbance history, and tree demography, revealed climatic effects across scales, from annual to decadal, and from local (<10^2 km^2) to mesoscale (10^4–10^6 km^2). The study stated that Climate–disturbance relations are more variable and complex than previously assumed and recognized that episodic dry and wet events have altered age structures and species composition of woodland and conifer forests. The scarcity of old, living conifers established before circa 1600, according to the author, suggests that the extreme drought of 1575–95 had pervasive effects on tree populations. The most extreme drought of the past 400 years occurred in the mid–twentieth century (1942–57). The drought resulted in broad scale plant die-offs in shrublands, woodlands, and forests and accelerated shrub invasion of grasslands. Drought conditions were broken by the post-1976 shift to the negative SO phase and wetter cool seasons in the Southwest. The post-1976 period shows up as an unprecedented surge in tree-ring growth within millennia-length chronologies. This unusual episode may have produced a pulse in tree recruitment and improved rangeland conditions (e.g., higher grass production), though additional study is needed to disentangle the interacting roles of land use and climate. The 1950s drought and the post-1976 wet period and their aftermaths offer natural experiments to study long-term ecosystem response to interdecadal climate variability. They conclude that ecological species responses to climatic variability.

Rainfall fluctuation is an important factor in assessing environmental dynamics. Omar and Norma (1999) detected amplified fluctuation in the time series of annual rainfall, starting about mid-1930s in the province of Córdoba (central Argentina). The timescale of this fluctuation initially had a value of approximately 10 years, and increased to a value of about 20 years. This fluctuation is structured as a train of centers of negative and positive rainfall perturbation alternating in time. The analyses of contribution from bands of wavelet timescale to reconstruction of time series of perturbation of annual rainfall amount indicate that trend is produced by fluctuations with timescale larger than 10 years. Before 1935, annual rainfall had a stationary mean. After that year, mean annual rainfall in this region is increasing at a rate of 5 mm/year. During the period 1935–1983, the trend produced by contribution from fluctuations with timescale greater than 10 years is 4.6 mm/year. The remaining 0.4 mm/year of trend is produced by fluctuations with timescale smaller than 10 years, and it does not have statistical significance. This amplifying fluctuation in the bands of fluctuations with timescale 10–17 years and 17–27 years was clearly detected in the 3-month periods November to January, and February to April. These are also the only two 3-month periods with trend statistically significant. The study concluded that finding what triggered this gargantuan amplifying fluctuation in annual rainfall is an important question for understanding multidecadal climate variability. This understanding of fluctuation in the time series of annual rainfall is vital to eco- climatic mapping and food security.

Furthermore, Srikantha and Uditha (2004) analysed long-term rainfall trends in central mountainous region of Sri Lanka. Using a 30-year, 60 rain gauge data set, inter-annual as well as intra-annual rainfall trends were investigated to understand the adverse impacts on water resources, floods and land degradation. It was found that there is a decrease in the annual rainfall in the region, while different seasons show mixed results. The March–April 1st inter-monsoon period showed the highest decrease in rainfall where almost all the rain gauges recorded decreasing rainfall. In addition to the decreasing rainfall trend, the numbers of rainy days reduced giving rise to an increasing rain intensity trend. In order to understand better the changes to rain intensity-frequency relation, the study carried out a universal multifractal analysis and multifractal models were calibrated to first and last decades of the rain series. This was used to estimate the intensity–frequency relations in the rainfall series. The results show that there is a decrease of inter-monsoon rainfall, while the intensities and return period of extreme events appear to become shorter. Rainfall characteristic is a central factor in land degradation process and a threat to food security.

Long term trend in climatic elements are vital in assessing changes over the surface; Henry (1996) demonstrated that there is no global long-term trend in any rainfall change over the period of instrumental record (*c.* 150 years), but there has been an increase of 0·5°C in global temperature over the past 100 years. This increase seems partly due to urbanization, as there is no evidence of it resulting from atmospheric pollution by CO_2 and other warming gases (SO_2, NO_2, CH_4, CFH etc.). On the other hand, the thermal increase is uneven, increasing with latitudes above 40° N and S. The study of tree-rings, lake level fluctuations and pollen analysis confirm the existence of climatic fluctuations, but with no long-term trends over the past 2000 years. He states that a possible increase of 1–3°C in arid lands over the next 50 years due to a doubling of the CO_2 content of the lower atmosphere to 700 p.p.m., as assumed by most scenarios stemming from GCM, would increase global potential evapo-transpiration (PET) by some 75–225 mm year^{-1}. The ratio of mean annual precipitation to PET would then decrease by about 4–5%, assuming that no substantial changes in rainfall took place in arid and semi-arid lands. However, the impact of CO_2on plants would boost photosynthesis and, therefore, primary productivity; it would also increase water-use efficiency via the reduction of stomatal conductance. The study believes it will therefore at present be difficult to predict the net balance of these two opposite consequences or to prophesy which phenomenon would prevail: increased aridity or higher productivity and more efficient water use. At all events, the possible effect of a climatic fluctuation (or change) of the magnitude envisaged would have a trivial consequence on arid environments, as compared with the past and present impact of humans and their livestock. Hence, there is need for mitigation of the processes and effects of climatic fluctuation.

Rainfall characteristics have been identified as a major factor in plant growth, development and thus cause agricultural drought in the Sudano – sahelian region. Adefolalu (1986a) observed that most studies on the Sahelian drought are concentrated on interannual rainfall variabilities and trends but studies on plant response to drought situations have shown that sometimes, the amount of recorded rainfall is quite irrelevant. A year with perhaps normal (or above normal) total annual rainfall but characterized by delayed onset or pre-mature cessation (or both) of the rainy season is worse for plants than one with definite shortfall in total amount but normal dates of onset and cessation. Also, shortened rainy season with above-normal rainfall implies high intensity precipitation which could be bad for arable lands with top-soils washed away by erosion. The study compared the period 1979–1983 to the drought conditions of the era with the average conditions during the 1941–1980 periods in Nigeria. Results indicate that shortfall in absolute rainfall amounts may be less critical than severe aberrations in the onset, cessation and length of the Hydrologic Growing

Season (HGS). It is therefore suggested that as a permanent solution to the perennial drought problems in the sub-region, drought escape and drought resistant plants are to be re-introduced while highly demanding plants (in terms of water) are to be re-appraised in relation to the available sources of water for irrigation in the area. In its conclusion the study affirmed precipitation effectiveness is to be associated with those and other factors — perhaps least should be the total rainfall amount. Precipitation effectiveness is vital for plant germination, seedling and likelihood for plant growth.

Intra- and inter- seasonal rainfall variability are imperative in studying moisture efficiency or moisture quality in the semi arid areas of the Sudano- Sahelian belt of Nigeria. Usman (2000b) examined existing seven rainfall variability indices and developed a conceptual and operational Monson Quality Index (MQI) using daily rainfall data for seventeen years (1970 - 1986) for two stations (Kano, lat 12.3^0 N and Maiduguri, latitude 11.15^0N) in the Nigerian Sahel to analyse intra- and inter – seasonal characteristics of rainfall. The result showed that variability in the annual rainfall amount is not as important as the intra – seasonal distribution of rains; as the index identified those extreme shortfalls in rainfall in the Sahel in 1973 and 1983 and the good years of mid and late seventies. Comparing MQI values for the two stations, the index revealed the spatial variability of rains; Maiduguri had relatively worse rainfall regime than Kano and concluded that the critical nature of the rains over the Sahel with respect to its impact on agriculture makes it mandatory that effective means are evolved for the assessment of the problems of drought and mitigation planning. Moisture quality is imperative for identification of variability in moisture distribution thus, a major determinant in eco climatic zones.

The variability in onset date was investigated by Zeewdu and Peter (2004) who examined the inter-annual variability of *karent* (rainfall) over the drought prone areas of Ethopia during1965-1999 in terms of its onset, cessation and growing season duration and identified preliminary association with ENSO events. Results showed significant inter-annual variability in the onset, cessation and growing length of *karent* that reflects some associations with ENSO events. Specifically (1982-1983) *karent* onset was later than normal and 23% to 26% effective *karent* were shorter/longer than normal *karent* onset and cessation dates, dry spell lengths and total and effective growing season durations were determined for individual stations. This is crucial for enhance food supply and food security in any region.

In addition, Tennant and Bruce (2002) used daily rainfall data in South Africa from 1936 to 1999 combined into homogeneous rainfall regions using Ward's clustering method. Various rainfall characteristics were calculated for the summer season, defined as December to February (Southern Summer); seasonal rainfall total, region-average number of station, rain days exceeding 1 and 20 mm, region-average of periods between rain days at stations >1 and >20 mm, region-average of wet spell length (sequential days of station rainfall>1 and >20 mm), correlation of daily station rainfall within a region and correlation of seasonal station rainfall anomalies within a region. It was identified that Rank-ordered rainfall characteristics data generally form an s-shaped curve, and significance testing of discontinuities in these curves suggests that normal rainfall conditions in South Africa consist of a combined middle three quintiles separated from the outer quintiles, rather than the traditional middle tercile. The relationships between the various rainfall characteristics show that seasons with a high total rainfall generally have a higher number of heavy rain days (>20 mm) and not necessarily indicate an increase in light rain days. The length of the period between rain days has a low correlation to season totals, demonstrating that season with a high total rainfall may still contain prolonged dry periods. The study concluded that these additional rainfall characteristics are important to end-users, and their analysis offers a valuable starting point for seeking physical relationships between rainfall characteristics and the general circulation. Daily rainfall data are pertinent in the identification of rainfall characteristics, which is vital to sustainable food security.

In addition, Lázaro *et al.,* (2001) mentioned that in order to understand the behaviour of ecosystems in semi-arid areas, rainfall must be analysed over time. For this reason, annual, seasonal and monthly time scales were studied, including rainfall volume, number of rain-days and one-day maximum rainfalls. Results showed neither trends nor abrupt changes in the series, although three periods, averaging 301, 183 and 266 mm year^{-1}respectively were observed from fluctuation in rainfall. Modal values of annual and monthly rainfalls were lower than average. Inter-annual variability was 36% and intra-annual variability up to 207%. Although there was often a rainfall maximum in autumn and a minimum in July, the only certainty was a summer drought, which is marking strong annual cycles. The estimated return periods for events of more than 50, 70 and 100 mm day^{-1}were over 5, 11 and 30 years respectively; the absolute maximum 1-day rainfall recorded was 98 mm. They concluded that vegetation is not only adapted to the amount of precipitation, but also to its timing. All types of rainfall, in terms of volume and timing, would have consequences for vegetation. Time series daily precipitation data is essential for identification of eco-climatic zones.

2.3 Estimation of Evapotranspiration

There are several mathematical relations for estimating potential evapotranspiration using teorological data with different levels of reliability. Jabloun and Sahli (2008) States that Food and Agriculture Organization of the United Nations had improved the version of Penman–Monteith method (FAO-56 PM) which has recently been proposed as the standard for estimating reference evapotranspiration (ET_o). However, some weather variables, especially solar radiation, relative humidity and wind speed, are rarely available in Africa, this limits the use of FAO-56 PM method. To overcome the problem of the availability of climatic parameters, procedures to estimate ETo with missing climate data were proposed as part of the FAO methodology, and these were used in assessing the accuracy of the procedures for different Tunisian locations. The study observed that comparison of ETo estimates using limited data to those computed with full data set revealed that the difference between ETo obtained from full and limited data set is small considering the 8 locations studied. Both the Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) of the comparison were less than 0.6 and 0.8 with a minimum of −0.4 and 0.2 mm day−1, respectively, leading to small errors in the ETo estimates. Finally, the study concluded that higher deviations occur when the only available information is minimum and maximum air temperature. Thus, in locations where only available information is maximum and minimum air temperatures, potential evapotranspiration can be estimated using Hargreaves method.

Gunston and Batchelor (1983) compared the equation for Potential Evaporation (PE) proposed by Priestley and Taylor in 1972 and the Penman Potential Transpiration (Et) equation and established that Priestley and Taylor's equation has fewer data requirements than the latter. From the definitions, PE and Et values should both provide acceptable estimates of Reference Crop Evapotranspiration (ETo), as defined by Doorenbos and Pruitt. Their analysis of mean monthly climatic data from 30 tropical stations widely spread within the latitude zone 25°N to 25°S, showed that PE and Et estimates agreed closely when monthly rainfall exceeded monthly Et. The minimum data requirements for the Priestley-Taylor equation are daily net radiation and mean air temperature. The Penman equation additionally requires daily data for humidity and run of wind. As reliable field net radiometers become more widely available, the Priestley-Taylor PE equation offers a satisfactory alternative to the Penman Et equation for estimating ETo in humid tropical climates. Priestley and Taylor's equation may be preferable in the tropics but due to the non-availability of cloud data necessary for estimation of atmospheric emissivity, also necessary for computation of net radiation, its usage is fraught with limitations.

Similarly Gavilan *et al.* (2006) mentioned that Hargreaves equation provides reference evapotranspiration (ET_o) estimates when only air temperature data are available, although it requires previous local calibration for acceptable performance. The equation was evaluated under semiarid conditions in Southern Spain using data from 86 meteorological stations, comparing daily estimates against those from the FAO-56 Penman–Monteith equation, which was used as standard. Variability of results among locations was clearly apparent, with MBE ranging from 0.74 to −1.13 mm d−1 and RMSE from 0.46 to 1.65 mm d−1. Maxima under- and overestimation amounted to 24.5 and 22.5%, respectively. In general, the findings reveals the following; larger under- and overestimations occurred in stations located close to the coast and at inland areas, respectively. Yearly means of windspeed (V) and daily temperature range (ΔT) fairly influenced the accuracy of the equation. It was more accurate for windy locations with large ΔT, and for locations with light wind conditions combined with low to moderate values of ΔT. According to the values taken by V and ΔT, the stations were represented by points on the ΔT–V coordinate plane, in which the four regions were delimited. A regional calibration was carried out considering only temperature and wind conditions. Correction was not necessary for stations located within two of them; for the other two regions, new values for the empirical coefficient of the equation are suggested (0.0027 and 0.0021). After this correction, average RMSE and maximum and minimum MBE decreased substantially (12, 24 and 41%, respectively), and 74 out of the 86 locations gave quite accurate results, with relative values of MBE lower than 10% in most cases. The consequences from the application of the corrections proposed for an irrigation district was discussed. Thus Sudano-sahelian belt falls between zones of windy locations with large ΔT, and the sub-humid zone are locations with light wind conditions combined with low to moderate values of ΔT suggesting that Hargreaves formula may give adequate estimation of evapotransipiration in the belt.

Ali-Akbar and Hoossein (2010) identified evapotranspiration as critical to many applications including water resource management, irrigation scheduling, and environmental studies. This evaluate the performances of the Makkink, Priestley-Taylor, and Hargreaves models versus the Penman-Monteith FAO-56 (PMF-56) method in arid and semiarid regions of Iran during 1993–2005 and to identify the alternative ET_0 model that presents results closest to the PMF-56 method. Additionally, a regional estimation of monthly ET_0 with the best-performed model is presented by using the spatially distributed physical parameters and geographical information system. The results indicated that the Hargreaves model was the best model to estimate ET_0 in eastern arid and semiarid regions of Iran. The spatial distribution maps of ET_0 showed that ET_0 values increased from north to south as the aridity increased in the study area. The estimated total monthly ET_0 revealed a significant variation during the growing seasons (April–September) so that the study region experienced the highest and lowest ET_0 values of 250 and 80 mm in July and April, respectively.

The major limitation of Hargreaves formula is higher deviations due to under or over estimation of evapotranspiration (Et). As a result, there are efforts to minimise the effect where there is no alternative due to availability of data. Martínez-Cob and Tejero-Juste (2004) evaluates the Hargreaves (HARG) equation for estimation of monthly ET_o under the semiarid conditions of the middle Ebro River Valley (NE Spain). First, the Hargreaves equation was compared against measured lysimeter ET_o values at Zaragoza for the period May 1997–October 2000. The average of estimated values was only 5.6% above the average of measured values. Later, the Hargreaves equation was compared against the FAO Penman–Monteith equation for monthly ET_o estimation at nine locations. These locations are grouped as non-windy (Alcañiz, Daroca and Tamarite) and windy (Almudévar, Ejea, Gallocanta, Monflorite, Sariñena and Zaragoza). Their simple linear regression and error analysis statistics suggest that agreement between the two estimation methods was quite good for the windy locations. Average errors ranged between 2 and 5% for Almudévar, Ejea, Sariñena and Zaragoza, and between 7 and 10% for Gallocanta and Monflorite where some underestimation was observed. Thus, the Hargreaves equation overestimated ET_o and average errors varied between 14 and 20%. According to these results, it proposed that, under the semiarid conditions, no local calibration would be required for windy locations (those where monthly average windspeeds above 2.0 m s−1 are frequent), while a value of 0.0020 instead of the original 0.0023 should be used in the Hargreaves equation for non-windy locations. Subsequently, this may minimise the deviation that characterized Hargreaves formula. Since, it is not feasible to use the Penman–Monteith (PM) method to compile detailed ET_0 in the sudano-sahelian belt where data is very scarce.

Fitzpatrick and Stern (2003) examines an environment with a wide seasonal range of radiation and vapour-pressure deficit, the energy and aerodynamic components of Penman's evaporation formula were calculated daily for a year, and the potential evaporation was determined from several sources of data and by alternate modes of computation. Reference values for the energy component were obtained from measured net radiation over a well-watered crop. Reference values for the aerodynamic component were calculated from wet- and dry-bulb temperatures and windspeed using a relationship defined by Penman.Total radiation and relative duration of sunshine were found to be effective alternative sources of data for the energy component. When calculating the effective terrestrial radiation, it was found that equally satisfactory results could be obtained from a relationship based on proposals by Swinbank as by Penman's method which includes a vapour pressure term. Daily Piche and tank evaporimeter data were found to be satisfactory alternatives to the aerodynamic component.The conclusions reached are: (*1*) the minimal instrumentation needed to determine potential evaporation is a net radiometer, a Piche evaporimeter, and maximum and minimum thermometers, provided a suitable relation between the Piche and aerodynamic component is available. If a solarimeter is used in place of a net radiometer or sunshine recorder, a reliable albedo coefficient is necessary. (*2*) The use of inappropriate constants in the Penman formula is probably a greater source of error when determining image of 1987, the Enhanced Thematic Mapper Plus (ETM^+) image of 2000, and the image with the Charge-Coupled Device Camera (CCD) on the China-Brazil Earth Resources Satellite (CBERS) of 2006. Five land-cover classes, including active sand dunes, fixed sand dunes, semi-fixed sand dunes, inter-dune grassland and wetlands, were identified. Results showed that the Otindag Sandy Land has been suffering desertification since 1987 with 2 different desertified stages. The first stage from 1987 to 2000 was a severe sandy desertification period, characterized by the fixed sand dunes decreasing at a high rate, and the semi-fixed and active sand dunes increasing remarkably. The second stage spanned from 2000 to 2006 and the sandy desertification was weakened greatly. The study concluded that although a large area of fixed sand dunes were transformed to other types; fixed sand dunes were still the dominant type in the Ointdag region as at 2006. Finally it was observed that spatial change detection based on active sand dunes showed that the expansion area was much larger than the reversion area in the past two decades, and that several active sand belts had been formed, suggesting that sandy desertification control of the Otindag Sandy Land will be a long-term task.

The devastating environmental conditions led to increased interest in environmental hazard analysis. Susana and Keller (2006) explores environmental hazards, more specifically desertification processes, in an area of west central Argentina, addressing the combined influence of the physical framework and the long lasting human settlement and use of natural resources. The study was based upon digital change detection, the results indicate a net decreased in the amount of vegetation between 1973 and 2001, and increasing fragmentation of vegetation classes. This was interpreted as a sign of the presence of land degradation processes likely linked to human activities in the areas of irrigated farming, grazing, firewood gathering and population settlement.

Wide-spread effects of desertification have led to increase effort in quantifying resource degradation. Zhang *et al.* (2006) quantified land degradation based on land resource variation survey data from 1991 to 2002. The article identified, defined and classified land resource degradation, and analyzed dynamic changes in the degradation and rehabilitation process. Through the establishment of a land resource degradation index, the status and trend of degradation in China was explored to enable the design and planning of interventions for mitigation and establishment of sustainable land use and management practices. Results showed that: (1) the total land degradation index (A) fluctuated upwards from 1991 to 2002, although some parts improved. (2) Sand and rock desertification, deforestation and wetland loss reduced slightly, whereas secondary salinification, non-agricultural land occupation and natural grassland further deteriorated. (3) 66.27% of degradation was in natural grassland and non-agricultural land; while 57.5% of rehabilitation focused on sandy desertification and forests. (4) Non-agricultural land occupation and wetland shrinkage are primary causes of land resource deterioration in China. (5) Grassland, cultivated land and forest land accounted for 83.9% of degradation. (6) All the degradation processes are interrelated. These results provide useful information to combat future land resource degradation in China.

Climatic variability is crucial factor for sustainable resource and environmental management. Hahn *et al.* (2005) used a combination of empirical data and consensus agreement, to develop a computer model that describe the long-term climate, livestock and vegetation interactions on the communal rangelands and investigate the impacts of a range of management strategies. The model suggests that the system (including livestock) is sustainable although not stable, and that its sustainability could be due to climatic variability. The model supports the view that when livestock numbers vary in a manner consistent with recorded observations herbivory has little long-term impact on productivity of the system. This supports recent views of rangelands in semi-arid and arid environments where non-equilibrium conditions are thought to dominate ecosystem processes. The study concluded that as a result of the continuous high stocking densities, significant changes in the vegetation have taken place. Farmers are now heavily reliant on an annual flush of vegetation following winter rains to keep their livestock alive.

Furthermore, Zhao *et al.* (2005) conducted a grazing experiment from 1992 to 1996 in Inner Mongolia to explore desertification processes of sandy rangeland. The results show that continuous heavy grazing results in a considerable decrease in vegetation cover, height, standing biomass and root biomass, and a significant increase in animal hoof impacts. As a result, small bare spots appeared on the ground and later merged into larger bare areas in the rangeland. Total bare area reached up to 52% and the average depth of wind erosion was 25 cm in the fifth year of the study. It concluded that sandy rangeland with wind-erodible soil is susceptible to desertification. Heavy grazing of such rangeland may be avoided.

Musa and Bukar (2010), depicts the monitoring capability afforded by remote sensing to analyze and map the desertification processes in Yobe State by using supervised classification by maximum likelihood technique. Three cloud-free Landsat; Multispectral

Scanner (MSS) sensor on board the Landsat-2, Thematic Mapper(TM)sensor on board the Landsat-5 satellite and EnhancedThematic Mapper (ETM +) scenes covering the study area were selected for analysis. Imageries were acquired in January (the dry and rainy season in the study area) in years 1973, 1986, and 2006, respectively. The results emphasized the phenomena of sand encroachment from the northern part (Yusufari) to the southern part (Bade), following the wind direction. The increasing wind speed during the dry season is mainly attributed to the increase of sand encroachment in the study area. The study comes out with some valuable recommendations and comments, which could contribute positively in reducing sand encroachments, as well as land degradation and desertification processes in Yobe State. It concluded thatremote sensing and satellites imageries with temporal and synoptic view, play a major role in developing a global and local operational capability for monitoring land degradation and desertification in dry lands, as well as in Yobe State.

2.5 Vegetation Index (VI)

There are numerous literatures on vegetation indexes. Volcani and Karnieli (2005) detected and assessed seasonal/phenological changes and inter-annual changes in the forest trees with respect to the drought effect. It identified the use of a spectral vegetation index, namely the Normalized Difference Vegetation Index (NDVI) to detect stress conditions using Landsat-TM and ETM+ images. The results indicate similarity between the photosynthetic activity and the NDVI dynamics along the growing season. Considerable NDVI decline was observed between 1995 and 2000 due to the drought events during these years, enabling assessment of the spatial and temporal effects of such a disaster. The NDVI measured from the forest trees was found to be inversely related to the age of the trees due to strong effect of soil background in the younger forest sections that are characterized by lower vegetation density. Drought years are a very frequent phenomenon in Israel. Between the years 1994/1995 and 2001/2002, Israel experienced four (non-consecutive) years of drought. Consequently the Yatir forest, a pine forest located in the desert fringe, suffered from a notable water shortage. NDVI are essential for identification of moisture stress and drought conditions but are burdened with the effect of soil background.

Satellite images are paramount in quantifying land cover changes and assessing degradation. Yufu. *et al.* (2006) used field data, Airborne Visible Infrared Imaging Spectrometer (AVIRIS) imagery, and Moderate-Resolution Imaging Spectroradiometer (MODIS) data, to conduct a multi-scale analysis of ecosystem optical properties for Sky Oaks, a Southern California chaparral ecosystem in the spectral network (SpecNet) and FLUXNET networks. The study covered a 4-year period (2000–2004), which included a severe drought in 2002 and a subsequent wildfire in July 2003, leading to extreme perturbation in ecosystem productivity and optical properties. Two vegetation greenness indices (Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)), and a measure of the fraction of photosynthetically active radiation absorbed by vegetation (fPAR), were compared across sampling platforms, which ranged in pixel size from 1 m (tram system in the field) to 1000 m (MODIS satellite sensor). The three MODIS products closely followed the same seasonal trends as the tram and AVIRIS data, but tended to be higher than the tram and AVIRIS values, particularly for fPAR and NDVI. Following a wildfire that removed all green vegetation, the overestimation in MODIS fPAR values was particularly clear. The MODIS fPAR algorithm (version 4 vs. v.4.1) had a significant effect on the degree of overestimation, with v. 4.1 improving the agreement with the other sensors (AVIRIS and tram) for vegetated conditions, but not for low, post-fire values. These results are consistent with several other recently published studies that indicate that MODIS overestimates fPAR and thus net primary production (NPP) for many terrestrial ecosystems, and demonstrates the need for proper validation of MODIS terrestrial biospheric products by direct comparison against optical signals at other spatial scales, as is now possible at several SpecNet sites. The study also demonstrates the utility of in-situ field sampling (e.g. tram systems) and hyperspectral aircraft imagery for proper interpretation of satellite data taken at coarse spatial scales. The differences between MODIS products and the products from the other platform sensors could not be entirely attributed to differences in sensor spectral responses or sampling scale.

Similarly, Willem *et al.* (2006) used representative canopy reflectance and NDVI data for simulation of historical, current and future AVHRR, MODIS and VIIRS land surface monitoring satellites to quantify the differences due to sensor-specific characteristics. Cross-sensor NDVI translation equations were developed for surface conditions. The effect of a range of atmospheric conditions (Rayleigh scattering, ozone, aerosol optical thickness, and water vapor content) on the sensor-specific reflectance and NDVI values were evaluated to quantify the uncertainty in the apparent NDVI for each sensor. MODIS and VIIRS NDVI data are minimally affected by the atmospheric water vapor, while AVHRR NDVI data are substantially reduced by water vapor. Although multi-sensor NDVI continuity can be obtained by using the developed cross-sensor translation equations, the interactions between the spectral characteristics of surface vegetation and soil components, sensor-specific spectral band characteristics and atmospheric scattering and absorption windows will introduce uncertainty due to insufficient knowledge about the atmospheric conditions that affect the signal of the Earth's pixels at the time of data acquisitions.

Processing strategies and algorithm preferences among data streams are also hindering cross-sensor NDVI continuity. It stated that consistent NDVI time series are paramount in monitoring ecological resources that are being altered by climate and human impacts. VI time series are fundamental for identification of sub – climatic region.

Data integration allows better viewing and understanding of physical features. Fabio (2001) used linear regression procedures to derive spectral end members using satellite images and superimposed abundance estimates of known components. The procedure is based on a local calibration of the regression statistics (mean vectors and variance/covariance matrices), which is obtained by weighting the values of the training pixels according to their distance from each pixel examined. The locally found regression statistics are then used to extrapolate pure class spectral endmembers, which are therefore different for each image pixel. An experiment was carried out using multitemporal NOAA-AVHRR NDVI profiles and class abundance estimates of Tuscany region in central Italy. The results show that the spatially variable spectral endmembers are far more accurate than conventional fixed endmembers to recompose the original NDVI imagery. It discussed how these spatially variable pure class NDVI values can serve for data integration and as input for agro-meteorological applications and ecosystem simulation modeling.

Climate dynamics is critical in the assessment of environmental degradation. Zheng *et al.* (2006) studies the dynamics of vegetation distribution over the past 40 years in the Xinjiang Uygur Autonomous Region (XUAR), China. The results indicated that Holdridge Life Zone diversity was highest in the 1960s, dramatically decreased in the 1970s, and then gradually increased in the 1980s and 1990s.It was observed that from 1970s, the environment in XUAR seemed to be increasing in stability, as characterized by a reduction in the number of days of sandy dust storm activity in the 1990s, and an increase in temperature and precipitation leading to an increase in water flow in some rivers. The study concluded that both changes in human activities and positive climate change contributed to the Holdridge Life Zone diversity dynamics and more stable environment in XUAR.

Furthermore, Kumar *et al.* (2006) used hybrid approach (supervised and unsupervised) classification of 8–10 months IRS WiFS composite data (Raw bands, Max NDVI) over the period of 1998 to 1999 to generated a vegetation cover type map .The study identified 35 cover classes with a description of 22 vegetation cover including 14 forest cover types from 188 m spatial resolution WiFS data. The WiFS vegetation cover map was compared to the estimates of forest cover area was derived from IRS LISS III images (as per Forest Survey of India). There was a good agreement on spatial distribution and area of forest between the WiFS product and the LISS product; however, the WiFS product provided additional information on vegetation cover types and other land use/cover classes. Its analysis of temporal NDVI profile allows identification of distinct growth pattern between the different vegetation cover types. The study concluded that, It is evident that WiFS data can be used to provide timely and detailed vegetation cover type maps with limited ancillary data and that WiFS derived maps could be very useful as input to biogeochemical models that require timely estimation of forest area and type. Multi-temporal IRS Wide Field Sensor (WiFS) data are vital for mapping of vegetation cover types.

Vegetation Index is vital in understanding the spatial and temporal variation in climate within a region. Kogan (1995) used AVHRR-based Vegetation Condition Index (VCI) for drought detection and tracking. This index was used to determine temperature-related vegetation stress and also stress caused by an excessive wetness. The VCI provides accurate drought information not only for well-defined, prolonged, widespread, and intensive droughts, but also for very localized, short-term, and non well-defined droughts. In addition to the VCI, the AVHRR-based observations in thermal bands were used to develop the Temperature Condition Index (TCI). The validations showed that the VCI has excellent ability to detect drought and to measure time of its onset, intensity, duration, and impact on vegetation.). The paper provides principles of these indices, describes data processing, and gives examples of VCI/TCI application in different ecological environments of the United States. It concluded that National Oceanic and Atmospheric Administration (NOAA) new AVHRR-based Vegetation Condition Index (VCI) has revealed the usefulness for drought detection and tracking.

Climate variability in the arid and semi arid region is fundamental to human activities. Jason and Roland (2004) presented a technique to discriminate between climate or human-induced dryland degradation, based on evaluations of AVHRR NDVI data and rainfall data. Since dryland areas typically have high inter-annual rainfall variations and rainfall has a dominant role in determining vegetation growth and minor biomass trends imposed by human influences are difficult to verify. The study performed many linear regression calculations between different periods of accumulated precipitation and the annual $NDVI_{max}$, and identified the rainfall period that is best related to the $NDVI_{max}$ and by this the proportion of biomass triggered by rainfall. Positive or negative deviations in biomass from this relationship, expressed in the residuals, are interpreted as human-induced. It discussed several approaches that used either a temporally fixed NDVI peaking time or an absolute one, a best mean rainfall period for the entire drylands or the best rainfall period for each individual pixel and the advantages and disadvantages of either approach or one of its combinations for discriminating between climate and human-induced degradation were discussed. Rain and VI values are important in determination of plant growth in relation to desertification

Similarly, Michael *et al.* (1990); Acquired Advanced Very High Resolution Radiometer (AVHRR) data from the National Oceanic and Atmospheric Administration (NOAA)-9 satellite of the western United States from March 1986 to November 1987. Monthly maximum value composites of AVHRR normalized difference vegetation index (NDVI) [(near infrared — visible)/(near infrared + visible)] were calculated for 19 coniferous forest stands in Oregon, Washington, Montana, and California. The leaf area index (LAI) of the conifer forests explained 70% and 79% of the variation of the summer maximum AVHRR NDVI in July 1986 and July 1987, respectively. The study related the seasonal variation of NDVI to phenological changes in LAI, as well as the proportion of surface cover types contributing to the overall reflectance. It was concluded that AVHRR NDVI data from July were related to the seasonal maximum leaf area index of coniferous forests of the western United States, and that seasonal differences in the AVHRR NDVI were related to: a) phenological changes in LAI caused by climate, b) the proportions of surface cover types contributing to the overall reflectance, and c) large variations in the solar zenith angle. NDVI and LAI values are essential in the determination of vegetation vigour.

Historical data are critical in change detection. Jude *et al.* (2005) presented an alternative image masking technique, called yield-correlation masking, which they used in the development and implementation of regional crop yield forecasting models and eliminates the need for a land cover map. The procedure requires an adequate time series of imagery and a corresponding record of the region's crop yields, and involves correlating historical, pixel-level imagery values with historical regional yield values. Imagery used for this study consisted of 1-km, biweekly AVHRR NDVI composites from 1989 to 2000. Using a rigorous evaluation framework involving five performance measures and three typical forecasting opportunities, yield-correlation masking is shown to have comparable performance to cropland masking across eight major U.S. region-crop forecasting scenarios in a 12-year cross-validation study. Their results also suggest that 11 years of time series AVHRR NDVI data may not be enough to estimate reliable linear crop yield models using more than one NDVI-based variable. A robust, but sub-optimal, all-subsets regression modelling procedure is described and used for testing, and historical United States Department of Agriculture crop yield estimates and linear trend estimates are used to gauge model performance. Availability of time series data is a prerequisite to successful image masking.

Natural climatic variability influences temporal and spatial distribution of vegetation. Jeremy *et al.* (2004a) used Linear correlations between seasonal and inter-annual measures of meteorological variables and normalized difference vegetation index (NDVI) was calculated at six nearby distinct vegetation communities in semi-arid New Mexico. The findings reveals that USA Monsoon season (June–September) precipitation shows considerable positive correlation with NDVI values from the contemporaneous summer, following spring, and following summer. Non-monsoon precipitation (October–May), temperature, and wind display both positive and negative correlations with NDVI values. It was thus observed that meteorological variables influence NDVI variability at different seasons and time lags and concluded that vegetation responds to short-term climate variability in complex ways.

In addition, Jeremy *et al.* 2004(b) showed that time-series of normalized difference vegetation index (NDVI) capture essential features of seasonal and inter-annual vegetation variability at six nearby yet distinct vegetation communities in semi-arid New Mexico. It was illustrated that USA NDVI values tend to follow a uniform order across communities and related directly to local vegetation. Their result reveals that all communities exhibit a bimodal growing season on average, with peaks in springtime and summer; NDVI fluctuations are more spatially uniform in spring than in summer and NDVI variability corresponds to precipitation variability from the North American monsoon and El Niño-Southern Oscillation, and shows agreement with regional ground measurements.

Changes in rainfall patterns may alter the extent of arid, semi-arid and dry sub-humid areas, this may intensify the effect of drought. Parinaz *et al.* (2004) evaluated the capability of NOAA-AVHRR data for drought monitoring in the northwest of Iran having cold semi-arid climate, a study plan was designed involving the production of normalized difference vegetation index (NDVI) and vegetation condition index (VCI) indices and correlating their values to precipitation data. Raw AVHRR images were processed and geometric and radiometric corrections were performed. Seven-day maximum NDVI maps were produced and VCI was calculated using the maximum and minimum NDVI values for the same time period. Precipitation statistics from 19 synoptic meteorological stations were collected. The study covered a five-year time period with three consecutive months in the growing season.

Pearson correlation was performed to correlate NDVI and VCI values to precipitation data. Different time lag schemes were tried and the highest correlation coefficients (*r* values) were obtained while correlating NDVI and VCI to three-month (current plus last two months) precipitation. There was agreement between NDVI and precipitation as compared with that between VCI and precipitation in individual stations; Good correlations were also obtained between average NDVI and VCI of the study area and average three-month precipitation. The conclusion indicates that NOAA-AVHRR derived NDVI well reflects precipitation fluctuations in the study area promising a possibility for early drought awareness necessary for drought mitigation. Precipitation values, NDVI and VCI are important in drought monitoring and Eco –climatic mapping.

Degradation trend in Africa can be explained by rainfall variability and intensive landuse practice. Andrew and Carol (2000) assessed deforestation from 1981 to 1992 in Mwanza District in southern Malawi using Normalized Difference Vegetation Index (NDVI) values calculated from multi-temporal Landsat Multispectral Scanner (MSS) images. A control site, where vegetation change was assumed to be minimal, was used to account for the large effect of phenology on NDVI variability between images, and to reveal more subtle differences indicative of changes in percentage woody canopy cover. The average annual deforestation rate was estimated to be 1.8% in Mwanza District between 1981 and 1992. Multi-temporal and multispectral images are critical in determining effect of phenology on NDVI variability between images.

Leonard and Felix (1998) identified drought as one of the major environmental disasters in southern Africa. Therefore they obtained data from the Advanced Very High Resolution

Radiometer (AVHRR) sensor on board the NOAA polar-orbiting satellites which have been recognized as a tool for drought monitoring and climate impact assessment in southern Africa. The AVHRR-based vegetation condition index (VCI) and temperature condition index (TCI) developed were used in the study because in other parts of the globe they showed good results when used for drought detection and tracking, monitoring excessive soil wetness, assessment of weather impacts on vegetation, and evaluation of vegetation health and productivity. The results clearly showed that temporal and spatial characteristics of drought in southern Africa can be detected, tracked, and mapped by the VCI and TCI indices. The results were numerically validated by in situ data such as precipitation, atmospheric anomaly fields, and agricultural crop yield. It was found that functional corn yield scenarios can be constructed from the VCI and TCI at approximately 6 weeks prior to harvest time. These indices can be especially beneficial when used together with ground data.

Maxwell et.al (2002), examine the role of satellite images collected from several spectral wavelength channels in mapping land cover of large regions. The study identified that very few studies have evaluated the importance of individual Channels of Advance Very High Resolution Radiometer (AVHRR) images for discriminating cover types, especially the thermal channels (channel 3, 4, & 5). Five years AVHRR data was evaluated using combinations of original AVHRR spectral channels (1-5) to determine which channels are most important for cover type discrimination, yet stabilizing inter-annual variability, with particular attention placed in the thermal portion of the spectrum. Fourteen cover types over the entire State of Colorado were evaluated using a supervised classification approach on all two -, three -, four – and five- channel combination for seven AVHRR biweekly composite datasets covering five years growing season. Results show that all three of the major portions of the electromagnetic spectrum capatured by AVHRR sensor are required to discriminate cover type effectively and stabilizing inter-annual variability.

Operational monitoring of vegetative cover by remote sensing currently involves the utilisation of vegetation indices (VIs), most of them being functions of the reflectance in red (*R*) and near-infrared (NIR) spectral bands (Gilabert *et al.* 2002), introduced a generalized soil-adjusted vegetation index (GESAVI), theoretically based on a simple vegetation canopy model.. It was defined in terms of the soil line parameters (*A* and *B*) as: $\mathrm{GESAVI}=(\mathrm{NIR}-BR-A)/(R+Z)$, where *Z* is related to the red reflectance at the cross point between the soil line and vegetation isolines. The paper stated that since *Z* is a soil adjustment coefficient, the new index was considered as belonging to the SAVI family. In order to analyze the GESAVI sensitivity to soil brightness and soil colour, both high resolution reflectance data from two laboratory experiments and data obtained by applying a radiosity model were used to simulate heterogeneous vegetation canopy scenes were used. VIs (including GESAVI, NDVI, PVI and SAVI family indices) were computed and their correlation with LAI for the different soil backgrounds was analyzed. Results confirmed the lower sensitivity of GESAVI to soil background in most of the cases, thus becoming a very efficient index. This confirms the ability of SAVI in minimizing the effect of soil on the recorded vegetation vigour.

Similarly, Anderson *et al.*(2006) used microwave-based remote sensing algorithms for mapping soil moisture sensitivity to water contained in surface vegetation at moderate levels of canopy cover. Correction schemes require spatially distributed estimates of vegetation water content at scales comparable to that of the microwave sensor footprint (10^1 to 10^4 m). This study compares the relative utility of high-resolution (1.5 m) aircraft and coarser-resolution (30 m) Landsat imagery in upscaling an extensive set of ground-based measurements of canopy biophysical properties collected during the Soil Moisture Experiment of 2002 (SMEX02) within the Walnut Creek Watershed. The upscaling was accomplished using expolinear relationships developed between spectral vegetation indices and measurements of leaf area index, canopy height, and vegetation water content. Of the various indices examined, a Normalized Difference Water Index (NDWI), derived from near- and shortwave-infrared reflectances, was found to be least susceptible to saturation at high levels of leaf area index. With the aircraft data set, which did not include a short-wave infrared water absorption band, the Optimized Soil Adjusted Vegetation Index (OSAVI) yielded best correlations with observations and highest saturation levels. This SAVI is vital for vegetation studies in the Sudao-Sahelian belt where vegetation is sparse.

Begue and Myneni (1996) studied improved estimation of primary production at a regional scale,using an assessment of the utility of fraction of absorbed photosynthetically active radiation (fAPAR) estimated from spectral vegetation indices (VI) for the case of the Sahelian vegetation. The study simulations used a three-dimensional radiative transfer model for two types of structurally distinct vegetation canopies: millet crop and savanna. A realistic range of values was extracted for each vegetation input variable (leaf area index, ground cover, height and spatial distribution) from published literature. Bidirectional reflectance factors were calculated in the NOAA-advanced very high resolution radiometer (AVHRR) spectral bands for a geometric configuration representative of the NOAA satellite series. Two vegetation indices were tested: normalized difference vegetation index

(NDVI) and modified soil adjusted vegetation index (MSAVI). The simulations indicate that the fAPAR-VI relationship is sensitive to the geometry of measurement and soil optical properties, especially in the case of a millet crop. This study proposed simple linear models that include this variability and are directly applicable to atmospherically corrected AVHRR data; also the error of estimation of fAPAR is evaluated.

A growing number of studies have focused on evaluating spectral indices in terms of their sensitivity to vegetation biophysical parameters, as well as to external factors affecting canopy reflectance (Driss *et al.* 2004). In this context, leaf and canopy radiative transfer models are valuable for modelling and understanding the behaviour of such indices. The study used PROSPECT and SAILH models to simulate a wide range of crop canopy reflectances in an attempt to study the sensitivity of a set of vegetation indices to green leaf area index (LAI), and to modify some of them in order to enhance their responsivity to LAI variations. The authors presented a method for minimizing the effect of leaf chlorophyll content on the prediction of green LAI, and to develop new algorithms that adequately predict the LAI of crop canopies. Analyses based on both simulated and real hyperspectral data were carried out to compare performances of existing vegetation indices (Normalized Difference Vegetation Index [NDVI], Renormalized Difference Vegetation Index [RDVI], Modified Simple Ratio [MSR], Soil-Adjusted Vegetation Index [SAVI], Soil and Atmospherically Resistant Vegetation Index [SARVI], MSAVI, Triangular Vegetation Index [TVI], and Modified Chlorophyll Absorption Ratio Index [MCARI]) and to design new ones (MTVI1, MCARI1, MTVI2, and MCARI2) that are both less sensitive to chlorophyll content variations and linearly related to green LAI.

The most frequently used vegetation index (VI), the Normalized Difference Vegetation Index (NDVI) may have some limitations Leprieur *et al.* (1996) discussed the usefulness and limitations of the various vegetation indices, with special attention to cloud contamination and green vegetation detection from space. The HAPEX Sahel database was used as a test case to compare these indices in arid and semi-arid environments. Simulated indices values behaviour at the surface level shows that these VIs were all sensitive to the presence of green vegetation but were affected differently by changes in soil colour and brightness. These showed that GEMI is less sensitive to atmospheric variations than both NDVI and MSAVI since it exhibits a high atmospheric transmissivity over its entire range for various atmospheric aerosol loadings and water vapour contents. MSAVI calculated at the surface level, has shown a great insensitivity to soil optical responses modifications.

The sensitivity of the normalized difference vegetation index (NDVI) to soil background and atmospheric effects has generated an increasing interest in the development of new indices, such as the soil-adjusted vegetation index (SAVI), transformed soil-adjusted vegetation index (TSAVI), atmospherically resistant vegetation index (AR VI), global environment monitoring index (GEMI), modified soil-adjusted vegetation index (MSAVI), which are less sensitive to these external influences (Geneviève *et al.* 1996). The study stated that the indices are theoretically more reliable than NDVI, although they are not yet widely used with satellite data. Indices are simulated with the SAIL model for a large range of soil reflectances, including sand, clay, and dark peat, with additional variations induced by moisture and roughness. The general formulation of the SAVI family of indices with the form VI = (NIR - R) / (NIR + R + X) is also re-examined. The value of the parameter X is critical in the minimization of soil effects.

2.6 Identification of Eco-climatic Zones

Roy *et al.* (2006) simulated climate variables and actual vegetation boundaries into maps of biomes, based on actual vegetation cover type map derived from wide field sensor onboard Indian remote sensing satellite (IRS WiFS—spatial resolution 200 m) and Holdridge life zone (HLZ) system. A biome level characterization (BLC) model was developed in which, temporal satellite data helps to define the phenologically discriminant vegetation cover type, climatic parameters viz., biotemperature, mean annual precipitation and potential evapotranspiration ratio have been used to identify potential life zones and finally describe the biome was boundaries based on the vegetation cover type and life zones. The study identified 35 cover classes and described 17 vegetation cover types.

Robert and Samuel (1969) reported that Grisebach's attempt at the classification of world vegetation was a challenge to students of climate to look for correspondences between temperature or precipitation data and the world distribution of vegetation. At the same time, among biologists there was extensive investigation of the effect of climate on the phenology, growth and development of plant species. The monographs of Carl Linsser are the outstanding monument to this phase; the work used the effects of temperature on phenology and rainfall on vegetation to divide the world into climatic zones, thereby making him the first to attempt a true classification of climates on the basis of vegetation zones. Later, de Candolle published a physiological classification of plants based on adaptation to climate in which the familiar terms "megathermal", "xerophilous", "mesothermal" and "microthermal" appeared for the first time.

Similarly, Denton and Barnes (1988) identified an ecological climatic classification method that emphasizes variables important to tree growth and survival for Michigan. Separate classifications of weather station data were made for winter variables, growing season temperature variables, and growing season water balance variables. Each classification was based on the combined results of 6 cluster analysis procedures and principal component analysis. Hierarchical agglomerative average link cluster analysis using a modified Canberra metric as a distance measure (CANA) was generally most effective in reflecting the underlying structure of the climatic data. A single unified classification was then made combining the climatic information with physiographic patterns. Three regions and 20 districts were identified. The final classification was evaluated with canonical discriminant analysis and analyses of variance.

Thornthwaite's climatic classification may be quickly and accurately used graphs and nomograms. The potential evapotranspiration adjusted for months and latitude of the station was accomplished graphically (Robert and Samuel 1969). It was reported that soil water storage, soil water deficiency, and soil water surplus were determined by the Thornthwaite accounting procedure and, once determined, the symbolization for the complete climatic designation of the station is obtained by further graphical means. The study concluded that Thornthwaite's climatic classification may be quickly and accurately determined by use of graphs and nomograms.

The principal parameter of Thornthwaite's classification is a climatic potential evapotranspiration. Dantas *et a.l* (2007) evaluated the climatic data tendency in the last 14 years of monthly rainfall and temperatures in Lavras region, MG State , compared to those of the historical series of 1961-1990 period. The Thornthwaite's water balance method was employed for the climatological data of 1961-1990 and for the last observed data of 1991-2004. Thornthwaite's climatic classification method determines the moisture and aridity index of climate. Köppen's climatic classification method, also employed in this work, showed no changes, remaining Cwa for both periods.

Literature reveals that there is no existing eco-climatic map of the Sudano-sahelian belt of Nigeria; a single map that integrate ecological and climatic parameter to depict the state of environment in quantitative term. Furthermore, most existing geography text books and Atlases do not contain climatic map of Nigeria, predominantly, they have precipitation, temperature and relative humidity map see [Afolabi (1974), Oboli and Harrison (1974), Harold (1976) and Adetoro (1982)]. Iloeje (1976)], used quantitative values of temperature, relative humidity and rainfall (total and mean) to identify four climatic zones in Nigeria; Sub-equatorial South, Tropical hinterland, Tropical continental North and High Plateaux. This classification is primarily based on Koppen's method of classification. Moreover, the parameters used are not crucial to agriculture as derived eco-climatic parameters (AI, Onset, Cessation, HGS, and MQI & VI).

Thornthwaite (1948), (reported by Robert and Samuel, 1969). State that Thornthwaite's first world classification of climate was presented in 1931-1933. It differed from earlier attempts by others in that it assigned the major role to the moisture factor. In 1948 it proposed an entirely new system based fundamentally on *potential evapotranspiration* (PE), which it defined as the evapotranspiration that would occur from a vegetation-covered surface if soil moisture conditions were adequate for unrestricted transpiration. The work continued on this system since its first publication not only by the present authors but also by climatologists, biologists, and agriculturists throughout the world. Certain improvements have been worked out and adopted and others are in prospect. Thornthwaite "reasoned that a moisture index must include both water surplus and water deficiency, since a deficiency in one season may be mitigated somewhat by storage of water in the soil in the preceding season of water surplus.

Andrade *et al.* (2005) presents a proposed method of climatic classification and regionalization for the semiarid region of Piaui, Brazil. Using the Thornthwaite moisture index estimates of soil water balance under different climatic conditions as a function of the rainfall scenario (dry, regular, wet and medium-depth rainfall years). The percentage of the countries under climatic types and rainfall scenarios were regionalized by geographical information systems. Six climatic types were defined, viz., arid, semiarid, subhumid dry, subhumid, and two humid variations, wherein occurrences in the State varied with rainfall conditions. It concluded that the variability observed in area and countries number show the natural tendency of the rainfall spatial and temporal variability, characterized as a function of the rainfall scenario, which is more compatible with the physical reality. Variability in rainfall is vital for identification and delineation of eco – climatic zones

Köppen's classification used simple temperature and precipitation values to define boundaries. Strahler (1969) identified Koppens method of climate classification as the most widely used scheme that defines the limits and boundaries of major climates of the world on the basis of quantitative definitions of temperatures and precipitation values of places. Koppen identifies five major climatic types by capital letters as; A, B, C, D and E; Tropical rainy, Dry climates, Warm climates, Cold climate and Snow climates. The temperature limits were based on some established relationships between temperature and vegetation (tree) growth. Further Subdivisions of each of the five major climatic types (except the B - group) were based on seasonal distribution of precipitation and are designated with small letters, f, m, s, w & B subgroups designated with second subgroups S and W. Koppen's combination of temperature and precipitation characteristics is strictly empirical; climate are defined according to fixed values of temperature and precipitation. This classification has been the simplest and easily adaptable.

Precipitation effectiveness is crucial in identifying dryness level and their ecological implications. Adefolalu(1988) used the ratio λ of precipitation to potential evaporation (hydrologic ratio) to qualify earlier climatic classifications of Nigeria for proper ecological zonation. The result showed that in the pure forest belt located south of latitude 7^0 N λ value is greater than 0.75, while in the middle belt (7-10^0 N) belonging to the wooden savanna and the areas further north gradually approaching steppe- type vegetation of pure sahel, the values of λ are below 0.40. It was observed that modulations of λ values (eco-zones) appear to be responses to variable precipitation, especially in drought years. In conclusion it mentioned that irreversible trends in uncontrolled human interference are mainly due to large- scale agriculture in areas where λ is less than 0.40 in the Sudan-Sahel belt of Nigeria. Hydrologic ratio is vital in the defining eco-climatic zones thus will be use to determine the level of aridity.

2.7 Inferences

Variability of rainfall distribution particularly in the semi-arid and sub-humid ecosystems is fundamental for the investigation and understanding of trends and its impact on the environment (Lázaro et al, 2001, Srikantha and Uditha, 2004). Rainfall and temperature have been identified as major climatic factors triggering landcover / landuse changes. Defining the State of the environment using rainfall amount is practically inadequate particularly in the Sudano-Sahelian region that is generally a moisture stress belt. Adefolalu (1986) and Usman (2000b) stated that plant response to drought situations have shown that sometimes, the amount of recorded rainfall is quite irrelevant. Hence, additional intra and inter- seasonal rainfall characteristics are essential for the identification and delineation of eco-climatic zones.

Scarcity of data, particularly in Africa have limited the use of FAO recommended (FAO-56 PM) method for estimation of evapotranspiration. As a result, procedures for estimating missing data and estimation where the only available information is minimum and maximum air temperature were suggested. Thornthwaite (1948) states that potential evapotranspiration for any place whose latitude is known and for which temperature records are available can be estimated. Several studies have quantified vegetation vigour using different types of vegetation indices (VCI, NDVI, TCI, LAI, SAVI, GESAVI and, OSAVI). The commonly used is NDVI that is associated with significant effect of soil background and SAVI depress soil effect on the recorded vegetation vigour particularly in areas with sparse vegetation like northern Nigeria. Satellite images are importance in the determination of VI; AVHRR-based vegetation index has shown good result in several studies. Central to prominent climatic classifications (Thornthwaite and Koppen) are seasonal concentration of moisture stress and deficit.

The foregoing gives an indication that rainfall characteristics (onset, cessation and hydrologic growing season, Moisture quality and, evapotranspiration) are fundamental in assessing land degradation and changes in the eco-climatic zones, as climate may be the key factor triggering desertification. Sudano-Sahelian belt falls between zones of windy locations with large ΔT, while sub-humid zone falls within light wind conditions combined with low to moderate values of ΔT suggesting that Hargreaves formula may give adequate estimation of evapotransipiration in the belt. Central to most climatic classifications is that they are determined by vegetation thus, these justify the focus of this research on integration of effective rainfall characteristics and vegetation biomass in the delineation of eco-climatic zones in northern Nigeria.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The primary data for this research include satellite data of the northern region, field survey, rainfall, maximum and minimum temperature data (1950- 2006). Other secondary data include outline map of the study area and textbooks. A high altitude space borne satellite image in near polar sun-synchronous orbits of National Oceanographic Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite images of 1.1km spatial resolution over northern Nigeria was acquired from the National Remote Sensing Centre Jos, Nigeria. The image was acquired 6th January 2009 using two bands; the near infrared band (0.72 - 1.1 μm) and the Thermal infrared band (3.55 – 3.93 μm); that is channel 2 & 3. Daily rainfall data (1950 – 1999) was collected from the Environmental Management Studies Programme, Department of Geography, Federal University Technology, Minna. Maximum and minimum temperature data (1950 – 2006) and daily rainfall data (2000- 2006) for the selected synoptic station in the country were collected from Nigerian Meteorological Agency, Headquarters, Maitama, Abuja. Garmin GPSMAP 76 was used for taking the X, Y coordinates during field work.

3.1.1 Description and Sourcing

Daily rainfall records for twelve selected meteorological stations in the study area were for; Minna, Zaria, Yola, Maiduguri, Bauchi, Sokoto, Yelwa, Kano, Jos, Gausau, Nguru, and Katsina. These data were used to derive vital rainfall characteristic and moisture quality in the belt. The derived rainfall characteristics; onset, cessation, hydrological growing season (HGS) and moisture quality is very crucial in assessing land degradation and eco climatic zones. These were determined using Intra – Seasonal Rainfall Monitoring Index [IRMI – Usman and Abdulkadir (2008)] and Moisture Quality Index [MQI – Usman (2000b)].

Maximum and Minimum Monthly temperature data (1950– 2006) were summarized statistically. These summaries were used to quantify the twin indicators of water loss in the region; evaporation and transpiration, referred to as evapotranspiration. Temperature is an important environmental factor in plant physiology and reproduction and is important for this reason in defining meaningful eco - climatic classes. Potential Evapotranspiration (PET), the maximum rate of evapotranspiration occurring under prevailing atmospheric humidity, available prevailing heat energy and wind speed. This, according to Thornthwaite (1948), is the evapotranspiration that would occur from a vegetation-covered surface if soil moisture conditions were adequate for unrestricted transpiration. This factor determines soil moisture availability for plants since energy and water have been identified as two vital components for plants growth and development. These, with precipitation were used to compute aridity index which defines soil moisture availability for plants and assesses moisture deficit or surplus.

Vegetation data was derived from interpretation of satellite images using Soil Adjusted Vegetation Index (SAVI) to quantify vegetation biomass in the Sudano – sahelian region of Nigeria where soil background is a significant component of signal detected. The SAVI was developed by Huete (1988), to minimize the effect of soil on vegetation signal. It is noteworthy that the vegetation Index has been used to identify environmental changes, drought and land degradation risk assessment (Andrew and Carol, 2000; Volcani, 2005;

Yufu. *et. al*., 2006; Willem *et. al*., 2006; Zheng *et. al*., 2006; & Yaw and Edmund, 2007). All the derived data are location specific except for vegetation. The location coordinates of the twelve data points were therefore used to extract SAVI value (Fig 3.1).

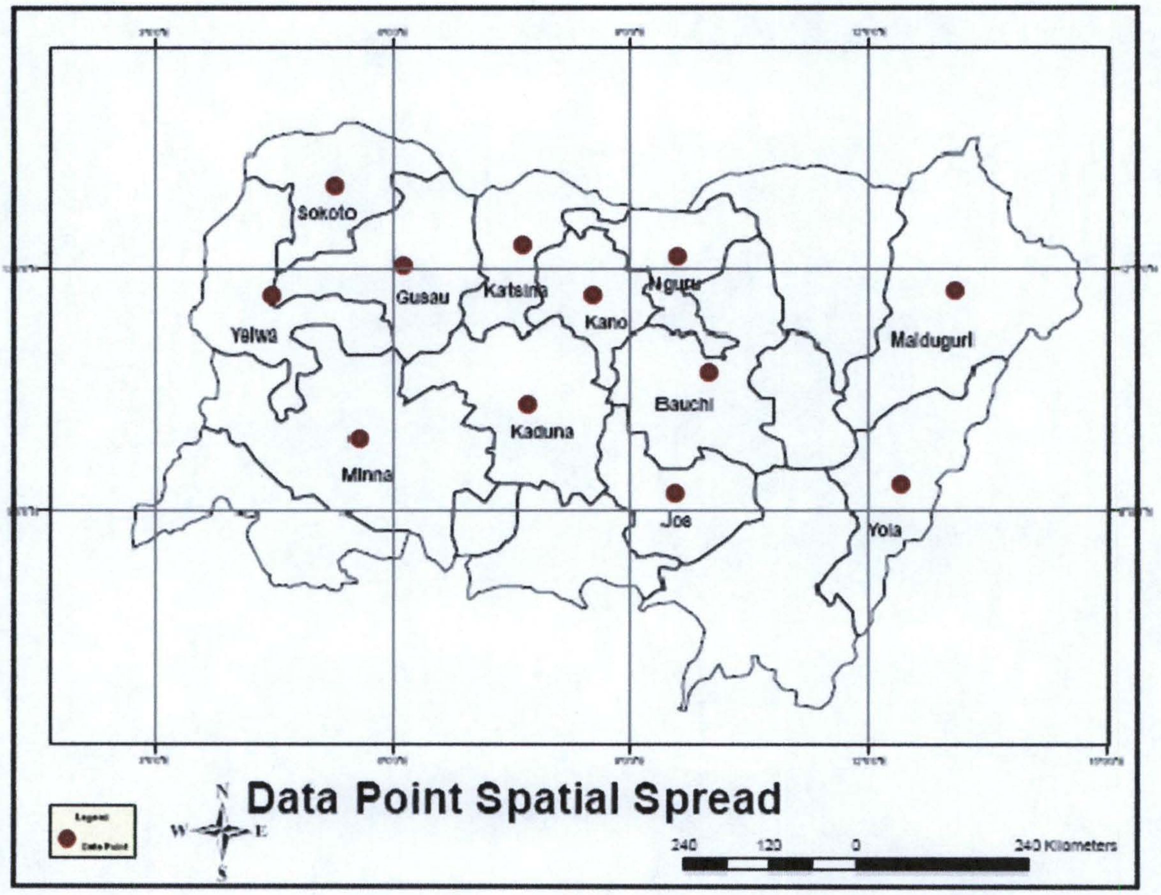


Fig.3.1 Data Point Spatial Spread Map

Field assessment was conducted to familiarize the researcher with the study area and to be able to physically establish relationships between features on the ground and on the images. Global Positioning System (GPS) readings were taken at specific location coordinates to confirm the various vegetation types in the study area and Photographs were also taken.

3.1.2 Research Method Flow Chart

The materials and method of the research are represented in a flow chart to describe the pattern for carrying out the research (Fig.3.2). The flow chart is made up of six layers; data set, computation techniques, derived parameters, ranking of all the parameters, establishment of GIS database and results. The first layer consists of three main types of data; rainfall, temperature and NOAA AVHRR data. These were summarized, processed and inputted for computation and processing. The following parameters were derived; onset, cessation, HGS, MQI, AI, and VI. All derived parameters were ranked and classified. The various classes were used to develop a GIS database using the following tools; SPSS 15.0, Golden Surfer 8, IDRISI Andes & ArcGIS 9.2 for final data processing and delineation of Eco-climatic zone.

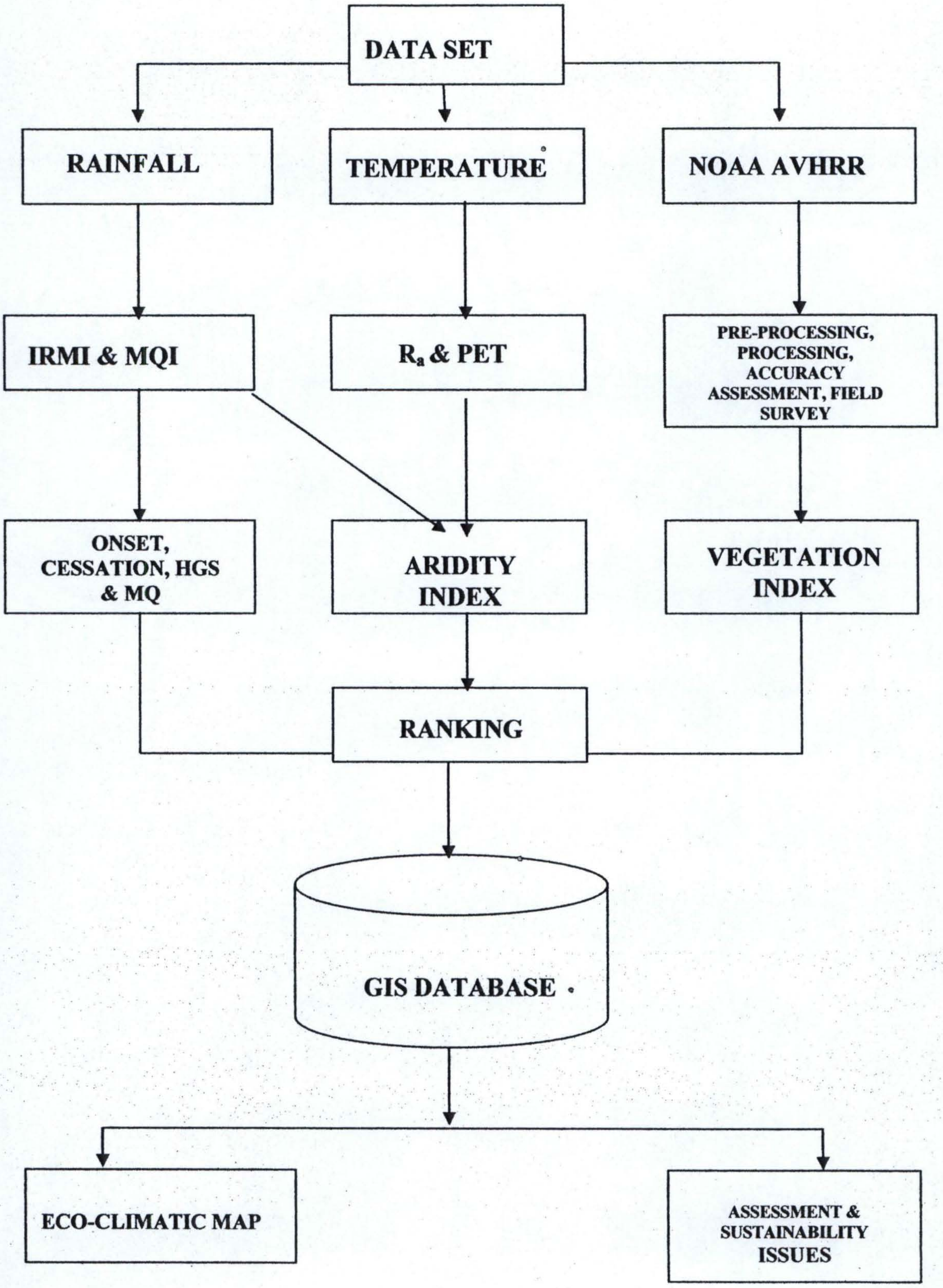


Fig.3.2 Method Flow Chart

3.2 Methods

These explain the method for analyzing, classifying and integrating the derived parameters for delineating the eco-climatic zones.

3.2.1 Computation of Derived Parameters

Five derived parameters Intra-seasonal Rainfall Monitoring Index (IRMI), Moisture Quality Index (MQI), Potential Evapo-transpiration (PET) and Aridity Index (AI) were computed

3.2.2 Intra-Seasonal Rainfall Monitoring Index Scheme (IRMI)

Daily rainfall totals were summed into pentad totals. As described in Usman (1999), any pentad with less than 5mm of rainfall is taken as a break. The 1st of May (25th Pentad of the year from 1st of January) is taken as the pentad of reference for semi-arid and dry, sub-humid areas of Sudano-Sahelian Nigeria. The choice of the beginning of May as reference point is based on the identification by Sultan and Janicot (2004) of mid-May as the first time an increase occurs in the positive rainfall slope in Sudano-Sahelian West Africa which is said to be connected to the Inter-Tropical Discontinuity (ITD) crossing 15^0 N and to the arrival of Monsoon winds advecting moist air on the Sahelian latitudes. The study also reported the identification of mid-May as a time for major changes in the atmospheric circulation over West Africa.

Cumulative amount of rainfall and the highest pentad total since the 25th pentad are noted and combined with the number of breaks to compute an Intra-Seasonal Rainfall Monitoring Index (IRMI) using the expression;

$$(Cpt^2)/(hpt \times Nb \times 100) \qquad 3.1$$

Where Cpt = Cumulative pentad rainfall since May 1

hpt = highest pentad total rainfall since May 1

Nb = Number of breaks in rainfall

100 = A factor

IRMI is zero under 'no rainfall' (dry season) conditions and increase gradually as rainfall is received. The 'actual' or 'real' onset of rains is taken as the pentad within which the index is greater than, or equal to, 1 (> 1) for the first time. Because the numerator is a measure of cumulative rainfall received and the denominator a measure of temporal spread of the rain, the index combines both quantity and spread and therefore holds the promise of being able to follow closely the soil moisture situation necessary for plant germination and establishment and, by inference, crop conditions (Usman and Abdulkadir 2008). Cessation is the first pentad of decline trend in IRMI value in September for two consecutive pentads. Thus IRMI was used to determine Real Monsoon Onset (RMO), cessation and HGS for the twelve meteorological stations; in addition this was used to define the threshold value that indicates the moisture situation and aridity levels in the zone.

3.2.3 Monsoon Quality Index

Monsoon Quality Index (MQI) measures the quality of the seasonal rains in terms of both annual amounts and seasonal spread. Annual rainfall totals, highest monthly totals and number of breaks computed from pentad values for each hydrologic growing season (1950 – 2006) was used in the computation of MQI developed by (Usman 2000b).

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

Where $_i$ = year identifier

r_{mm} = Highest monthly rainfall total

R = Annual rainfall total

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

The index is small if the annual amount is high and the rains are not concentrated in any one month. Thus the smaller the index, the better the season quality - wise.

3.2.4 Potential Evapo-transpiration

Potential Evapotranspiration was quantified to indicate the expected soil moisture loss. Hargreaves (1985) model was adopted for the computation of evapotranspiration; this uses mean monthly temperature (Tmean), mean monthly temperature range (TD) and extraterrestrial radiation (R_a), radiation on top of atmosphere) to calculate PET, as per the equation below:

$$PET = 0.0023 \bullet R_a \bullet (Tmean + 17.8) \bullet TD^{0.5}\ (MJ\ m^{-2}\ day^{-1}) \qquad 3.3$$

This requires the calculation of estimates of extraterrestrial radiation (R_a). This procedure assumes a planar surface that receives equal solar radiation at every site on the plane (Allen *et al.*, 1998). Following Hargreaves (1985) method, R_a is calculated theoretically as a function of latitude and the month of the year;

$$R_a = \frac{118}{\pi}\left\{\cos^{-1}(-\tan\delta\tan\phi)\sin\phi\sin\delta + \cos\phi\cos\delta\sin\left[\cos^{-1}(-\tan\delta\tan\phi)\right]\right\} MJm^{-2}day^{-1} \qquad 3.4$$

δ is the Calculated declination; $\delta = 0.4102\sin\left(\frac{2\pi}{365}(J-80)\right)$ 3. 5

J= Calculated day of the year, Jan= 15, Feb=45……Dec=345

Φ is the Latitude Converted to radians;

$$\Phi = \left(latitude * \frac{\pi}{180} \right) \qquad 3.6$$

R_a is calculated in MJ m^{-2} day^{-1} , this was changed to mm day^{-1} according to the method of Allen et.al (1998) 1 MJ m^{-2} day^{-1} = 0.408mm day^{-1}.

Thus $PET = 0.408 * 0.0023 \cdot R_a \cdot (Tmean + 17.8) \cdot TD^{0.5}$ *(mm/d)* 3.7

similar approach was adapted by (Vicente-Serrano, et.al .2007).

This was used to estimate hydrologic ratio that is the relationship between incoming moisture and amount of moisture lost in the region.

3.2.5 Aridity Index (AI)

This was developed from hydrological ratio which is defined as the ratio between mean annual rainfalls to potential evapotranspiration. It refers to the degree of wetness or dryness of the soil and was consequently computed using Mean annual precipitation totals and potential evapotranspiration. Hydrologic ratio (ג) has the following attributes: (ג) = 1 implies hydro – neutral condition defined in Eco –Climatic Atlas as the zone where the field capacity is 100% with neither deficit nor surplus soil moisture 'stress'. It is the criteria for optimum plant and crop requirement, ג less than 0.6 implies severe stress will occur in plant and ג greater than 1 indicates water logging as the capacity is exceeded. Hydrologic ratio estimates was used to determine soil moisture requirement and regional aridity level quantifying precipitation deficit over atmospheric water demand. The relation below was used to determine the Hydrologic Ratio that was used as aridity index.

Aridity Index (AI) = annual precipitation / Potential evapotranspiration 3.8

3.3 Processing of Satellite Images

The NOAA - AVHRR images were subjected to radiometric, geometric correction and image enhancement for visual and digital analysis.

3.3.1 Pre- Data processing

The primary satellite images were imported into IDRISI Andes soft ware for radiometric, geometric corrections. The secondary data, Ileoje (1976)'s climate, drainage and outline maps of Nigeria, were scanned and subjected to on-screen digitalization.

3.3.2 Image Enhancement and Geo- referencing

Image enhancement (mean digital filtering) was to remove the effect of noise, haze and cloud from the images. This improves the interpretation of an image by increasing the apparent distinction between features in that scene and the information contained in the image were readily interpreted visually. Image enhancement was performed using IDRISI Andes software for the removal of noise, haze and cloud effects thereby optimizing visual interpretation and preparing the Images for SAVI transformation. Ground Control Points were extracted from geo-referenced drainage map of Nigeria (rivers / streams intersection and shoreline features) and corresponding positions on the image were used to resample the image. These geographical locations were used in resampling the pixels to match the image grid referencing system.

3.3.3 Vegetation Index (VI)

The Soil Adjusted Vegetation Index (SAVI) incorporates a constant soil adjusted factor (L) into the denominator of Normalized Difference Vegetation Index (NDVI) equation of the infrared and the red region. Generally, (L) varies with the reflectance characteristics of the soil such as colour and brightness. Maxwell, *et.al* (2002), reported that vegetation mapping using AVHRR images in South East Asia (Achard and Estreguil (1995), Africa (Lambin and Enrlich1995), the continental USA (Nemani and Running 1997) as well as globally (Hansen *et.al* 2000); confirm that including AVHRR thermal channels improved cover type separation. In addition, Malingreau *et.al* (1989) selected AVHRR channel three to be preferable to channels four and five. This justifies the inclusion of thermal channel (band three) for quantifying vegetation vigour in the zone. Amodou and Ronald (2006) stated that Walther and Shabaani (1991) suggested that the best (L) value to select is where the differences between SAVI values for dark and light soil is minimal for L = 0, SAVI = NDVI. For L = 100, SAVI is approximately Perpendicular Vegetation Index (PVI) which is the parent of all the vegetation indices. Soil Adjusted Vegetation Index model as suggested by Walther and Shabaani (1991) is as follows:

$$SAVI = P_{nir} - P_{red} / P_{nir} + P_{red} + L * (1 + L) \tag{3.9}$$

Where P_{nir} = Near Infrared band (expressed as reflectance)

P_{red} = Visible red band (expressed as reflectance)

L = Soil adjusted factor

Consequently, the modified SAVI equation is: $P_{tir} - P_{nir} / P_{tir} + P_{nir} + L * (1 + L)$ 3.10

Where P_{tir} = Thermal Infrared band (expressed as reflectance)

P_{nir} = Near Infrared band (expressed as reflectance)

L = Soil adjusted fact

This was used to identify and classify the various vegetation types in the region.

3.3.4 Vegetation Classification

Classification is the process of developing interpreted maps from remotely sensed images. As a result, classification is one of the most important aspects of image processing. Computer assisted classification was adopted using IDRISI Andes software programme to quantify and identify features in the scene of multi-spectral image data. Spectral pattern recognition of features on the image was adopted; using reclassification of the vegetation index value (vegetation vigour) to uncover the commonly occurring features using cluster and this serve as catalyst for interpretation of the vegetation type. Five classes of vegetation were identified; 5, 4, 3, 2 &1. Field work was carried out to resolve interpretation difficulties and ambiguities.

3.4 Analysis and Classification of Derived Parameters

The computed derived parameters; Precipitation Effectiveness, Moisture Quality & Aridity Index values were input into SPSS 15.0 for further analysis and classification. Five classes were identified for each parameter; 5, 4, 3, 2 & 1, that is, Very Good, Good, Fair, Poor and Very Poor respectively indicating Moisture Effectiveness Classes (MECs).

3.4.1 Aridity Index, Cessation and Hydrologic Growing Season

The computed derived parameters were summarized, analyzed and classified using SPSS software. Aridity index, Cessation dates and Hydrological Growing season (1950-2006) summary were classified (ranked) using numerical identifiers for the interpretation of the various moisture effectiveness classes; Very Good, Good, Fair, Poor and Very Poor zones (Table 3.1).

Table: 3.1 Aridity Index, Cessation and Hydrologic growing Season Interpretation Scheme

Aridity Index	MECs	Cessation Dates(Pentads)	MECs	Hydrological Growing Season (days)	MECs
≥ 0.6	5	≥ 60	5	≥150	5
≥ 0.5 < 0.6	4	≥ 57 < 60	4	≥120 < 150	4
≥ 0.4 < 0.5	3	≥ 54 < 57	3	≥90 < 120	3
≥ 0. 3 < 0.4	2	≥ 51 < 54	2	≥60 < 90	2
< 0.3	1	< 51	1	<60	1

3.4.2 Onset Date and Monsoon Quality Index

Onset dates and MQI values were also summarized and classified using 5, 4, 3, 2 & 1 as Very Poor, Poor, Fair, Good and Very Good respectively, since the higher values are indications of moisture stress thus, reflecting the level of environmental dryness (Table 3.2). Generally, the identifiers were allocated in such a way that the higher the value of the derived parameters, the higher the value of the identifier.

Table: 3.2 Real Monsoon Onset & Monsoon Quality Interpretation Scheme

Onset Dates (Pentad number)	MECs	Monsoon Quality Index	MECs
> 42	5	> 0.015	5
$\geq 36 < 42$	4	$\geq 0.01 < 0.015$	4
$\geq 30 < 36$	3	$\geq 0.005 < 0.01$	3
$\geq 27 < 30$	2	$\geq 0.001 < 0.005$	2
< 27	1	< 0.001	1

3.4.3 Multi-temporal Data Summary

Multi- temporal database was developed for the five factors (AI, C, HGS, MQI and Ø). Classes were defined for each factor using quantitative definitions for the time series, 1950-2006, (Table 3.3a&b). The total possibility of occurrence of a class for each factor is assumed to be 100% and each classified pixel has a total proportion 100% for the entire factor over the 57 data years. Consequently, the pixel which acquires the identifiers, 4 and 5, at least 70% of the time, was classified as the best class, 5. Those with identifiers 4 and 5 at least 50% of the time and identifier 3 not less than 40% of the time, was classified class 4. Class 3 pixels were those with identifiers 4 and 5 not less than 20% of the time and identifier 3 not less than 50% of the time while class 2 pixels were those with identifiers 5, 4, and 3 not less than 40% of the time and identifier 2 not less than 40% of the time. Class 1 pixels have no identifiers 4 and 5 throughout the data years. Inversely, Onset and Monsoon quality index were classified as shown in Table 3.3b. These were used to produce the map of each (AI, C, HGS, *Ø* & MQI) factor.

Table: 3.3 Multi-temporal data summary and Interpretation Scheme

Factor Classification	Interpretation Basis (C, HGS, AI,)	Interpretation Basis(*Ø* & MQI)
5	$5\&4 \geq 70\%, 1,2,\&3 \leq 30\%$,	$1\&2 = 0, 3 \leq 20, 4 \geq 40 \& 5 \geq 40$
4	$5\&4 \geq 50, 3 \geq 40, 1\&2 \leq 20$	$1, 2 \&3 \geq 40, 4 \geq 40 \& 5 \leq 20$
3	$5\&4 \geq 20, 3 \geq 50, 2 \&1 \leq 30$	$1\&2 \geq 20, 3 \geq 50, 4 \&5 \leq 30$
2	$5, 4 \&3 \geq 40, 2 \geq 40 \& 1 \leq 20$	$1\&2 \geq 50, 3 \geq 40, 1\&2 \leq 20$
1	$5\& 4 = 0, 3 \leq 20, 2 \geq 40 \& 1 \geq 40$	$1\&2 \geq 70\%, 3,4,\&5 \leq 30\%$

3.5 Spatio-temporal Trend Analysis

The time series data summaries and ranks (1950-2006) for the five factors (AI, C, HGS, MQI and Ø) were subjected to trend analysis using decadal mean for the various classes. To reveal the dynamics of eco-climatic characteristics the rainfall series was subdivided into the decadal periods (1950-1959, 1960-1969……..2000-20006) these derived decadal sub means were ranked, classified and then transformed to point data. These were interpolated to surfaces and the eco-climatic characteristics map produced, for the various factors to assess changes occurring over time. The short-term (decadal) and long term changes (1960-2006) were identified for the moisture characteristics. Spatio-temoral MEC rate of change were used to determine the rate of desertification using rate of change as the ratio of the differences in value of the MECs during the period of study; the relative change in its aridity is as follows

$A_C = A_2/A_1$ 3. 11

A_C = Aridity change ratio

A_1= Aridity of initial date (Time)

A_2 = Aridity of later date (Time)

Then the year interval was identify as (Later date – initial date) 3. 12

And the growth rate of aridity is:

$A_2/A_1 = (1+r)^n$ 3. 13

Where r = annual growth

n = year interval

Converting this to logarithm format:

$\text{Log}\,(1+r) = \log A_2/A_1 / n$ 3.14

This is use to determine aridity rate in the belt.

The trend is confirmed using decadal image differencing (earlier minus later 1950-2000)

3.6 Vegetation Index Interpretation

The five classes of vegetation were defined numerically for the study as follows; as in 3.3.4 and Table 3.3

Table: 3.4 Vegetation Type and Interpretation Scheme

Vegetation Types	Vegetation Interpretation Scheme
Tall Tree /Grasses	5
Tree / Grasses	4
Scattered Trees / Shrub	3
Tough Isolated Trees/Shrub/bare ground	2
Bare Ground	1

Finally, all other parameters are point specific. Thus, vegetation biomass were extracted using the twelve synoptic meteorological stations location coordinate (Lat, Long). Subsequently vegetation point data were converted to spatial data using krigging geo-statistical module for interpolation to surface vegetation map.

3.7 Geo-Spatial identification of the Eco-Climatic Zones

A Geospatial database was developed using the above interpretation scheme for each of the five factors; rainfall effectiveness, onset (Ø), cessation dates (C), hydrologic growing season (HGS), Aridity Index (AI), and monsoon quality index (MQI) (table 3.1& 3.2). In addition, a geo-reference base map for the Sudano-sahelian zone was digitized and the point data was transformed to spatial data X, Y, Z (longitude, latitude and factor) using krigging geo-statistical defaults in SURFER 8 to produce an accurate grid of the base map. These were resampled using the spatial resolution of the image and imported into GIS environment (ArcGIS 9.2).The numerical MEC identifiers of each pixel for all the factors

(AI, C, HGS, Ø, MQI, &VI) were used to produce the factor map layers. These were input into an overlay module which will superimpose the whole factor in a GIS environment for further analysis using equation 10. The overlay was hinged on a theoretical basis which holds the values of the Aridity index, cessation, hydrologic growing season and vegetation index as directly proportional to eco-climatic zones while those for onset and MQI are inversely proportional to the quantitative character of the eco-climatic zones. This is expressed as:

$$ECZ = AI * VI * HGS * C / \O * \qquad 3.15$$

By implication the highest value was 625 for the best ECZ class and the least value was 0.04 for the lowest class. However, in reality the highest class for this analysis is 477.242 while the least is 0.202. As a result, the eco-climatic zones were ranked and interpreted as Wet, Humid, Sub- humid, Dry Sub-humid, and Semi Arid /Arid (wet, for the best class and Semi/Arid for the worst). The pixel which acquires the identifiers for ECZ class 5 has values equal to or greater than 350 and less than or equal to 477. Class 4 pixels were greater than 250 and less than 350 while, class 3 pixels were greater than 150 and less than 250. The class 2 values were greater than 50 and less than 150 and class 1 was all values less than 50. Also, the pixel values within each of the eco- climatic classes automatically take the value of the appropriate class identifier. These were used to delineate the final map showing the Eco-climatic zones (Table 3.5). Integrating these derived climatic parameters and remotely sensed data using GIS techniques provides fundamental basis for identifying, delimiting and describing the major types of eco-climatic conditions in quantitative time.

Table 3.5: Eco-climatic Class Interpretation Scheme

Eco-climatic Class	Eco-climatic Zones	Interpretation Scheme
5	Wet	$350 \leq ECZ \leq 477$
4	Humid	$250 \leq ECZ < 350$
3	Sub-humid	$150 \leq ECZ < 250$
2	Dry Sub-humid	$50 \leq ECZ < 150$
1	Semi Arid /Arid	$ECZ < 50$

3.8 Comparison of Eco-climatic and regional Map

Ileoje (1976)'s scanned and digitized regional climatic map visualize four climatic regions in Nigeria. The five eco-climatic zone features were extracted using contour lines to demarcate eco-climatic zones limit, and this was overlaid on the climatic region map to visualize the differences and similarities that exist between the two. In addition, information was extracted from other eco-climatic parameter maps (NIMET & CCCFR) for comparison with the derived eco-climatic parameter zones.

CHAPTER FOUR

4.0 RESULTS

4.1 Assessment of the Eco-climatic Characteristics

The derived eco-climatic characteristic index values for the entire factors (AI, C, HGS, MQI and Ø) in the Sudano-sahelian belt of Nigeria revealed climatic variability typical of the rainfall distribution in the zone figure (4.1- 4.5). These factors Moisture Effectiveness Index (MEI) captured moisture stress of the sub-humid and dry ecosystem at different levels, such that the qualities of the biological and economic resources uncertainties are apparent. Cessation index value ranges from 2.4 - 5.0, HGS index varies from 1.0 -5.3 and AI index progresses from 0.82 – 4.9 while, Onset index values depreciated from 1.7- 4.9 and MQI from 0.2 - 4.8 (as the index rises, the moisture effectiveness decrease). Principally, krigging geo-statistical interpolation technique to surfaces revealed that interpolation generally connects occurrences of the same property or generate pattern of events that are functionally or casually related.

4.1.1 Cessation Moisture Effectiveness

Figure 4.1 presents the index that depicts the cessation moisture effectiveness typical of the northern Nigeria; the value ranges from 2.4 – 5.0

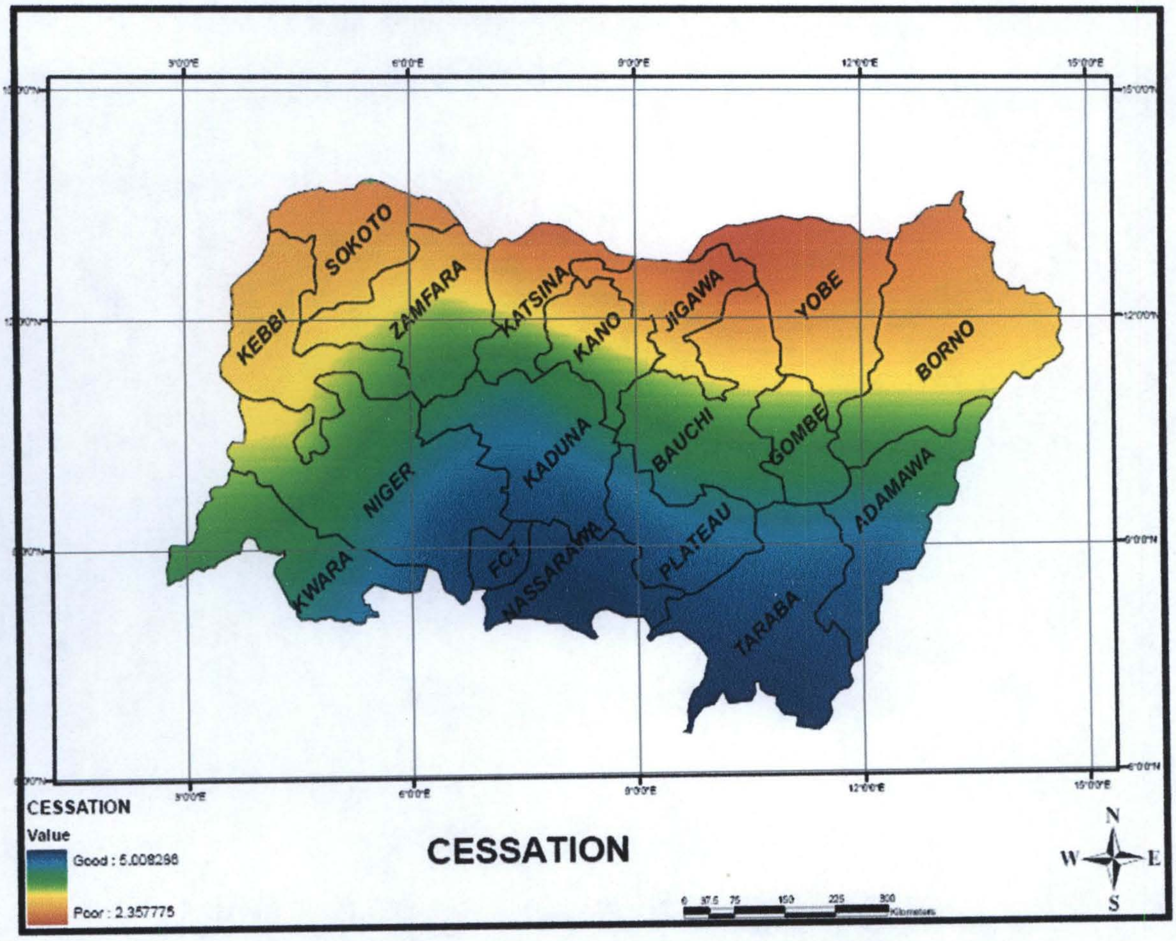


Fig. 4.1 Cessation Moisture Effectiveness Index

4.1.2 Hydrologic Growing Season Moisture Effectiveness

Figure 4.2 illustrates the moisture effectiveness variability that characterize the hydrologic growing season in northern region; HGS index varies from 1.0 -5.3

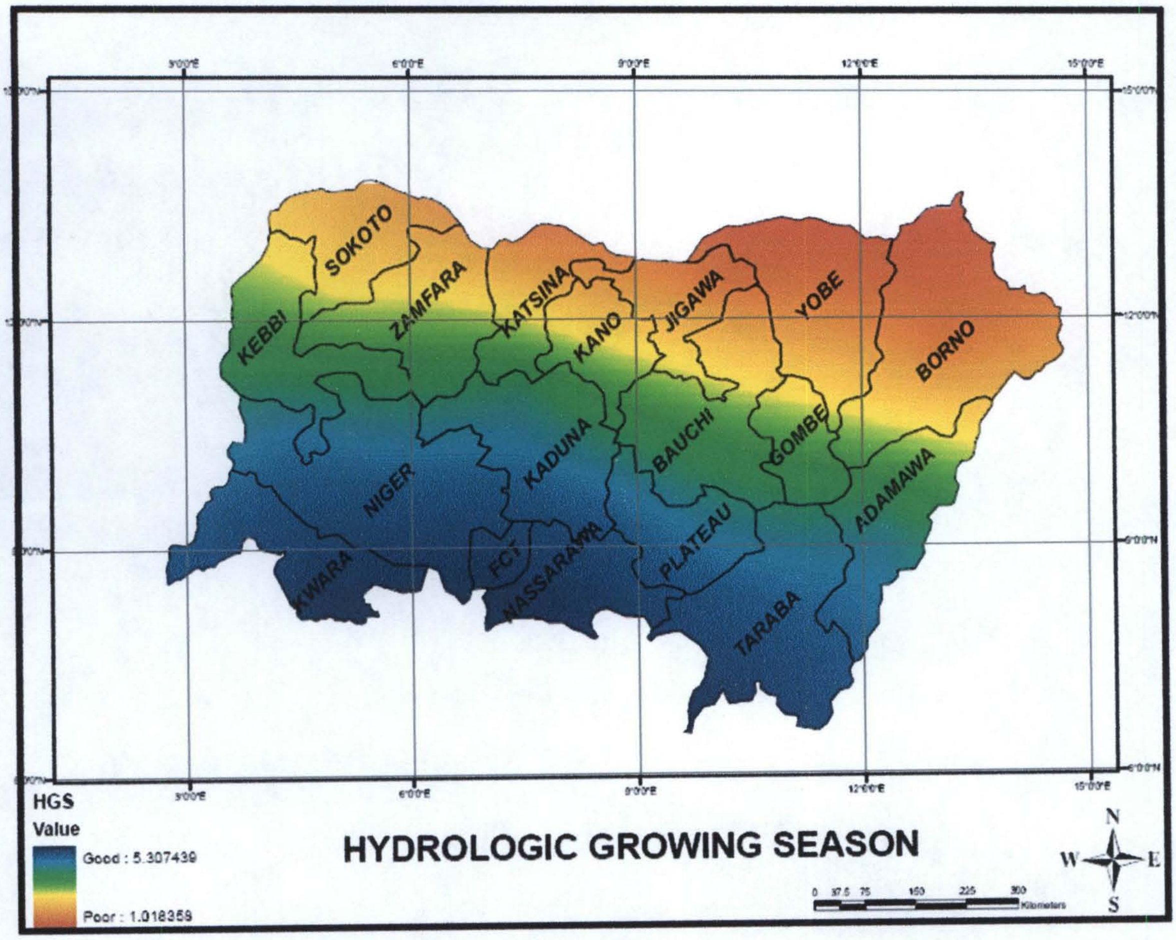


Fig. 4.2 Hydrologic Growing Season Moisture Effectiveness Index

4.1.3 Aridity Index Moisture Effectiveness

Aridity intensified gradually northwards showing moisture stress across the region (fig.4.3); the value progresses from 0.82 – 4.9

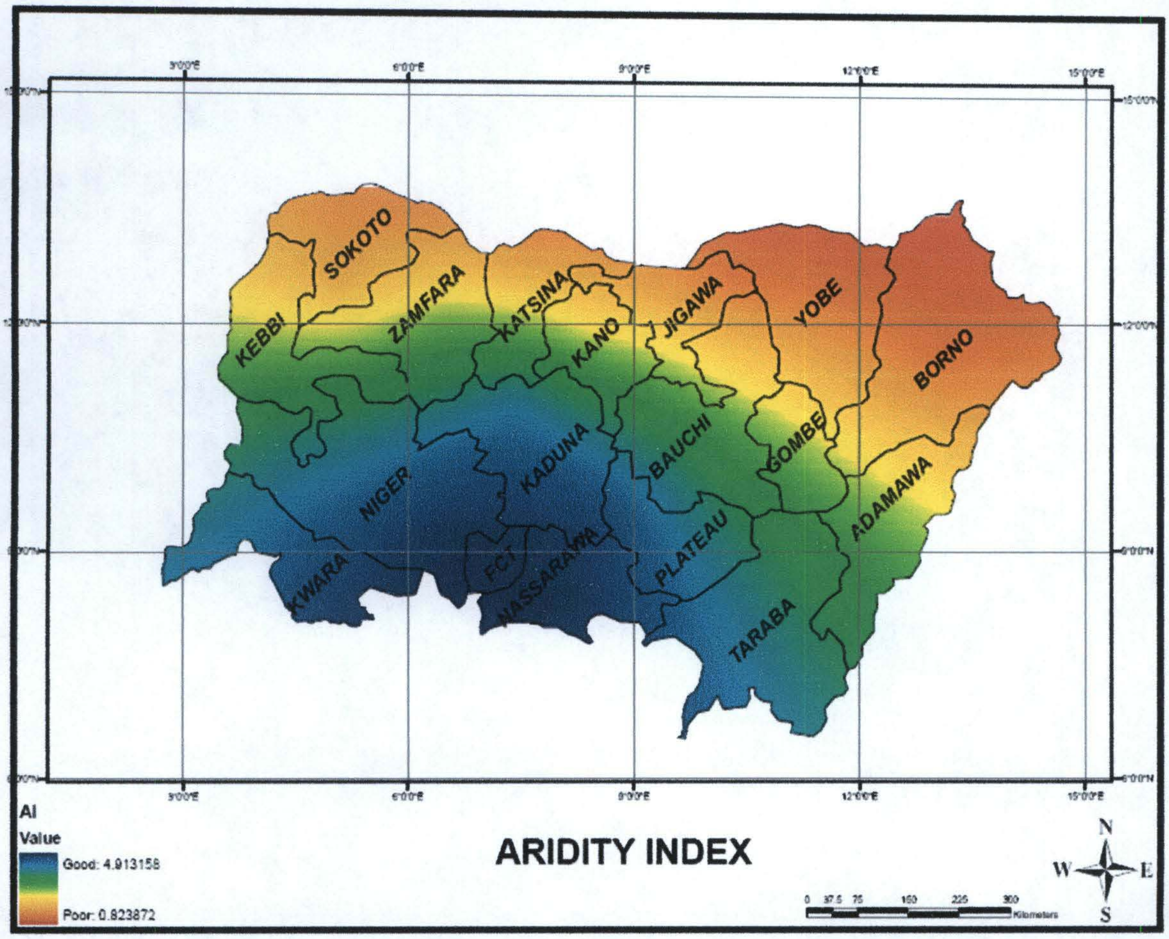


Fig. 4.3 Aridity Moisture Effectiveness Index

4.1.4 Real Monsoon Onset Moisture Effectiveness

The index reveals the severity of rainfall onset moisture effectiveness that is typical of the entire study area as the earliest Real Monsoon Onset (1) is not portrayed. Onset index values ranges from 1.7- 4.9

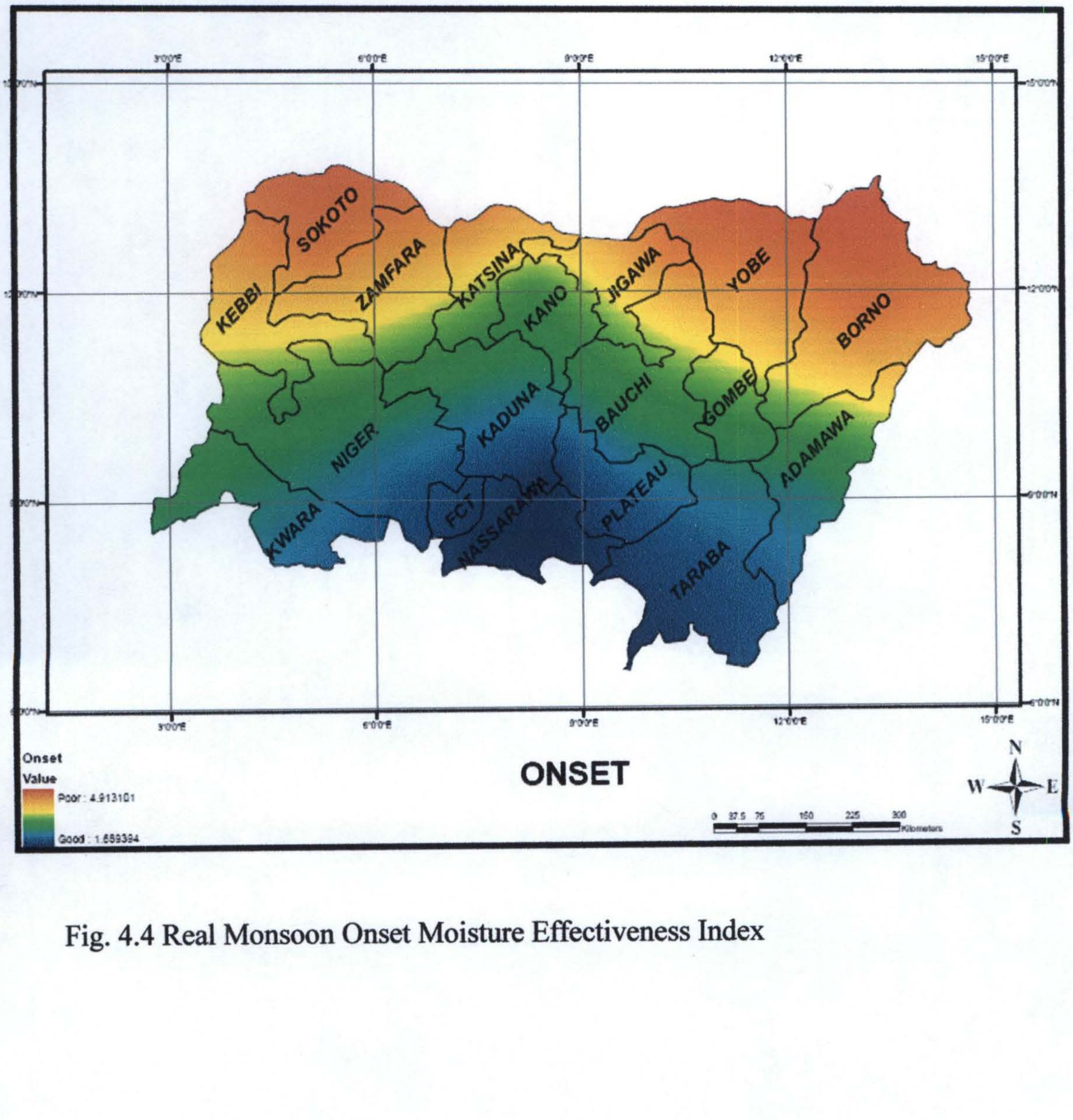


Fig. 4.4 Real Monsoon Onset Moisture Effectiveness Index

4.1.5 Monsoon Quality Moisture Effectiveness

Figure 4.5 explains the variability that characterized the moisture quality in northern Nigeria as MQI values varies from 0.2 - 4.8

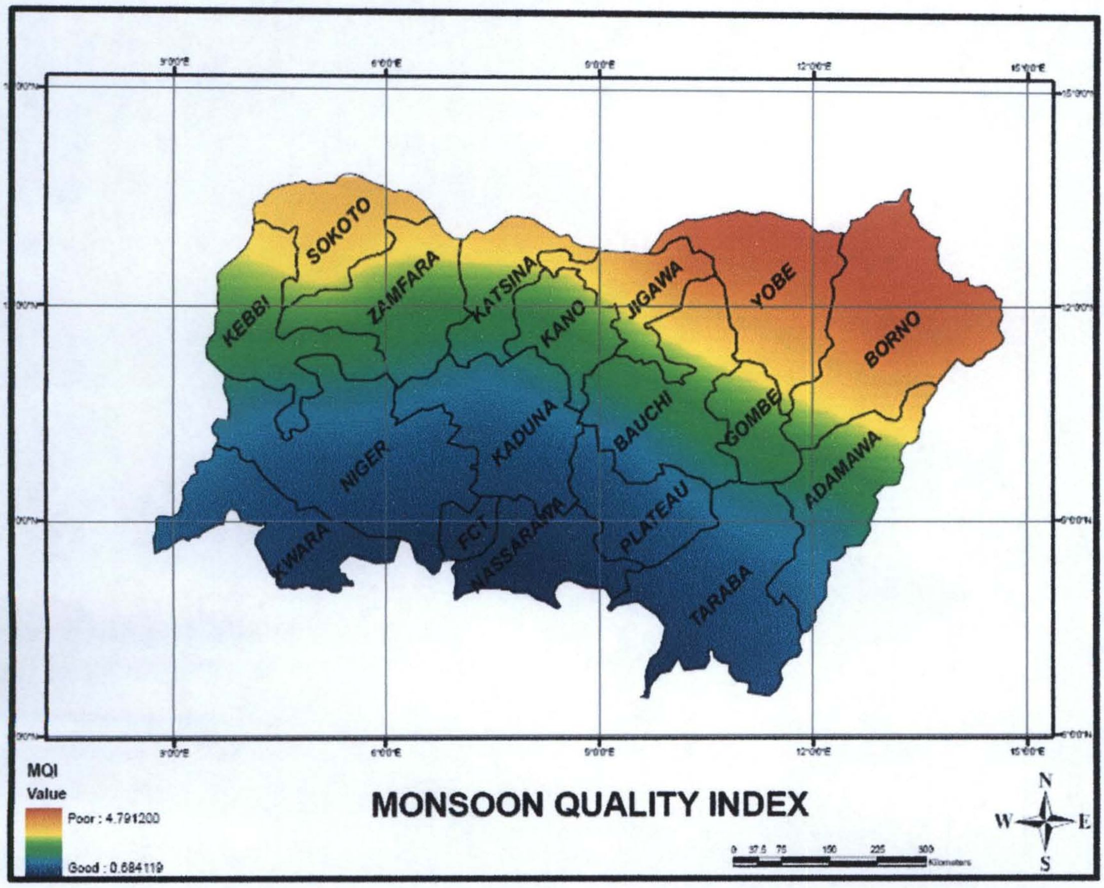


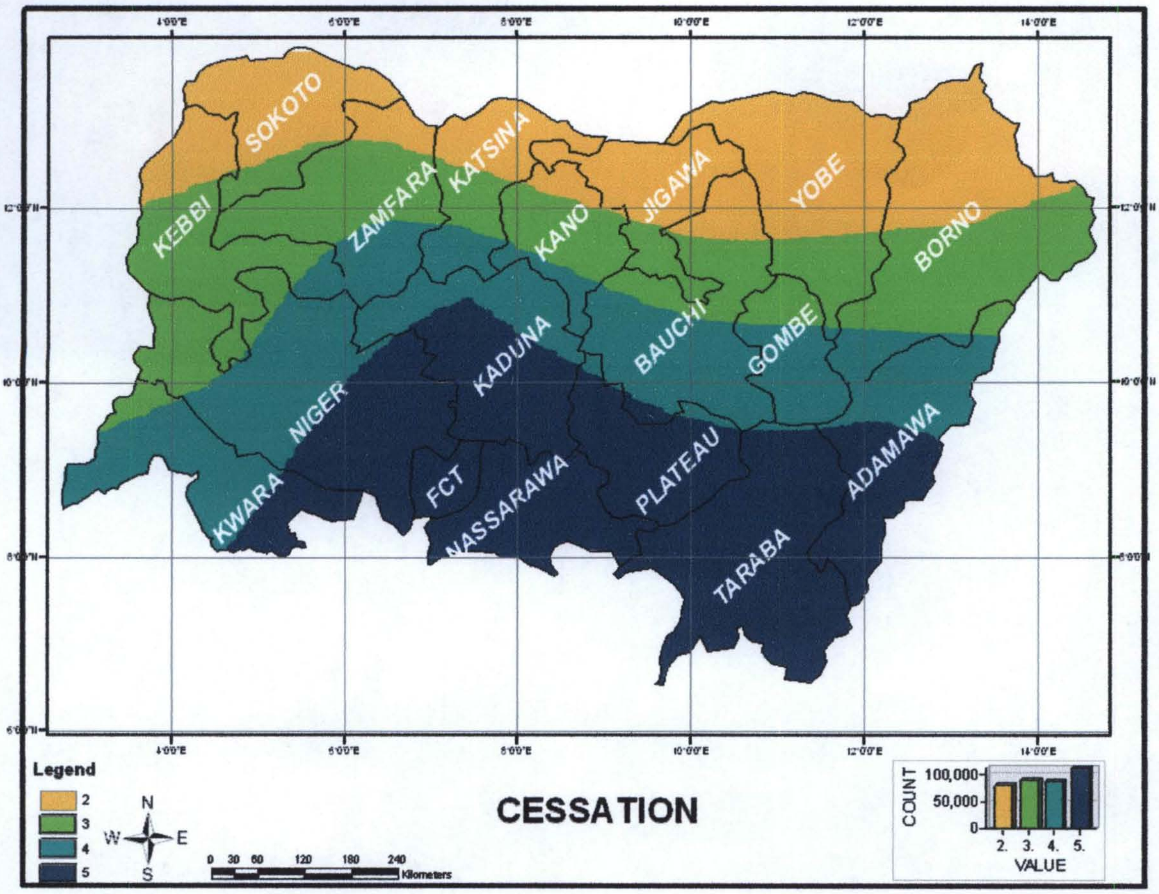
Fig. 4.5 Monsoon Quality Moisture Effectiveness Index

4.2 RECLASSIFICATION OF MOISTURE EFFECTIVENESS INDICES

The surface index maps were quantitatively reclassified, to depict the spatial extent of the eco-climatic factors Moisture Effectiveness Zones (MEZs). Five or four MEZs were identified for all the factors and the moisture effectiveness generally decreases north wards. In addition, there is variability in the number MEZs captured; AI, HGS, MQI capture five MEZs while onset and cessation captured four classes each. Onset map uncover the late effective onset of rain that characterized the region, as there was no earliest onset rainfall zone while cessation does not indicate extremely early rainfall cessation in the zone. Furthermore, these derivative maps show the extent of each MEZ for each factor; the worst classes are dominant to extreme north while the best are to the south and the central parts are mostly moderate Fig.(4.6 - 4.10).

4.2.1 Cessation Moisture Effectiveness Map

Cessation moisture effectiveness map identified four moisture effectiveness zones; Latest, Late, Early and Very Early cessation zones.

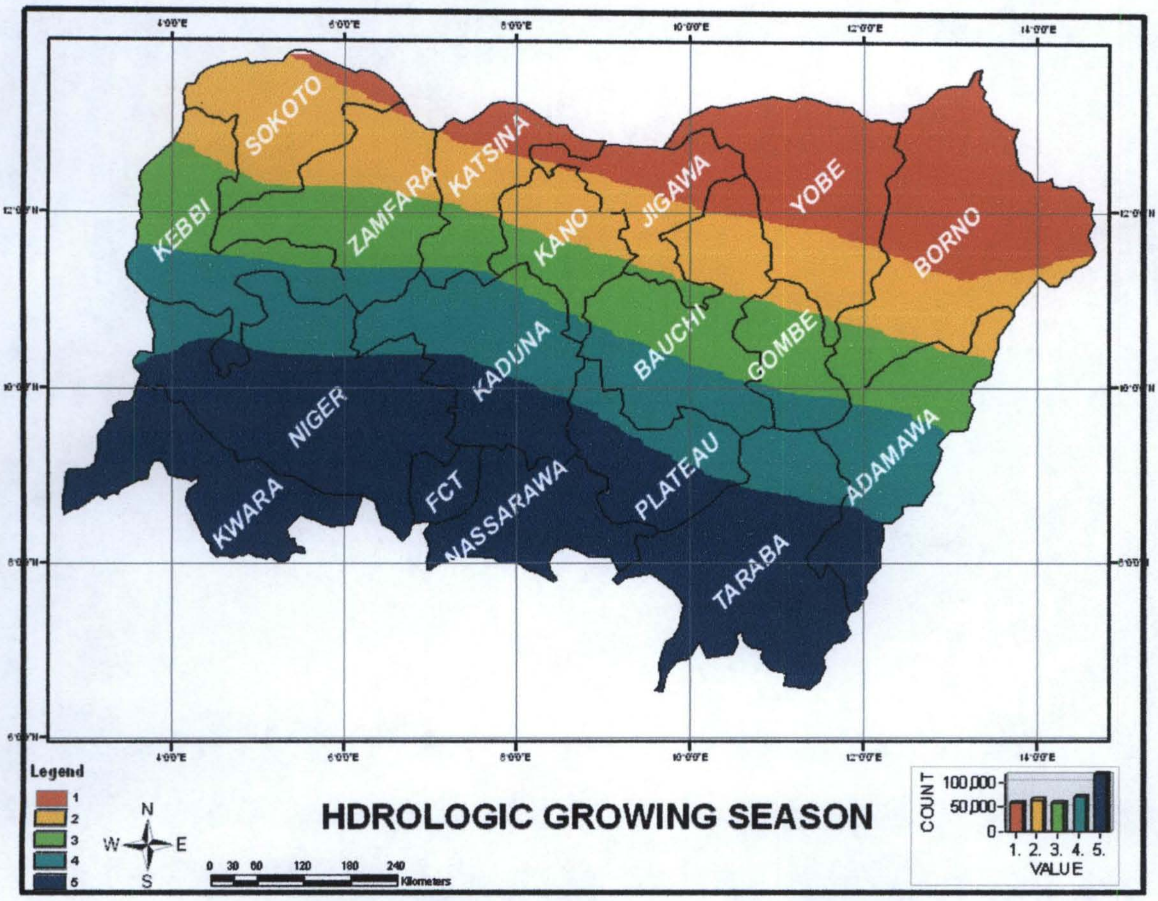


5, 4, 3, 2 = Latest, Late, Early &Very Early

Fig. 4.6 Cessation Moisture Effectiveness Zones

4.2.2 Hydrological Growing season Moisture Effectiveness Map

This captured five moisture effectiveness zones; Longest, Long, Short, very Short and Extremely Short hydrological growing season.

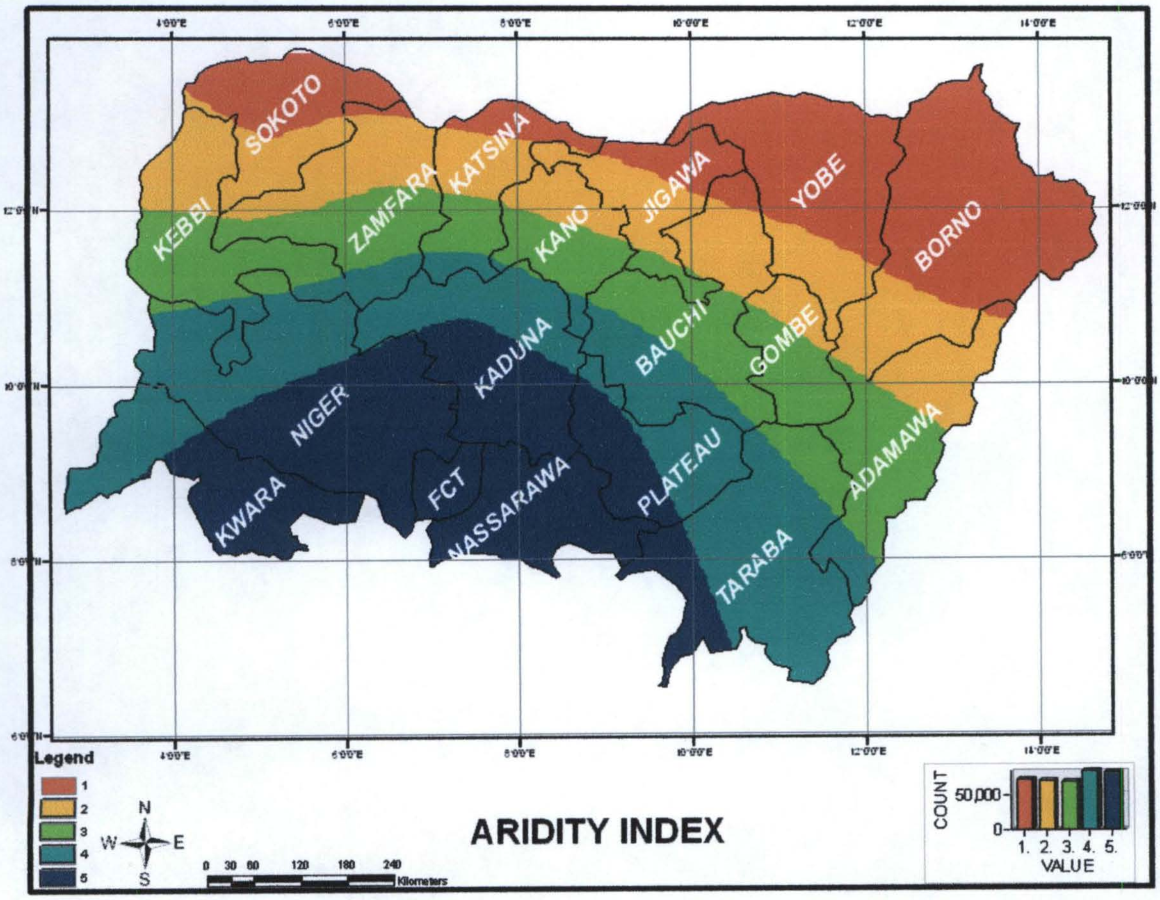


5, 4, 3, 2, & 1 = Longest, Long, Short, Very Short, Extremely Short HGS

Fig. 4.7 Hydrologic Growing season Moisture Effectiveness Zones

4. 2.3 Aridity Index Moisture Effectiveness Map

Similarly, Aridity Index recognized five moisture effectiveness zones across the belt;, , Lowest, Low, High, Very High and Extremely high (Fig. 4.8).

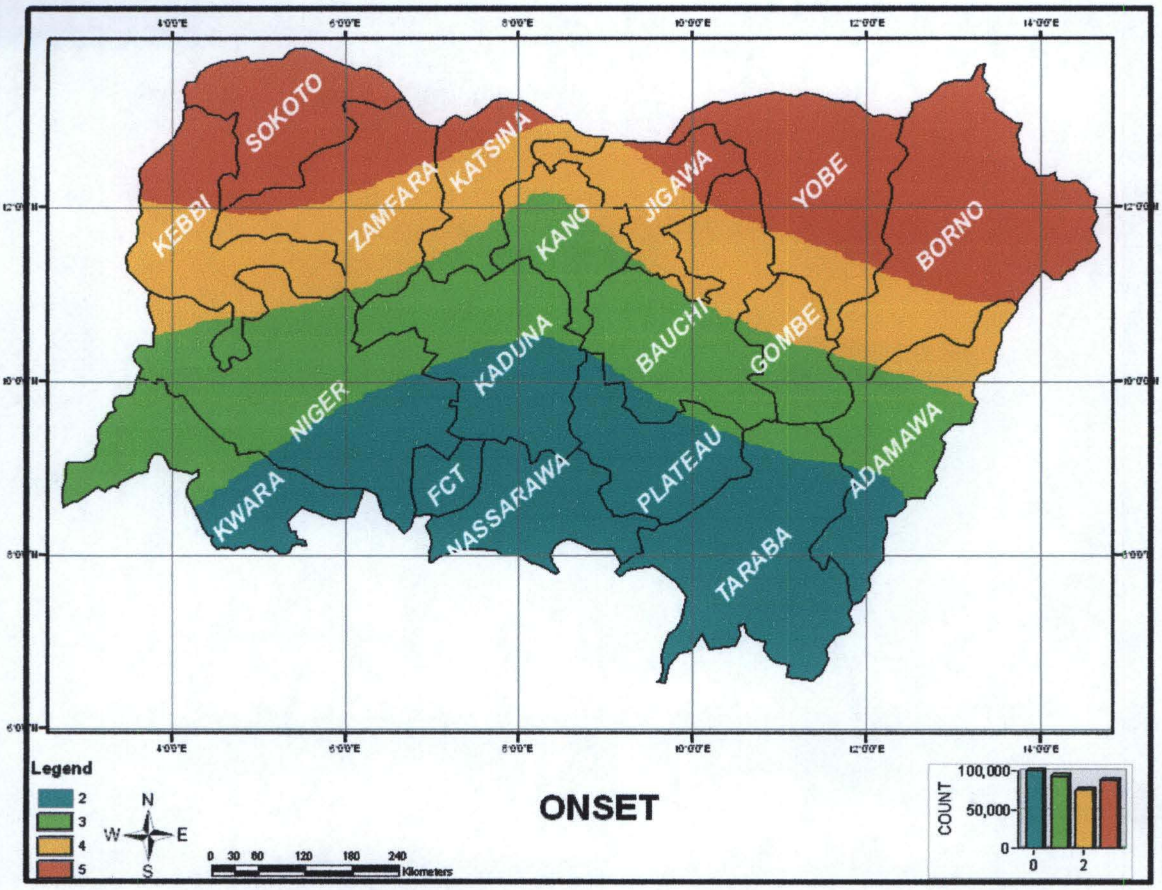


5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig. 4.8 Aridity Index Moisture Effectiveness Zones

4. 2.4 Real Monsoon Onset Index Moisture Effectiveness Map

Real monsoon onset effectiveness map depicted four moisture zones; Extremely Late, Very Late, Late and Early (Fig.4.9) indicating the severity of rainfall onset across the region.

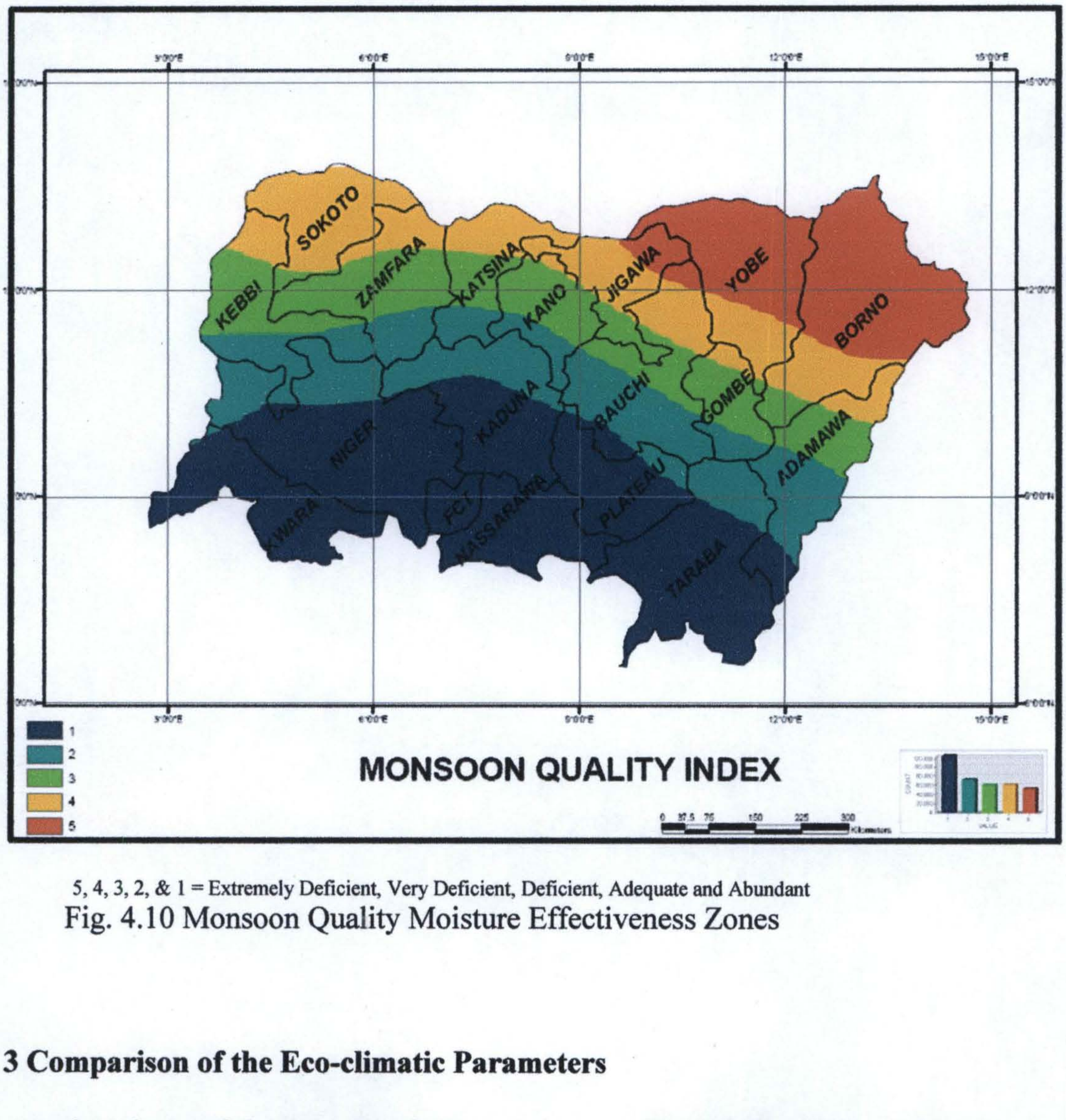


5, 4, 3, 2, & 1 = Extremely Late, Very Late, Late, Early & Earliest

Fig. 4.9 Real Monsoon Onset Moisture Effectiveness Zones

4. 2.5 Monsoon Quality Moisture Effectiveness Map

This portrayed five MQI zones; Extremely Deficient, Very Deficient, Deficient, Adequate and Abundant moisture effectiveness zones (Fig.4.10)



5, 4, 3, 2, & 1 = Extremely Deficient, Very Deficient, Deficient, Adequate and Abundant

Fig. 4.10 Monsoon Quality Moisture Effectiveness Zones

4. 3 Comparison of the Eco-climatic Parameters

Comparing the spatial extent the factors moisture effectiveness using multiple bar graph (fig. 4.11), unveiled the variability that exist within the spatial extent of the factors MEZs. As AI, C, HGS, Ø & MQI shows variability relative to one another in terms spatial extent of each factor MEZs. Thus, illustrating the variability in the spatial extent of each factor's MEZs.

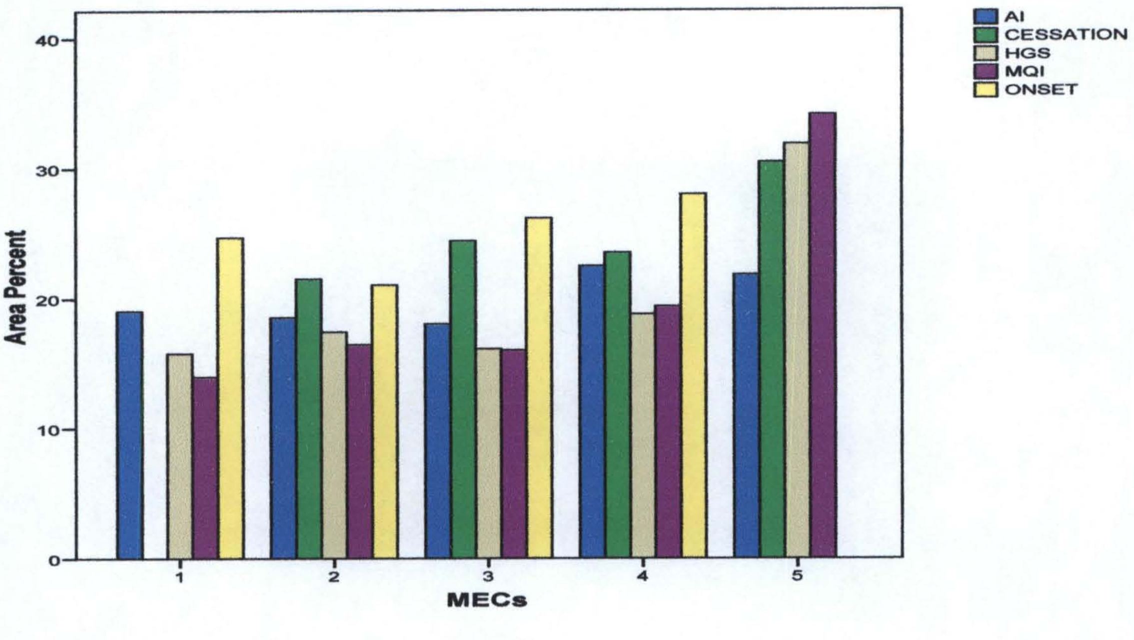


Fig. 4.11 Eco-climatic Factors MEZs Comparison

4.3.1 Eco-climatic Factors Pearson Correlation Relationship

Despite the observed variability, comparison between the figures revealed an inference of certain relationships between the factors. Pearson product moment correlation coefficient confirms positive relationship (0.5 - 0.99) at 0.05 significant level exist between the entire factors (Table 4.1)

TABLE 4.1 Eco-climatic Factors Pearson Correlation Relationship

Eco-climatic Factors	Relationship
Aridity Index / Hydrologic Growing Season	0.6
Aridity Index / Cessation	0.5
Aridity Index / Monsoon Quality Index	0.7
Aridity Index / Onset	0.8
Cessation / Hydrologic Growing Season	0.9
Cessation / Monsoon Quality Index	0.9
Cessation / Onset	0.5
Hydrologic Growing season / Monsoon Quality Index	0.99
Hydrologic Growing season / Onset	0.8

4.3.2 Principal Component Analysis

Principal Component Analysis (PCA), identified the union that exists between the two extreme MECs (The best and worst) although, the intersection shows the relationship that exists between all the factors as indicated in the overlap of the intermediate classes signalling the fact that additional techniques is essential for the identification and delineation of these middle classes (Fig.4.12).

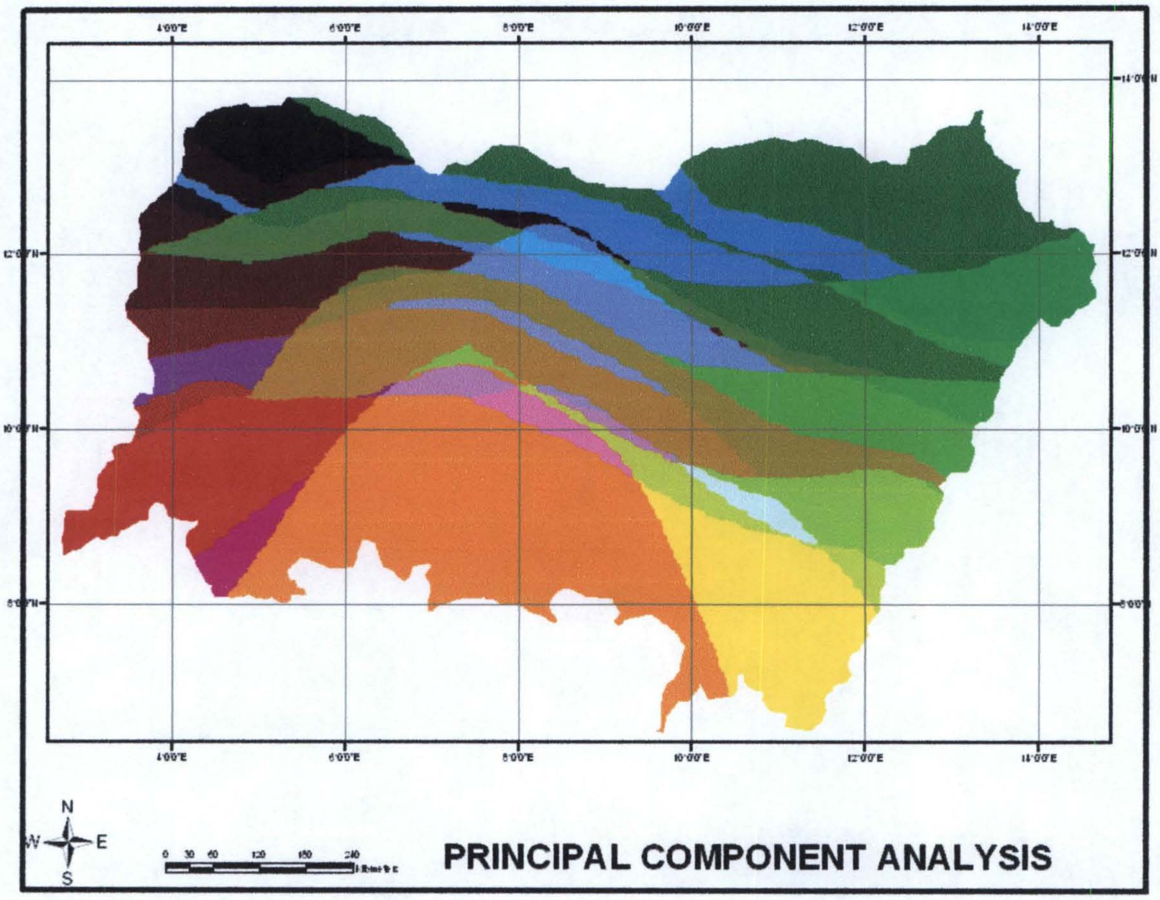


Fig. 4.12: Principal Component Analyses

4.3.3 Moisture Effectiveness Map

The intersections of the various factors' MEZs serve as basis for integration and reclassification of the PCA to derive Moisture Effectiveness Maps (MEM). Supervised classification of the PCA identified five MEZs; extremely deficient, very deficient, deficient, adequate and abundant moisture zones as evident in figure 4.13.

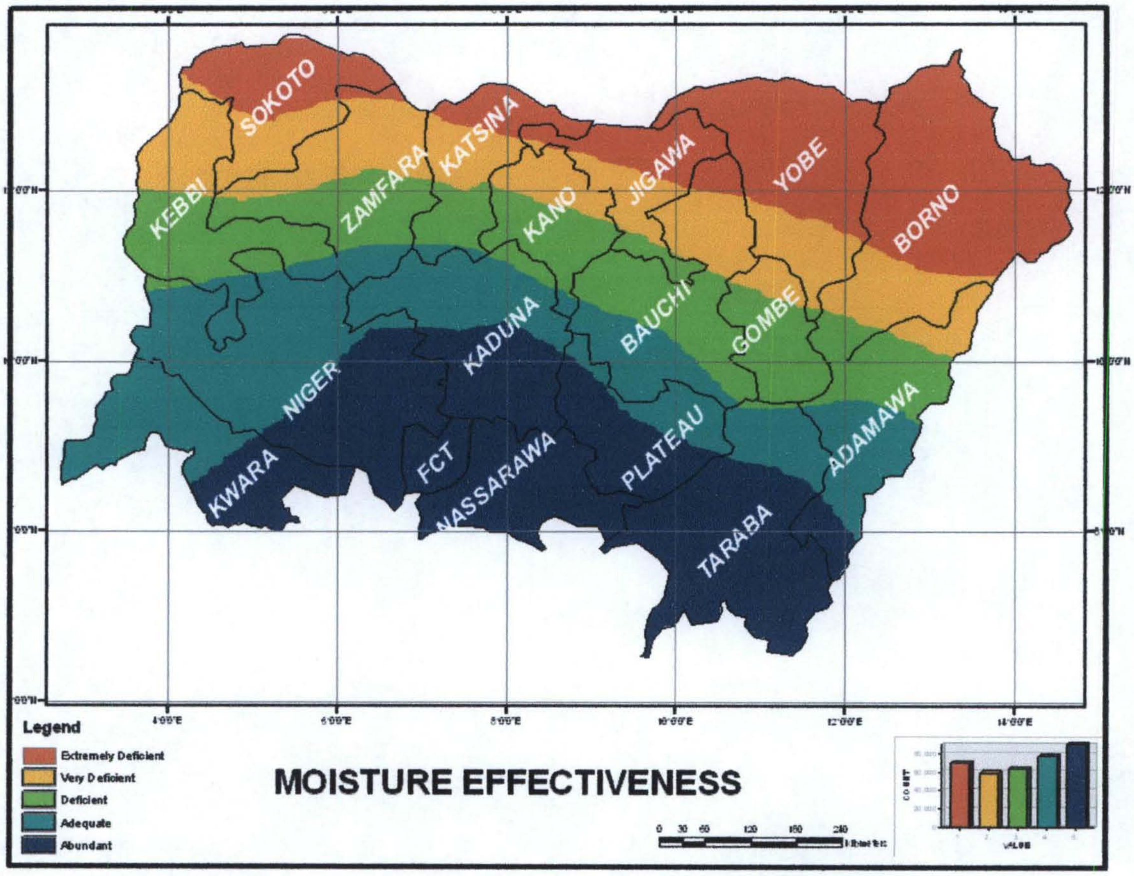


Fig. 4.13: Moisture Effectiveness Map

4.3.4 Relationships between Moisture Effectiveness Map and Eco-climatic Factors

An investigation of the relationship that exist between MEM and the various eco-climatic factors shows that there is positive to positive perfect relationship between them at 0.05 significant level (Table 4.2). Also the regression analysis confirms that the MEM is a good predictor of the dependent variable since R square change is 0.9 that is 90% of MEM can be explained by the factors. The result was complemented by Pearson correlation analysis linking the entire factors to derive eco- climatic characteristics map.

TABLE 4.2 Pearson Correlation Relationships between Moisture Effectiveness Map and Eco-climatic Factors

Eco-climatic Factors	Relationship with MEM
Aridity Index	0.8
Cessation	0.9
Hydrologic Growing season	0.9
Onset	0.8
Moisture Quality Index	0.9

The MEM identified five moisture effectiveness zones; extremely deficient, very deficient, deficient, adequate and abundant. Abundant moisture zone comprises, FCT, Nassarawa and southern part of Kwara, Niger, Plateau, Taraba and Kaduna States. Adequate Moisture zone encompasses Northern Kwara, Niger, Plateau, Taraba and Kaduna State and southern Bauchi and Adamawa States. Deficient moisture zone covers Northern Bauchi and Adamawa States, southern Gombe, Kebbi , Zamfara and Kano States. Very deficient moisture zone is characteristic of northern Gombe, Kebbi , Zamfara and Kano States in addition to southern Sokoto, Katsina,Jigawa, Yobe and Borno States. The Extremely deficient moisture zone is a quality of the extreme north.

4.4 Spatio-temporal Trend Analysis

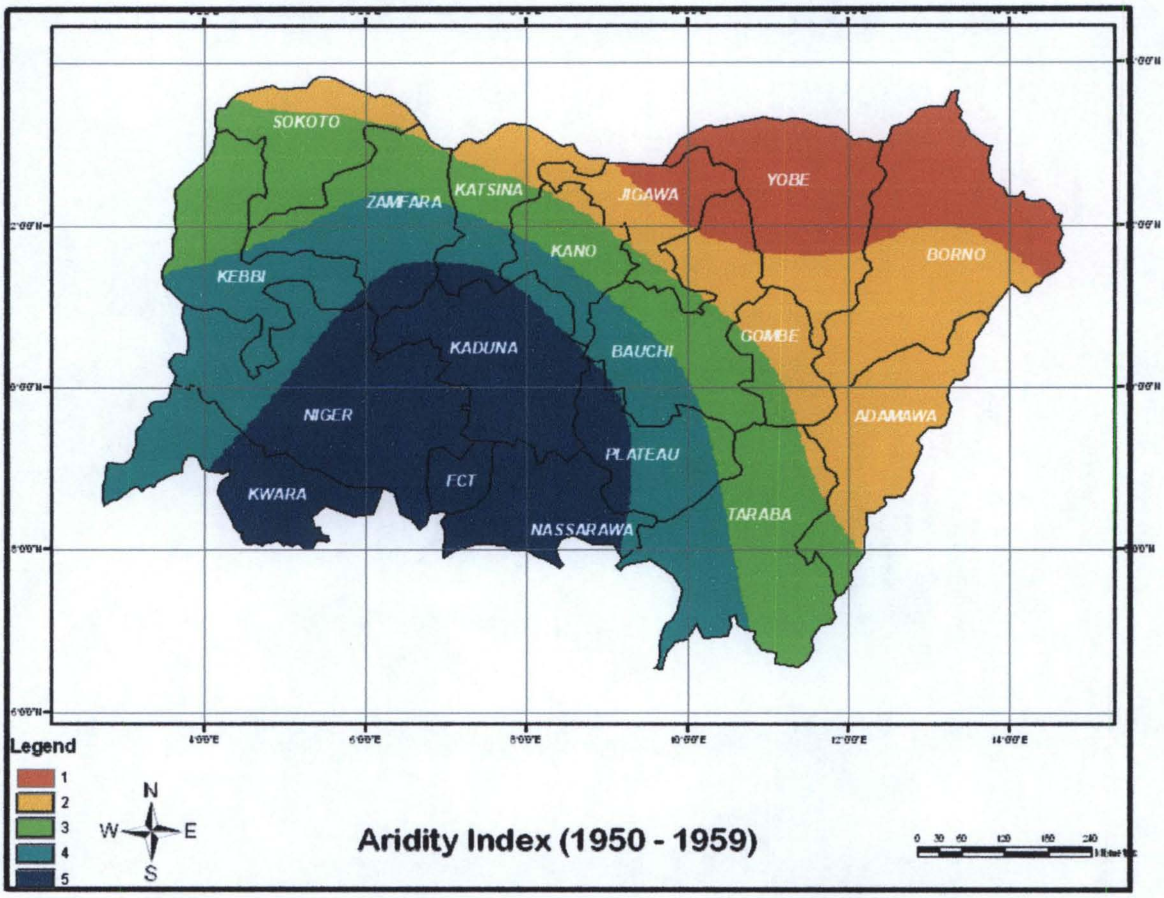
Trend analyses of all the factors provide fundamental evidence of drastic ecological changes experienced in the Sudano-sahelian belt of Nigeria (fig 4.14 - 4.48). These surface maps portray the moisture effectiveness and spatial ecological degradation throughout the decades particularly, during the drought decades.

4.4.1 Spatio-temporal Aridity Index Trend

The 1950s, 1960s, 1990s & 2000s, decadal aridity index maps indicate five classes with variability in the spatial extent of MEZs. In the 1950s, extreme north east about longitude 10^0E to 14^0E and roughly areas above latitude 12^0N was a zone of extremely high aridity. North of Sokoto and Katsina States extending to vast areas south of this extreme aridity zone; Gombe, Southern Borno, Jigawa and Adamawa State was a very high aridity zone. South of this is a zone of high aridity and the central and parts of southern States Kwara, Niger, Kaduna, F. C. T, Nassarawa and plateau States were zones of either low and lowest aridity (Fig.4.14).

4.4.2 Aridity Index 1950s Decadal MEZs

The 1950s aridity index decadal map identified five moisture effectiveness zones; lowest, low, high, very high and extremely high (Fig.4.14).

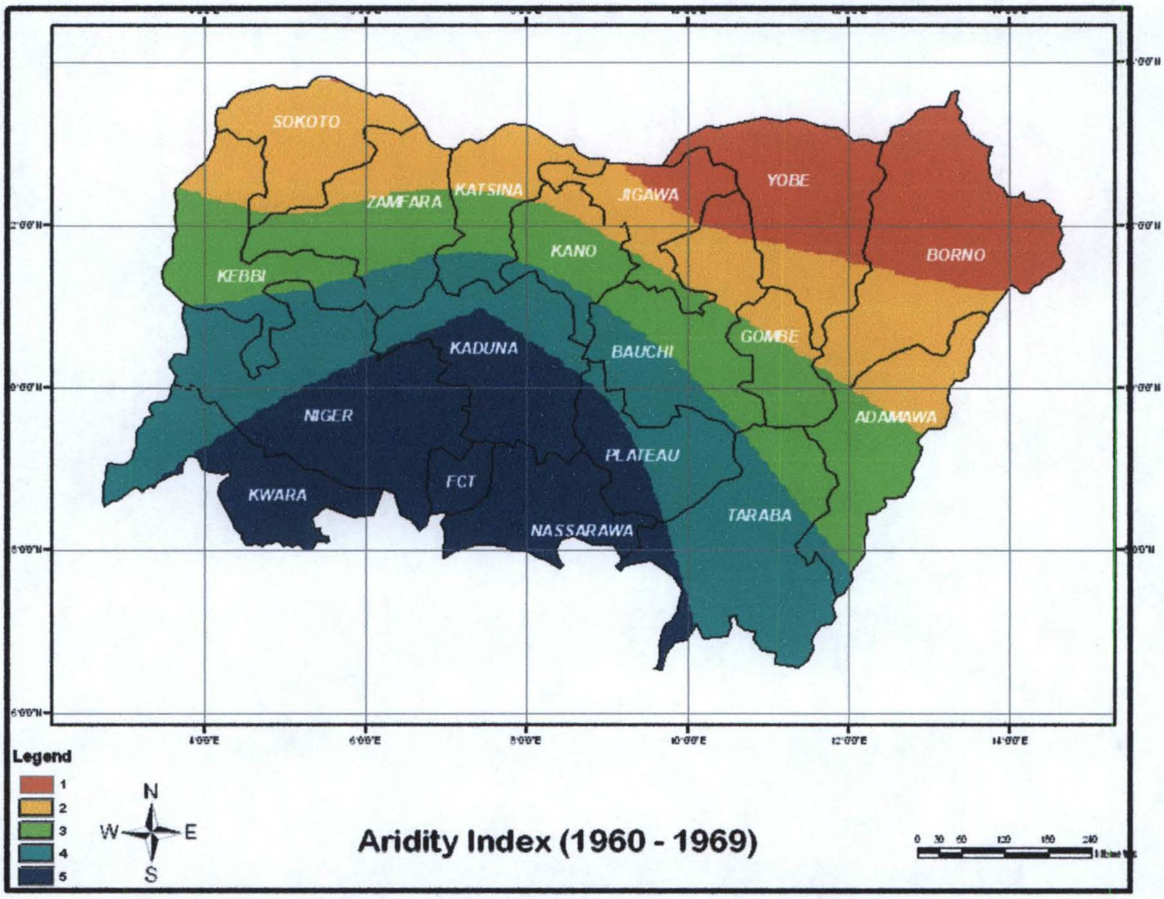


5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig. 4.14: 1950s Decadal Aridity Index MEZs

4.4.3 Aridity Index 1960s Decadal MEZs

Similarly, 1960s moisture conditions portrays gradual intensification of moisture stress across the MEZs; extremely high aridity condition extending to about Lat 11^0N 24^1, very high aridity condition had spread across entire Sokoto State, part of Zamfara, Katsina and Jigawa States. Areas of low and lowest aridity had declined slightly; indicating short term changes and south ward shift of the moisture stress zone (Fig. 4.15).

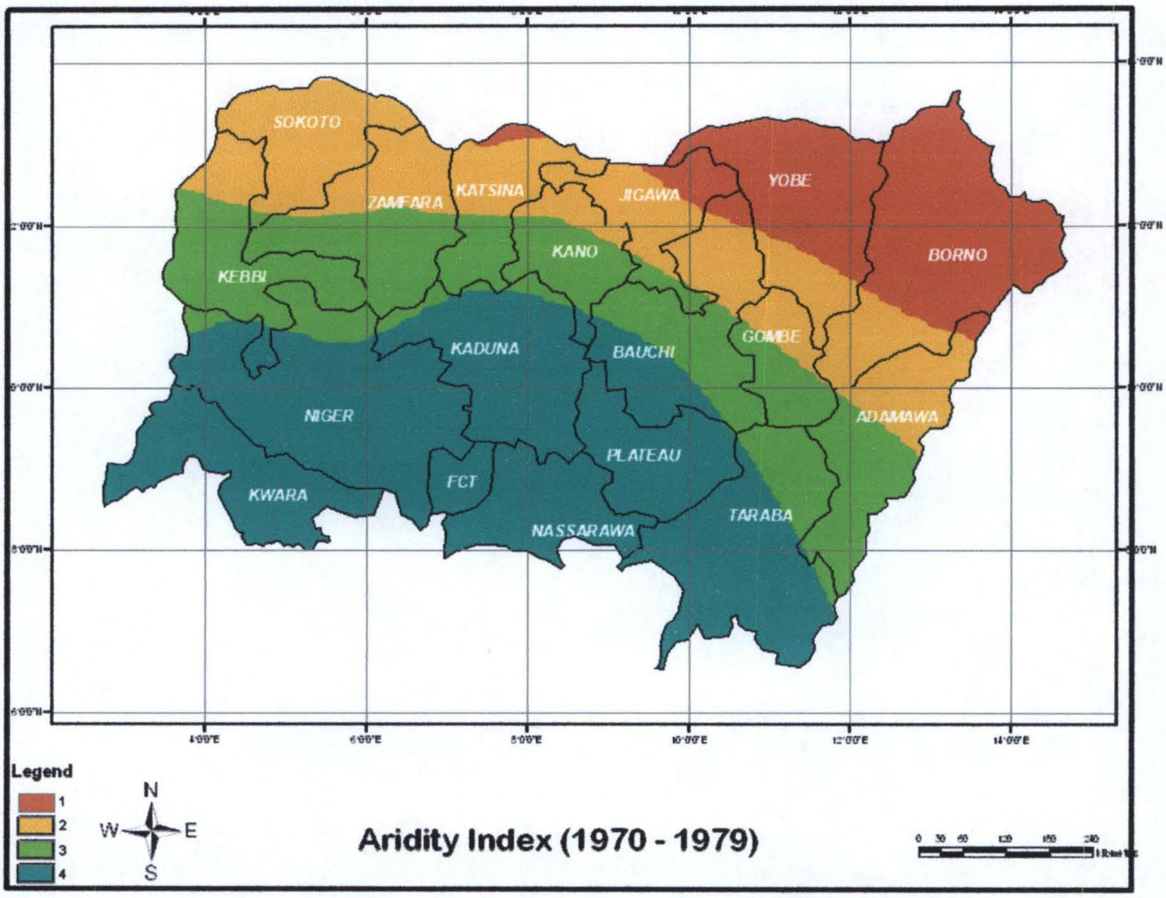


5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig.4.15: 1960s Decadal Aridity Index MEZs

4.4.4 Aridity Index 1970s Decadal MEZs

The 1970s aridity index decadal map reveals the disappearance of lowest aridity zone hence, four moisture aridity zones were captured; low, high, very high and extremely high. Generally, drastic moisture stress was evident of drought decades, with the disappearance of the lowest aridity zone coupled with the increase in areas of high, very high and extremely high aridity moisture zones (Fig. 4.16).

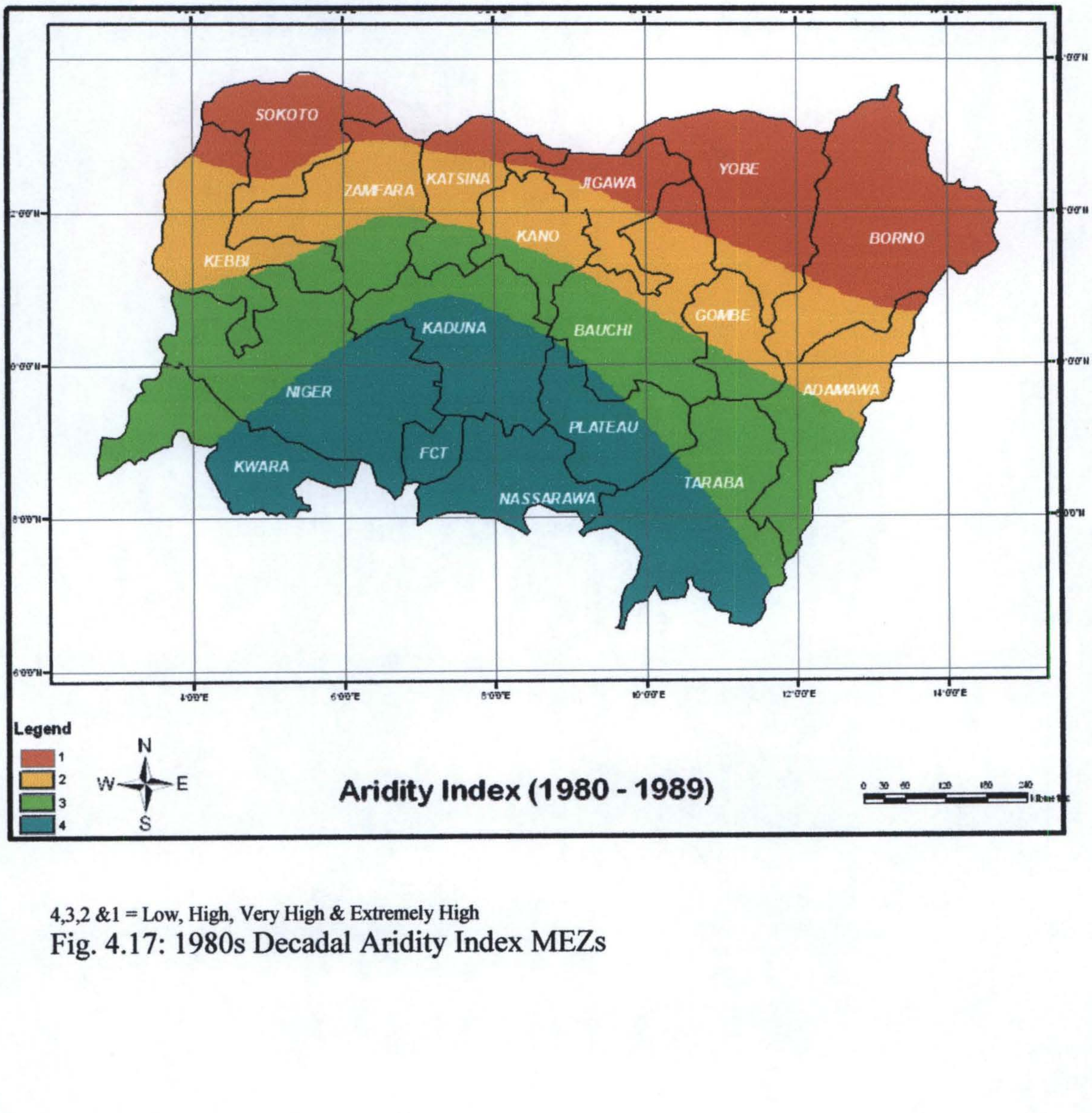


4,3,2 &1 = Low, High, Very High & Extremely High

Fig. 4.16: 1970s Decadal Aridity Index MEZs

4.4.5 Aridity Index 1980s Decadal MEZs

Figure 4.17 shows that the drastic moisture stress appreciated in the 1980s; the low aridity moisture zone decreased significantly and was only limited to the south. The high and very high aridity moisture zones extended southward, while the extremely high aridity moisture zone extended to south west covering parts of Sokoto, Katsina and Jigawa States (Fig. 4.17). Thus medium-term changes were apparent.

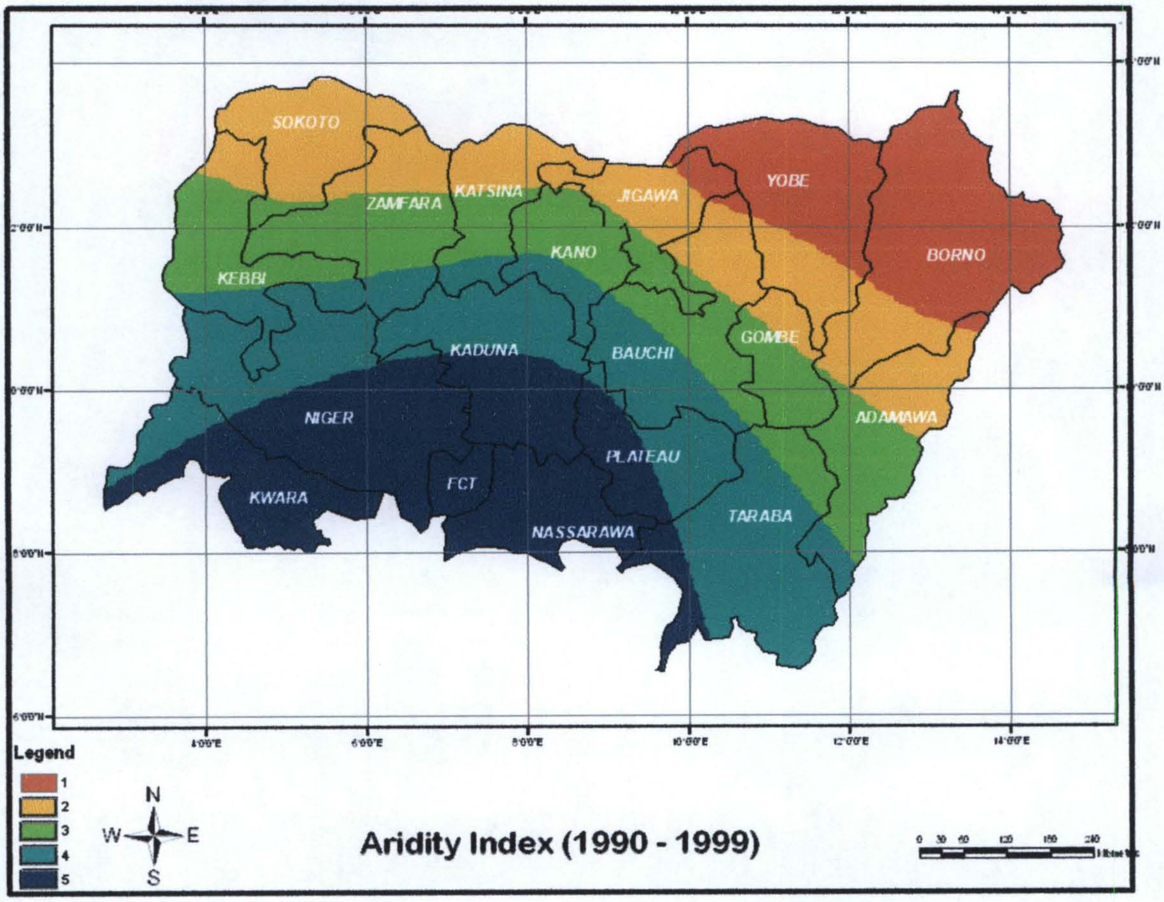


4,3,2 &1 = Low, High, Very High & Extremely High

Fig. 4.17: 1980s Decadal Aridity Index MEZs

4.4.6 Aridity Index 1990s Decadal MEZs

The moisture Effectiveness appreciated generally in the 1990s and 2000s and the five moisture classes were captured. As a result, the lowest and low aridity moisture zones were evident and skewed to the south west and the central portions. However, the extremely high aridity moisture zones extended to about Lat 10^0N 40^1 and 10^0N in the 1990s and 2000s respectively. Areas of very high and high aridity moisture conditions spread southwards (Fig. 4.18 & 4.19).

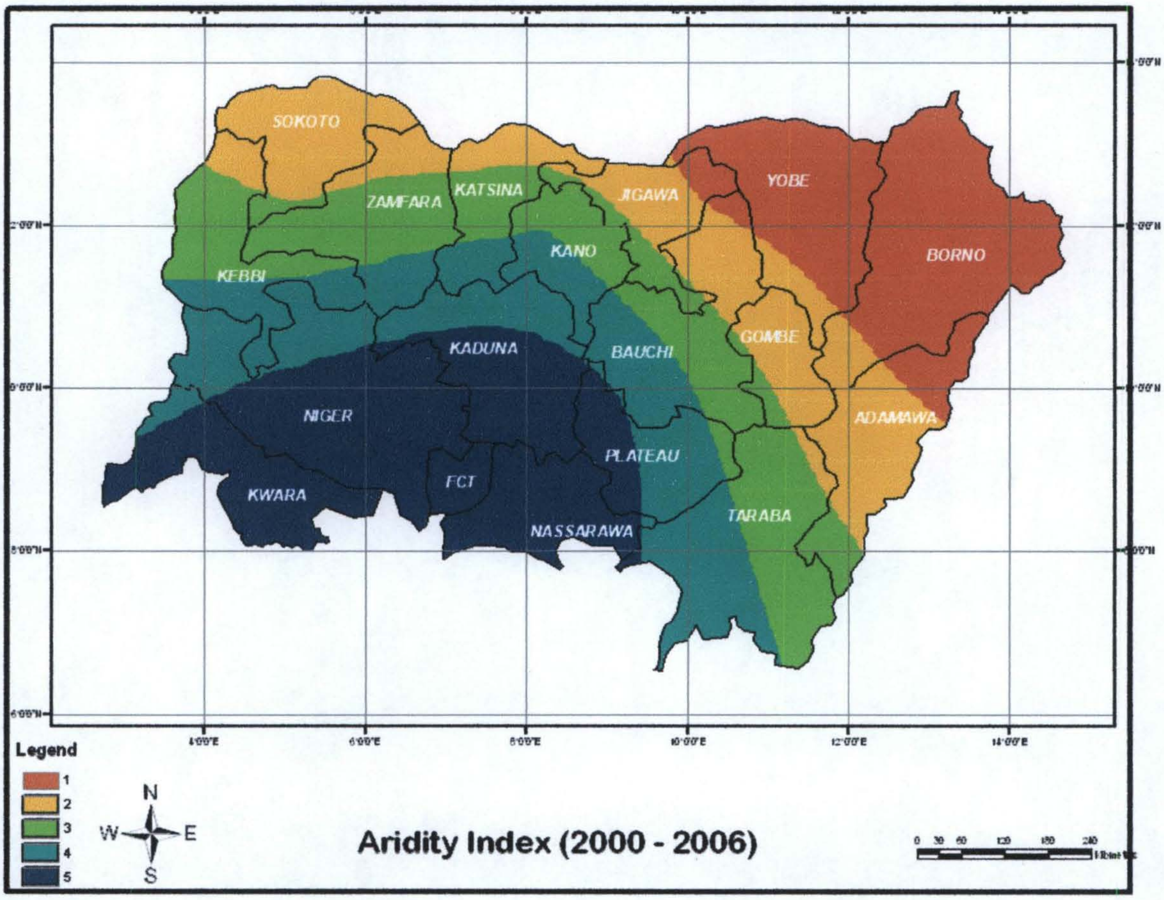


5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig. 4.18: 1990s Decadal Aridity Index MEZs

4.4.7 Aridity Index 2000s Decadal MEZs

Similarly, in the 2000s decade moisture appreciation persists however; the entire northeast is characterized by extremely high aridity zone. Also, long-term changes are apparent in the spread of high, very high and extremely high MEZs as well as decline in areas low and lowest aridity between 1950s and 2000s (fig.4.14 & 4.19).



5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig. 4.19: 2000s Decadal Aridity Index MEZs

4.4.8 Aridity Index Decadal Moisture effectiveness Zones Comparison

An assessment of the spatial areal coverage for the MEZs of the six decades confirms the variability in decadal moisture effectiveness. Moisture degradation intensified gradually in the earlier decades in response to short - term changes and drastically in the middle decades (1970s and 1980s) and Long term moisture stress is evident between 1950s and 2000s (Fig.4.20).

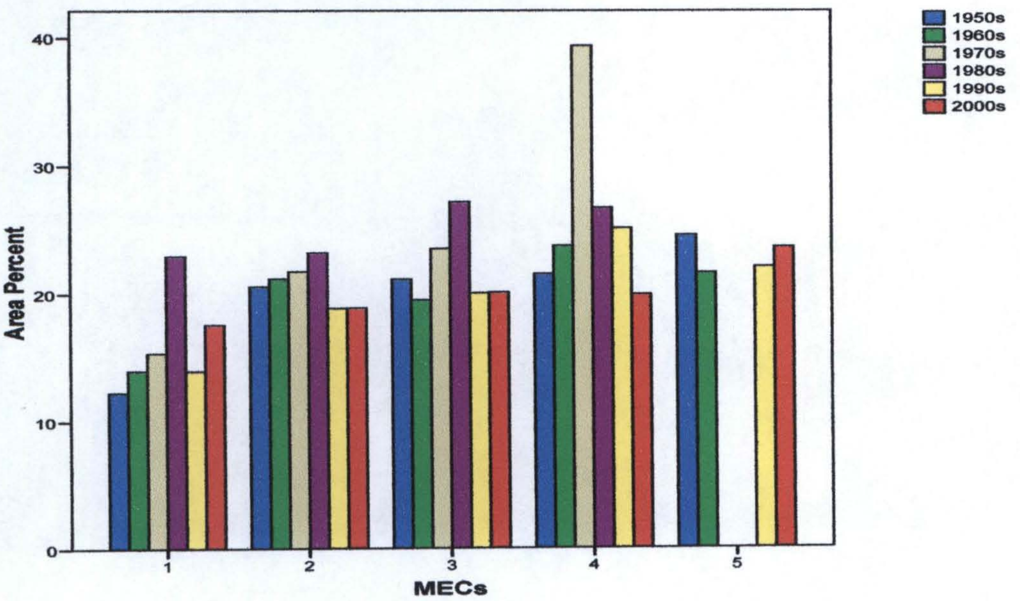


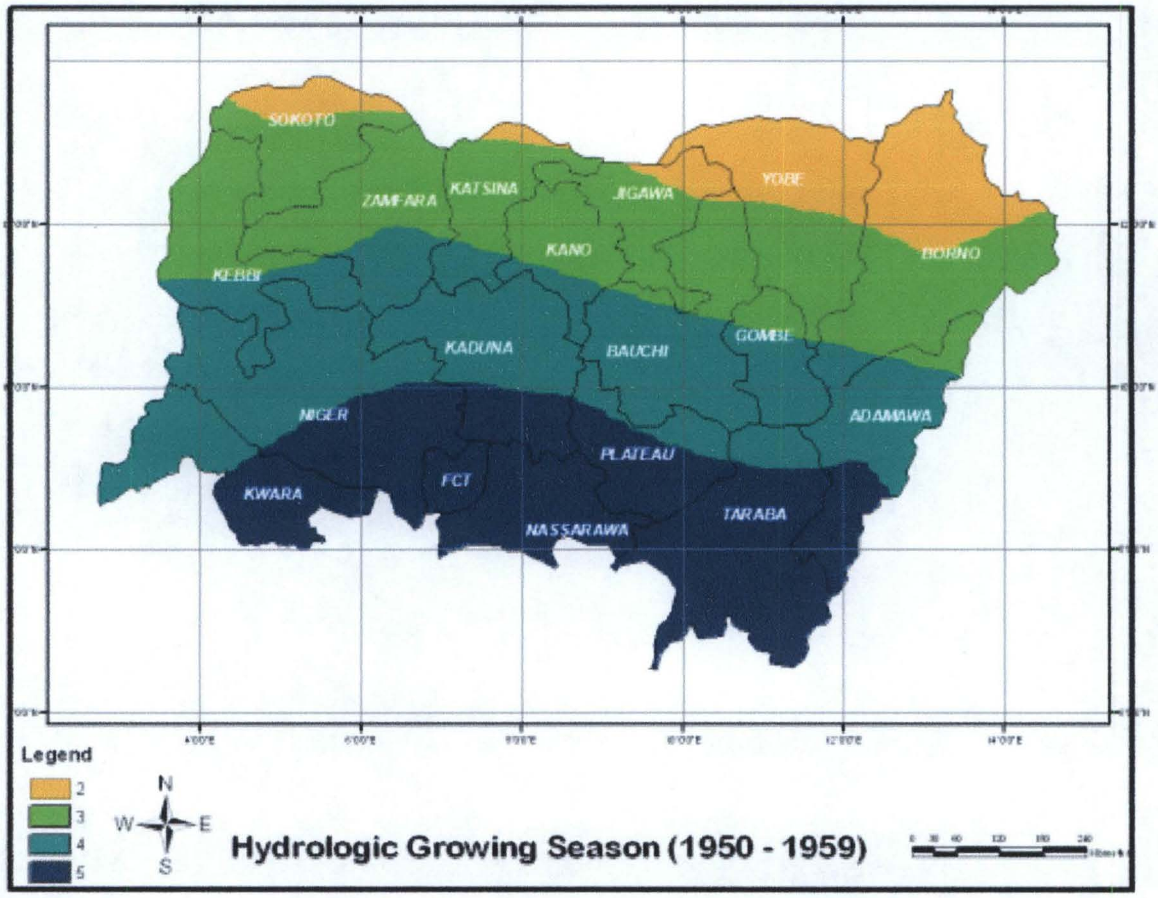
Fig. 4.20: Aridity Index Decadal MEZs Comparison Graph

4.4.9 Hydrologic Growing Season Index Spatio-temporal Trend

HGS decadal maps 1950s to 2000s revealed variability that characterized growing season in northern Nigeria, these portrays gradual decadal, Middle and Long term moisture stress across the region.

4.4.10 Hydrologic Growing Season 1950s Decadal MEZs

Figure 4.21 shows that there was no extremely short HGS moisture zone in 1950; however, very short HGS moisture conditions are evident along areas above Lat 12^0N in the extreme North east and extreme north of Sokoto and Katsina States. Vast areas of northern State had short HGS moisture; Zamfara, kano, parts of Sokoto, Katsina and Gombe States as well as southern Yobe and Borno States. Southern belt have longest HGS moisture while central portion have long HGS moisture.

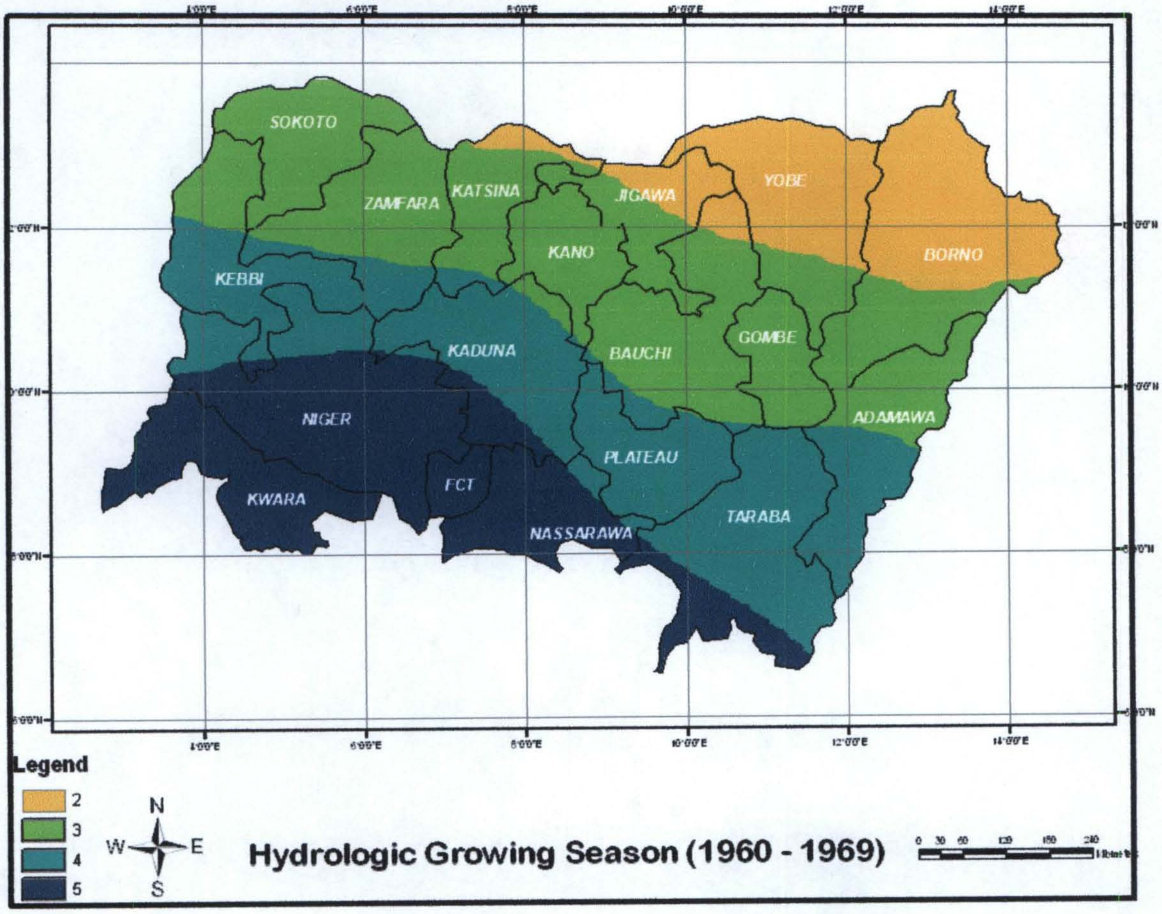


5, 4, 3 & 2 = Longest, Long, Short & Very Short,

Fig. 4.21: Hydrologic Growing Season 1950s Decadal MEZs

4.4.11 Hydrologic Growing Season 1960s Decadal MEZs

Similar moisture condition prevailed in the 1960s, though in the northeast, very short HGS moisture zone had spread southwards to about Lat 11^{o}N 24^{1} and short HGS moisture zone had extended southwards along the north east. In addition, there was gradual decline in the area extents of longest HGS zone and it is skewed to south west (Fig. 4.22).

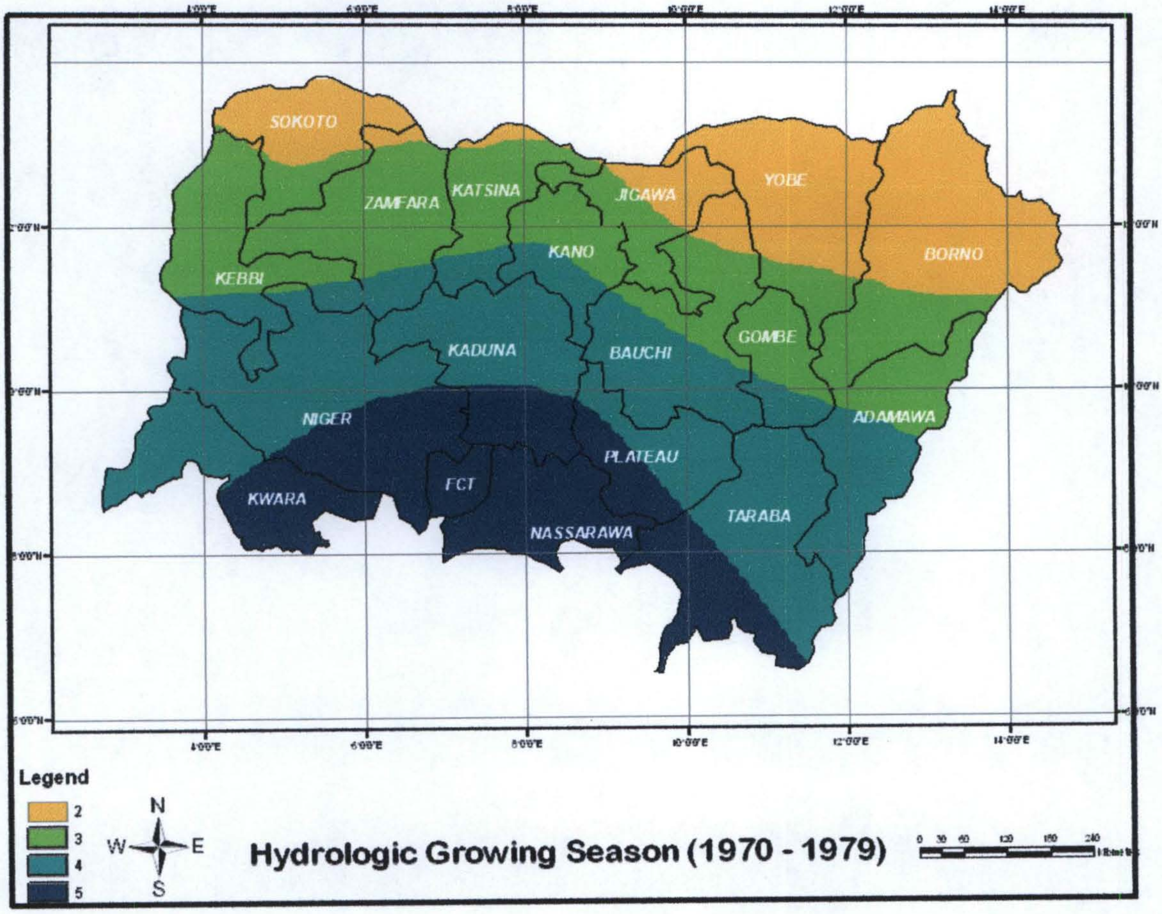


5, 4, 3&2 = Longest, Long, Short & Very Short

Fig.4.22: Hydrologic Growing Season 1960s Decadal MEZs

4.4.12 Hydrologic Growing Season 1970s Decadal MEZs

Figure 4.23 reveals Moisture effectiveness stress intensified in the 1970s decade as there was spread in the spatial extent of very short, short and long HGS moisture effectiveness zones while, areas of longest HGS moisture zones had reduced.

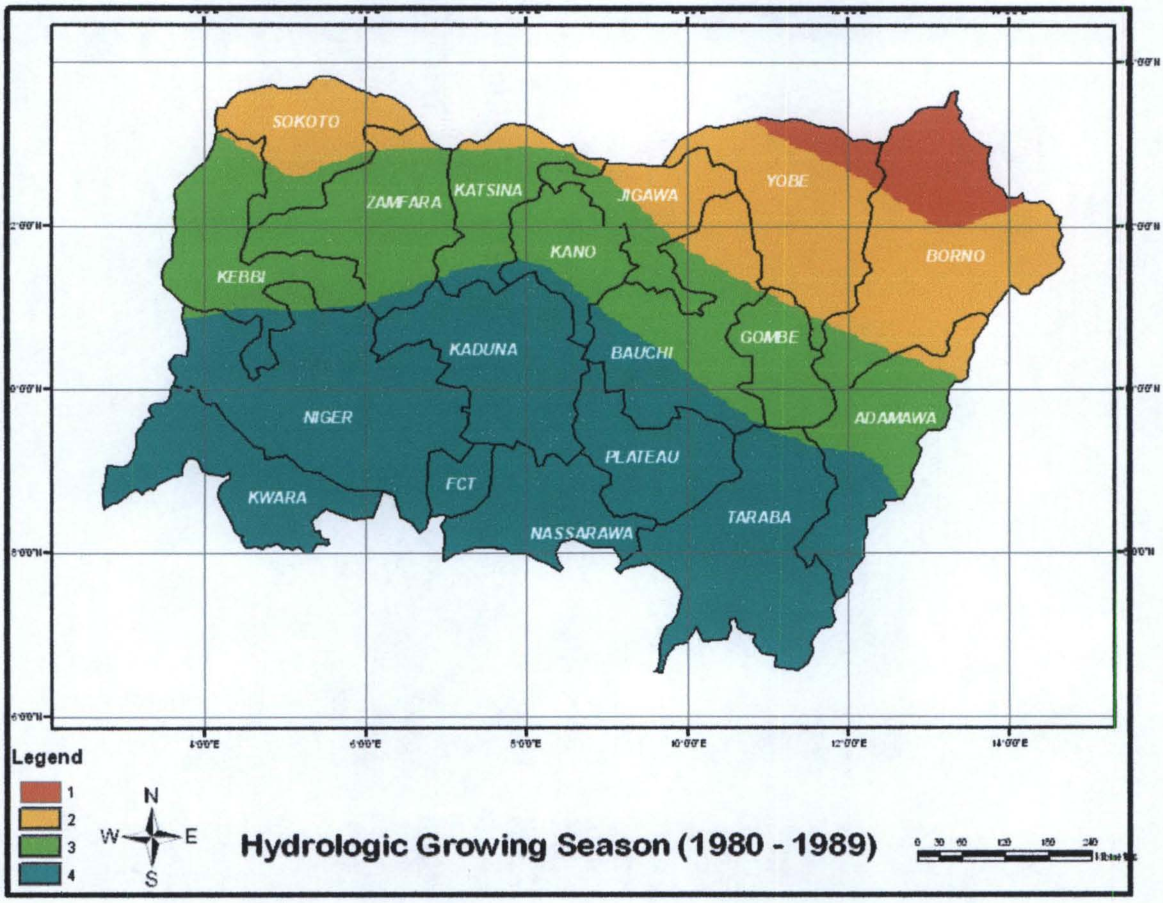


5, 4, 3& 2 = Longest, Long, Short & Very Short

Fig. 4.23: Hydrologic Growing Season 1970s Decadal MEZs

4.4.13 Hydrologic Growing Season 1980s Decadal MEZs

The moisture stress intensified in 1980s with the extreme north east having extremely short HGS moisture, very short HGS zone stretched to northern parts of Sokoto, Katsina, Jigawa and the rest parts of Yobe and Borno States. Specifically this extended to about Lat 10^0 N along the north east. There were no areas with longest HGS moisture zone whereas long HGS moisture zone dominated the south and parts of central States (Fig. 4.24).

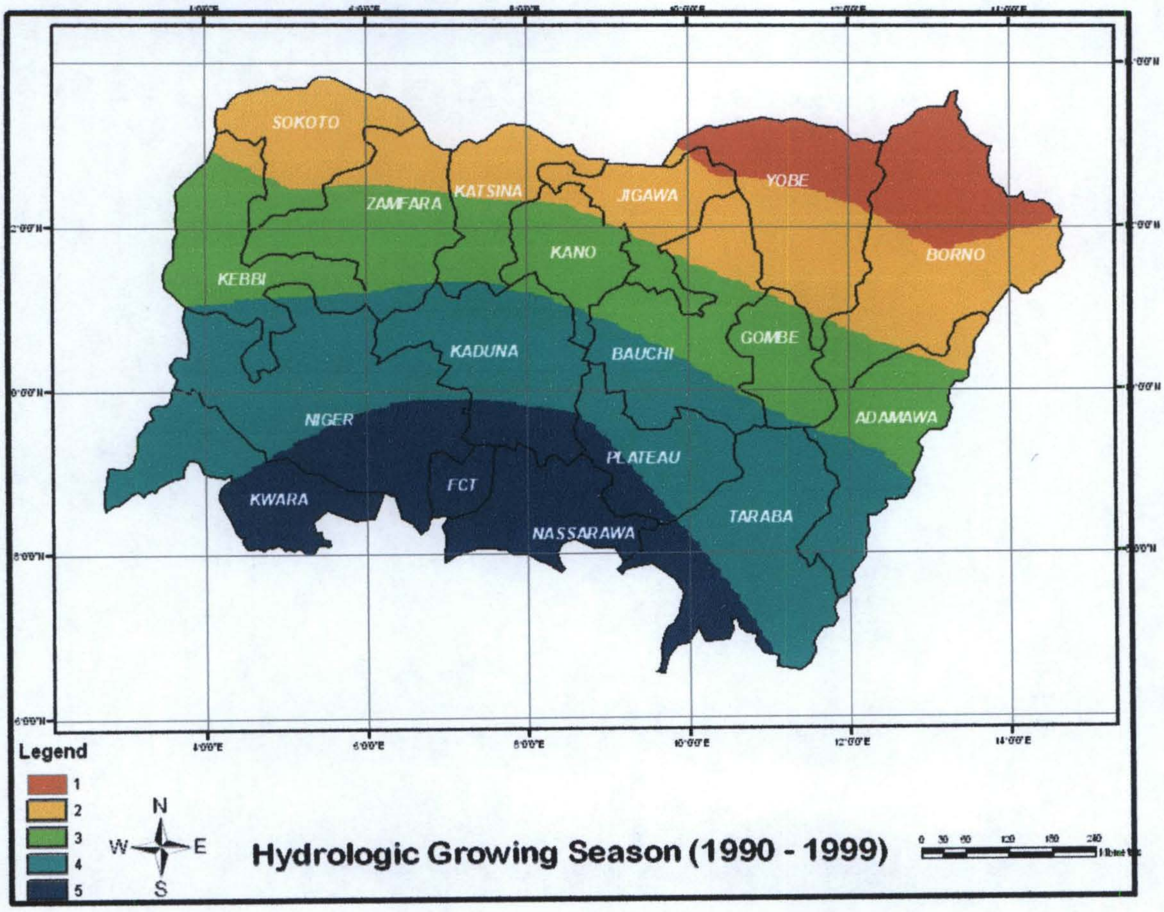


5, 4, 3, 2, & 1 = Longest, Long, Short, Very Short & Extremely Short HGS

Fig. 4.24: Hydrologic Growing Season 1980s Decadal MEZs

4.4.14 Hydrologic Growing Season 1990s Decadal MEZs

There was significant appreciation in moisture effectiveness in the 1990s as five MECs were recognized; areas of, long, short, very short and extreme short HGS moisture zone had decreased whilst longest HGS moisture zone was evident along the southern belt (Fig.4.25).

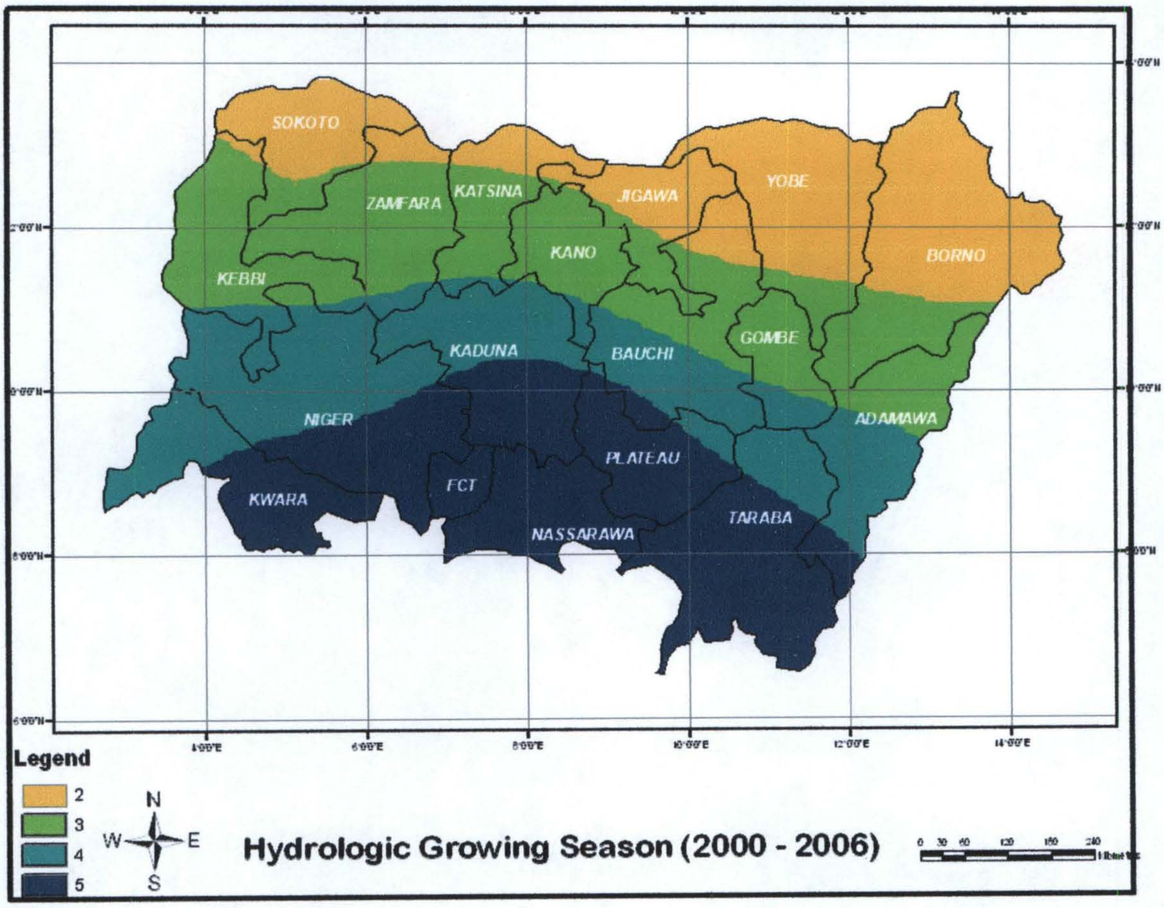


5, 4, 3, 2, & 1 = Longest, Long, Short, Very Short & Extremely Short HGS

Fig. 4.25: Hydrologic Growing Season 1990s Decadal MEZs

4.4.15 Hydrologic Growing Season 2000s Decadal MEZs

This trend persist in the 2000s as there was no extremely short HGS moisture zone, very short HGS moisture zone dominated the extreme north and areas of longest HGS moisture zone increased figure 4.26.



5, 4, 3& 2 = Longest, Long, Short &Very Short

Fig. 4.26: Hydrologic Growing Season 2000s Decadal MEZs

4.4.16 Hydrologic Growing Season MEZs Decadal Comparison

An assessment of the entire decades covered by this study unveil the short, medium and long term dynamics that characterised the hydrologic growing season in the Sudano-sahelian belt of Nigeria. A decadal depreciation of long and longest MEZs were evident as well as the appreciation of extremely short and very short HGS moisture conditions across the belt (Fig.4.27).

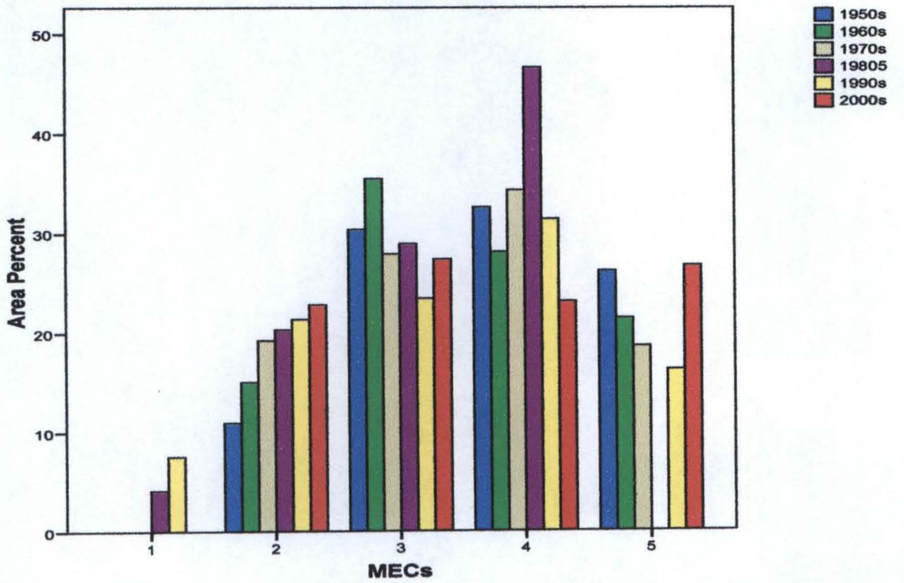


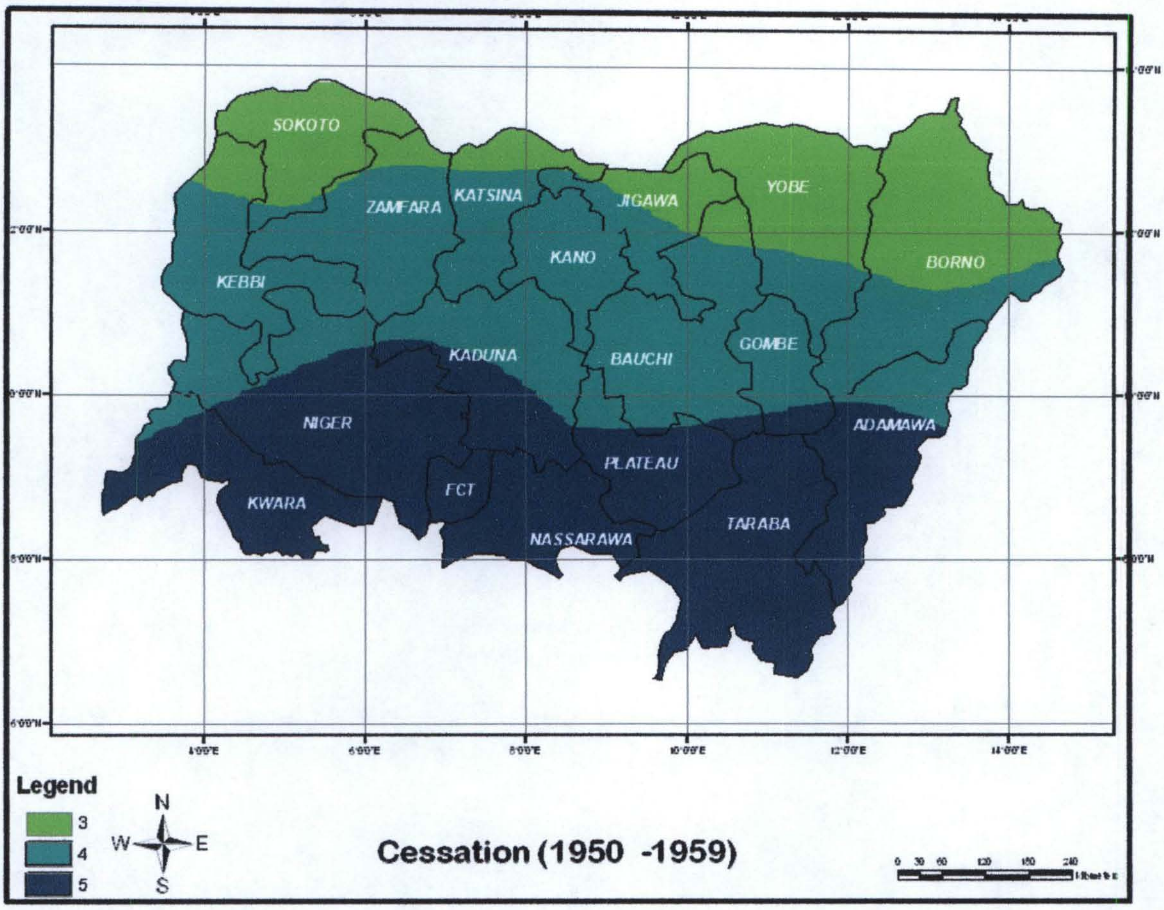
Fig. 4.27: Hydrologic Growing Season MEZs Decadal Comparison Graph

4.4.17 Cessation Index Spatio-temporal Trend

Despite the variability that is typical of rainfall cessation in northern Nigeria, it has been less stressful across compared to other eco-climatic parameters

4.4.18 Cessation 1950s Decadal MEZs

Cessation 1950s decadal map shows that cessation moisture effectiveness is less stressful across the belt. Three moisture effectiveness zones were identified; latest, late and early cessation zones (Fig.4.28).

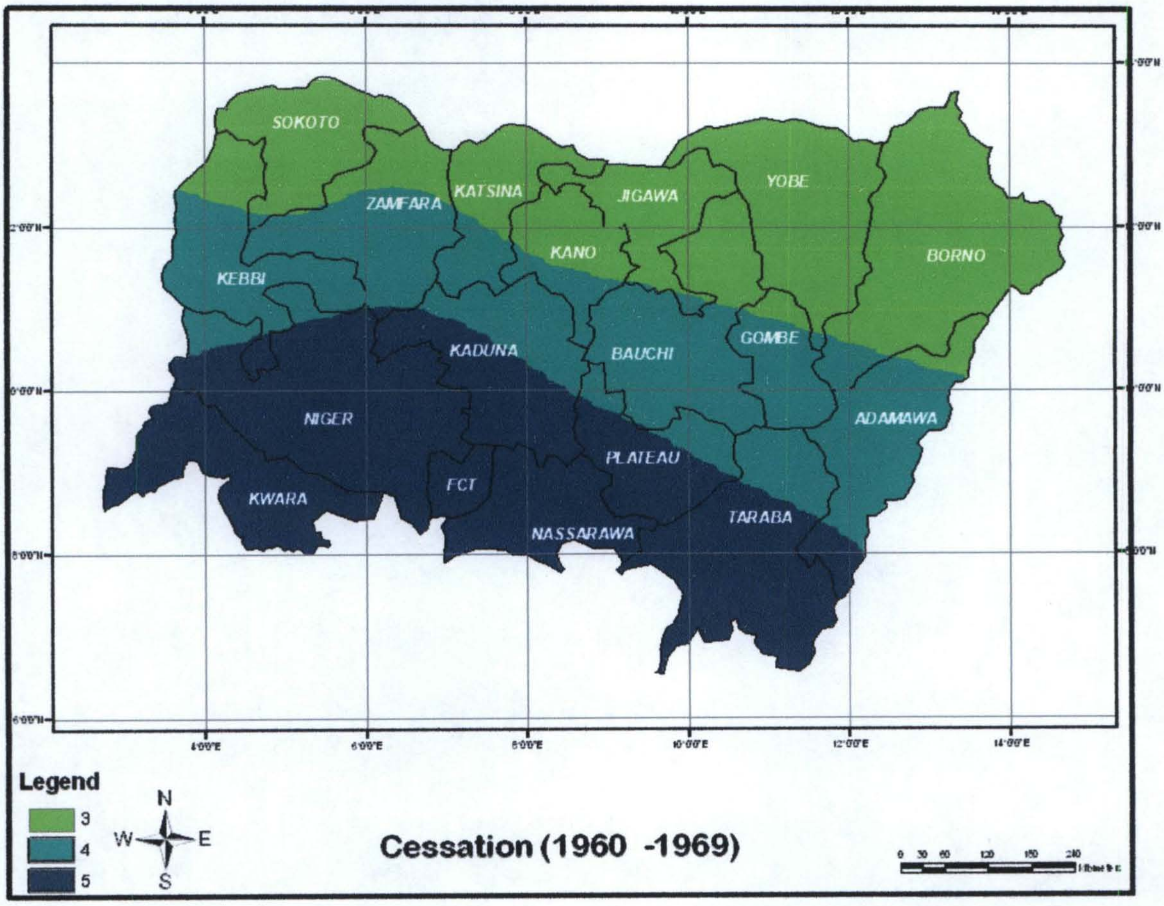


5, 4, 3= Latest, Late & Early

Fig.4.28: Cessation 1950s Decadal MEZs

4.4.19 Cessation 1960s Decadal MEZs

By 1960s similar MEZs were recognised but with increase in the extent of early cessation moisture zone to about Lat 12^0N in North West and Lat 10^0N in the northeast. The late cessation moisture zone decreased as the latest cessation moisture zone skewed to southwest and western portions of the region (Fig. 4.29).

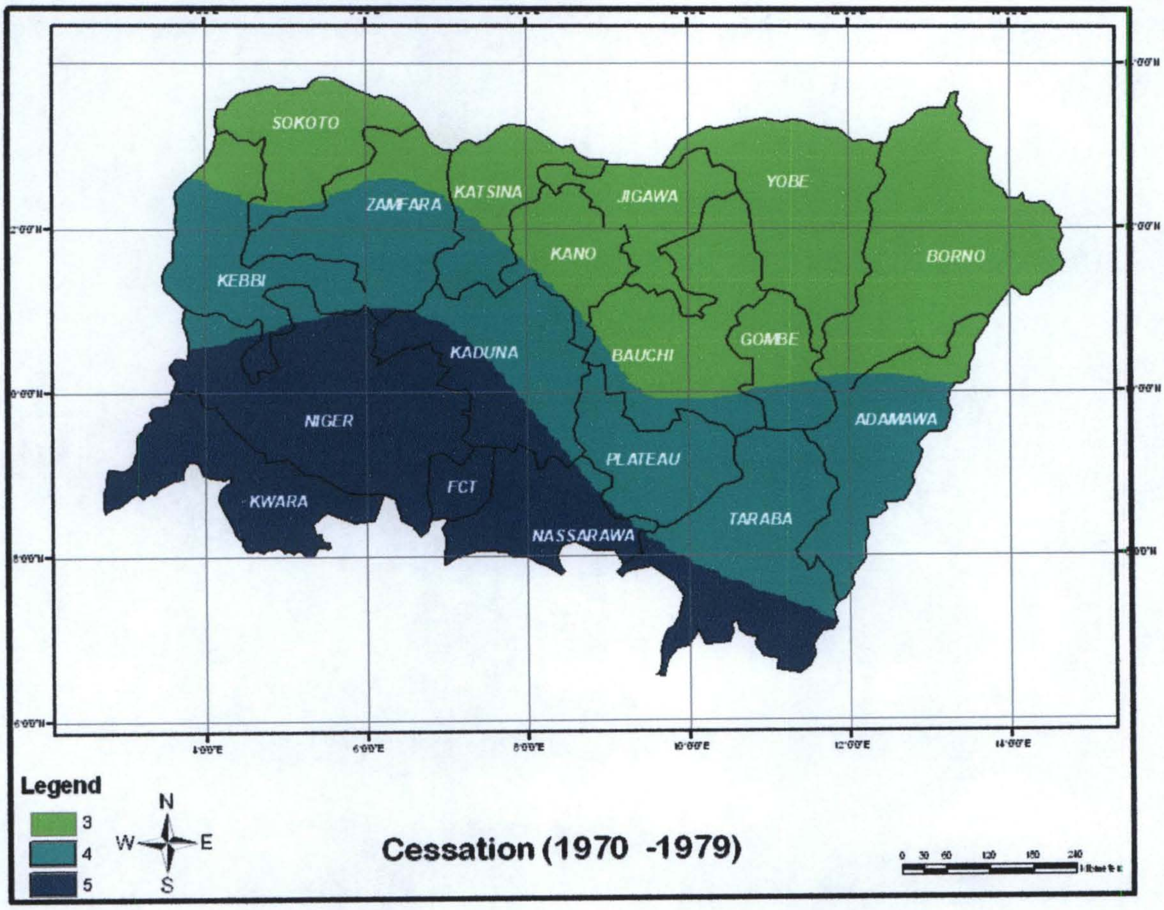


5, 4, 3 = Latest, Late &Early

Fig. 4.29: Cessation 1960s Decadal MEZs

4.4.20 Cessation 1970s Decadal MEZs

Figure 4.30 depicts the intensification of cessation moisture effectiveness stress in the 1970s decade, with vast areas of north eastern and central States; Bauchi, Kano, Jigawa, Yobe, Gombe, and Borno experiencing predominantly early cessation moisture condition. .

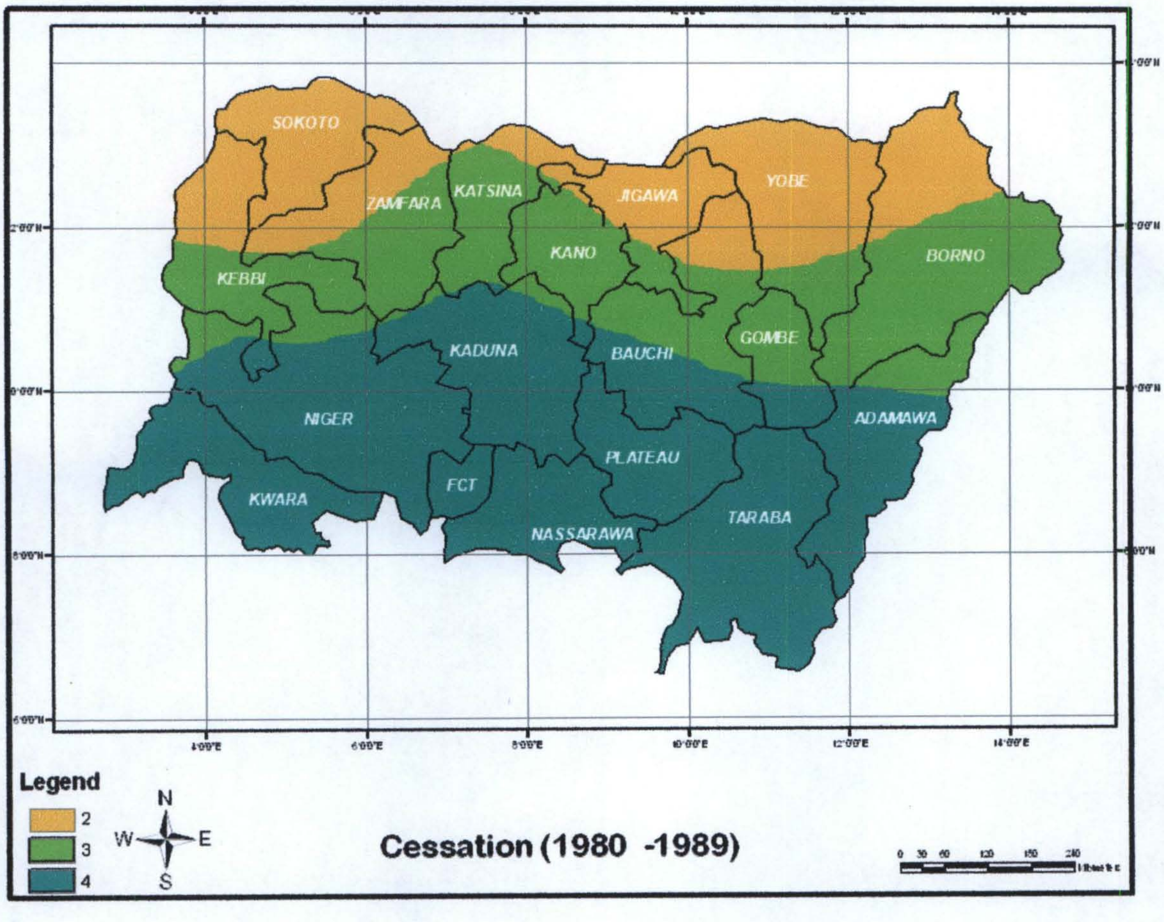


5, 4, 3 = Latest, Late & Early

Fig. 4.30: Cessation 1970s Decadal MEZs

4.4.21 Cessation 1980s Decadal MEZs

Similarly, moisture stress intensified in 1980s decade across the region; very early cessation zone was established and there was disappearance of latest cessation zone (Fig.4.31).



4, 3&2 = Late, Early &Very Early

Fig. 4.31 Cessation 1980s Decadal MEZs

4.4.22 Cessation 1990s Decadal MEZs

In the 1990s, (Fig. 4.32) moisture stress appreciated in the extreme north with extremely early cessation dominating and latest cessation moisture zone also appreciated across the south.

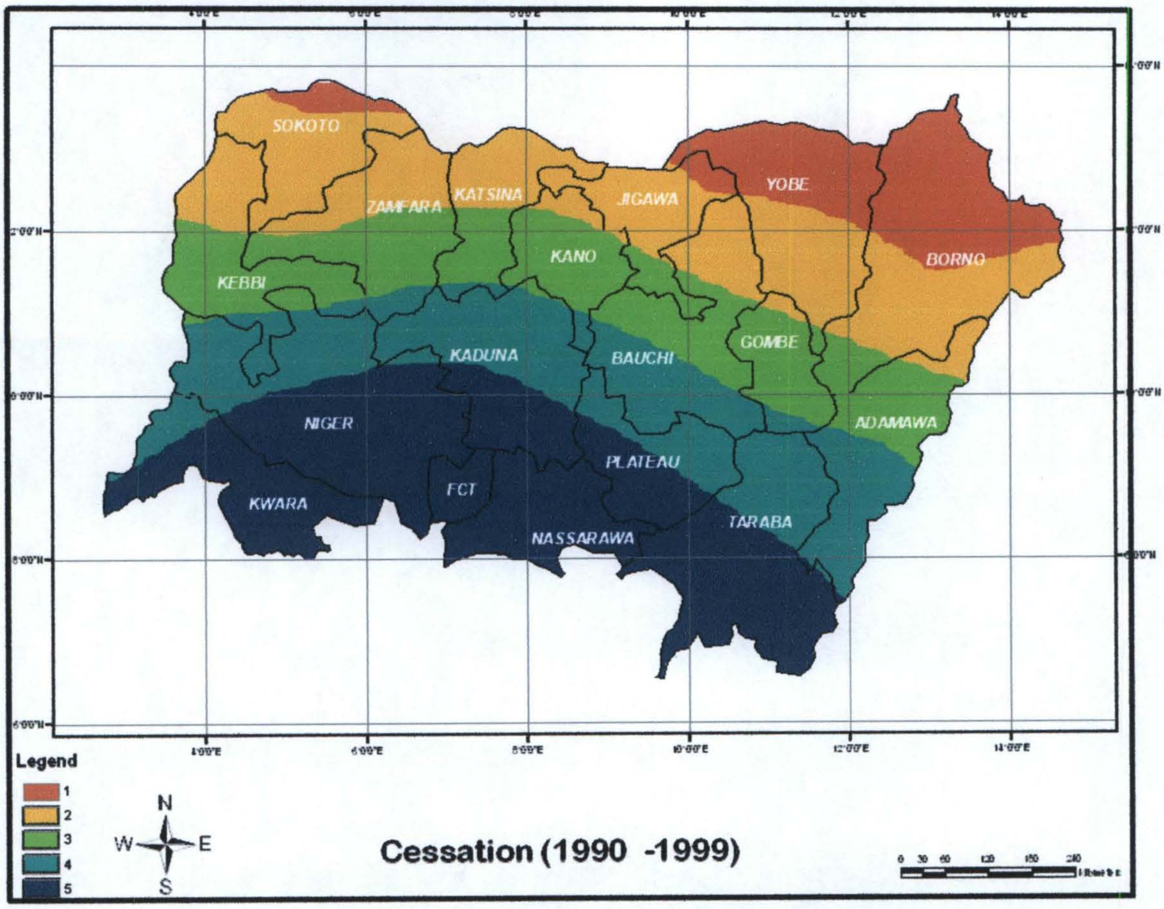
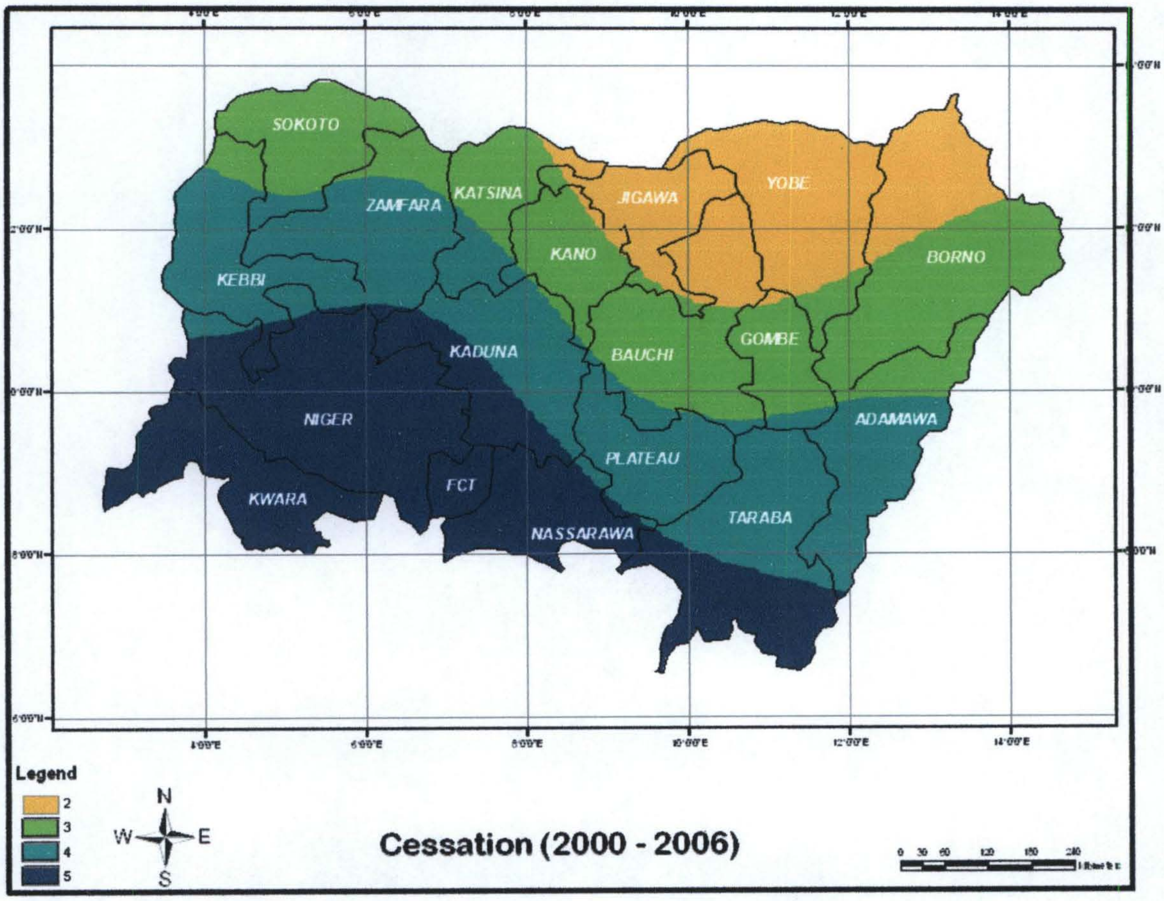


Fig. 4.32: Cessation 1990s Decadal MEZs

5, 4, 3, 2& 1 = Latest, Late, Early, Very Early & Extremely Early

4.4.23 Cessation 2000s Decadal MEZs

By 2000s there was no extremely early cessation across the belt; however, the north eastern zone was dominated by early cessation. The late and latest cessation moisture zones were skewed to the southwest and western portion of the region (Fig. 4.33).



5, 4, 3, 2 = Latest, Late, Early &Very Early

Fig. 4.33: Cessation 2000s Decadal MEZs

4.4.24 Cessation Moisture Effectiveness Zones Decadal Comparison

A decadal variability of the various MEZs is evident in figure 4.34 with a rapid increase in the spread of early, very early and extremely early cessation moisture zones in addition to decline in areas of late and latest cessation moisture zones, particularly in the medium and later decades. By and large, despite appreciation of moisture in the later decade, the extreme north was characterized with very early and extremely early cessation thereby intensifying plant moisture stress across the region.

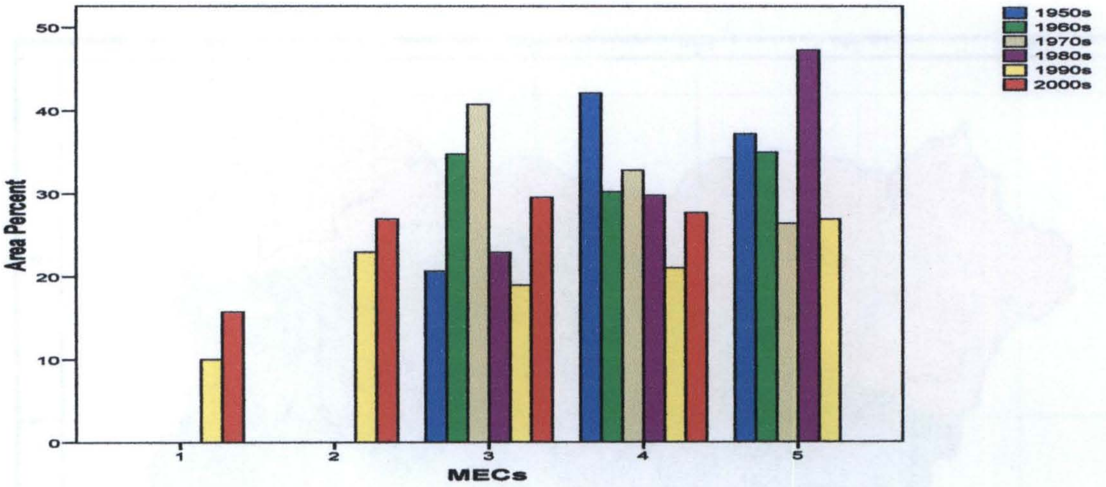


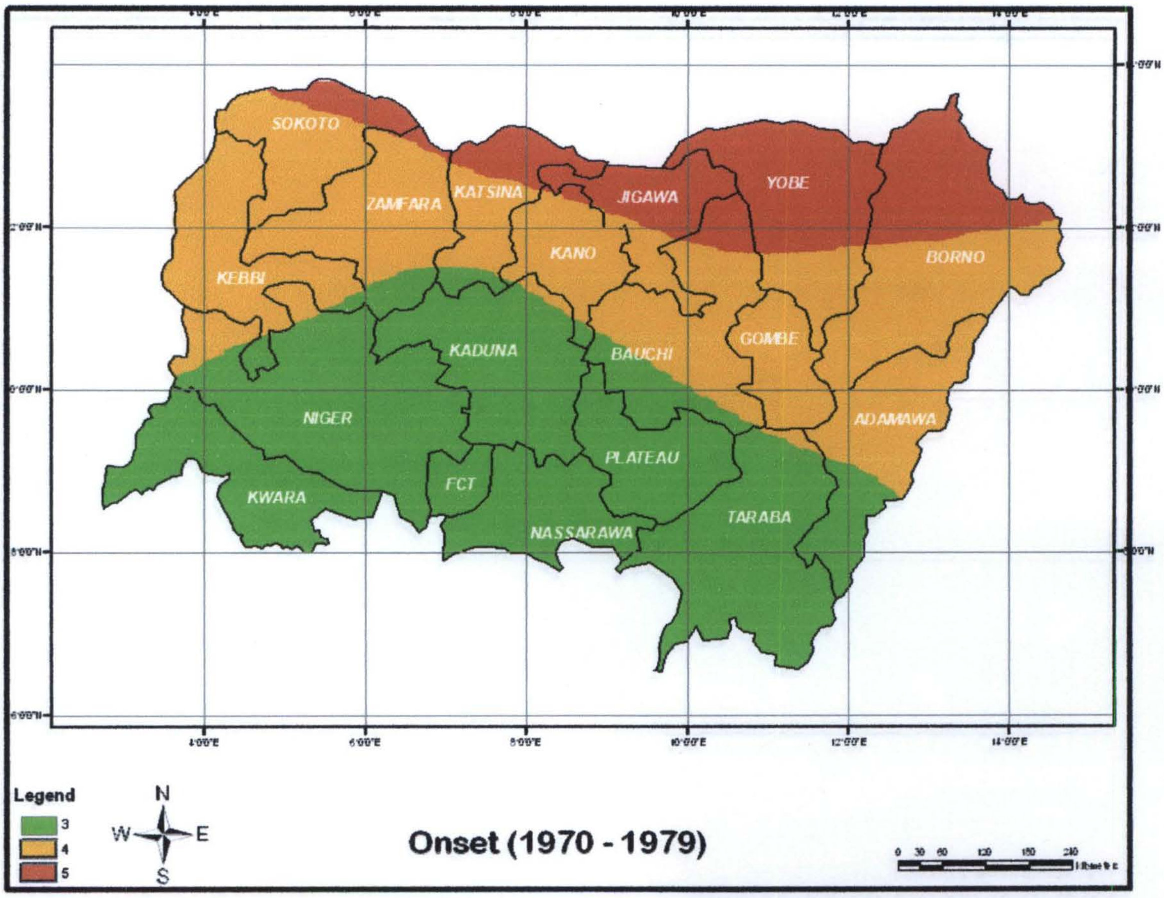
Fig. 4.34: Cessation MEZs Decadal Comparison Graph

4.4.25 Real Monsoon Onset Index Spatio-temporal Trend

Real monsoon onset is highly variable across the region as effective onset of rainfall in the region is characterized with vary levels of lateness, this signals moisture stress that is typical of northern Nigeria particularly the extreme Sudano-sahelian belt.

4.4.28 Real Monsoon Onset 1970s Decadal MEZs

The expected dry trend of drought years was evident in rainfall onset of the 1970s & 1980s when no zone experienced a dominance of early onset. All the zones were associated with one form of late rainfall onset or the other, late onset zone to south and extremely late onset zone to the extreme north Figure 4.37.



5, 4 & 3 = Extremely Late, Very Late & Late

Fig. 4.37: Real Monsoon Onset 1970s Decadal MEZs

4.4.32 Real Monsoon Onset Moisture Effectiveness Zones Decadal Comparison

Figure 4.41 reveals the severity of moisture stress associated with effective rainfall onset across northern Nigeria. In addition, to the absence of earliest rainfall onset zone there were drastic disappearances of early rainfall onset in the drought years and in the 2000s, the region was generally characterized with late onset. Furthermore, rapid spreads of late, very late and extremely late moisture zones were apparent.

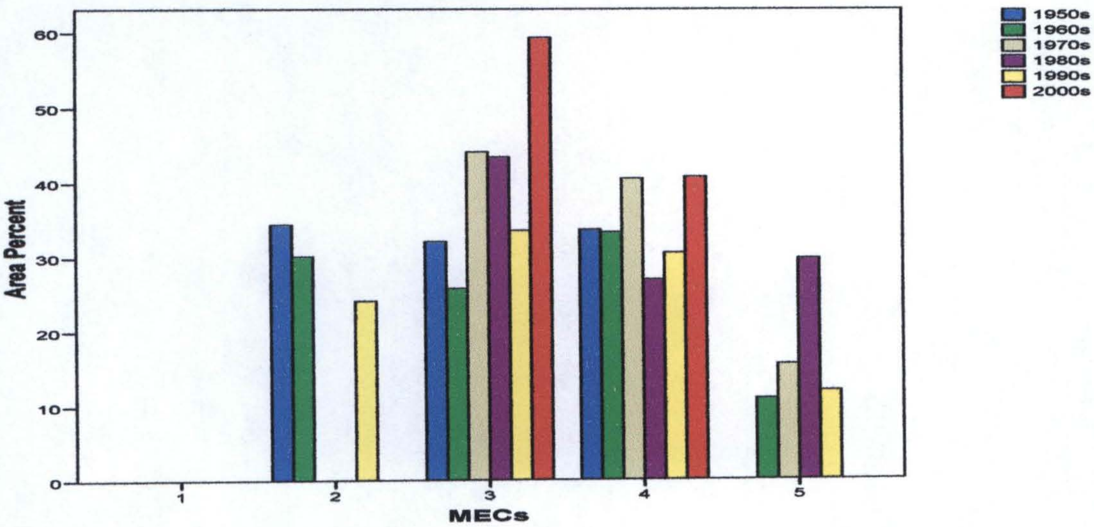


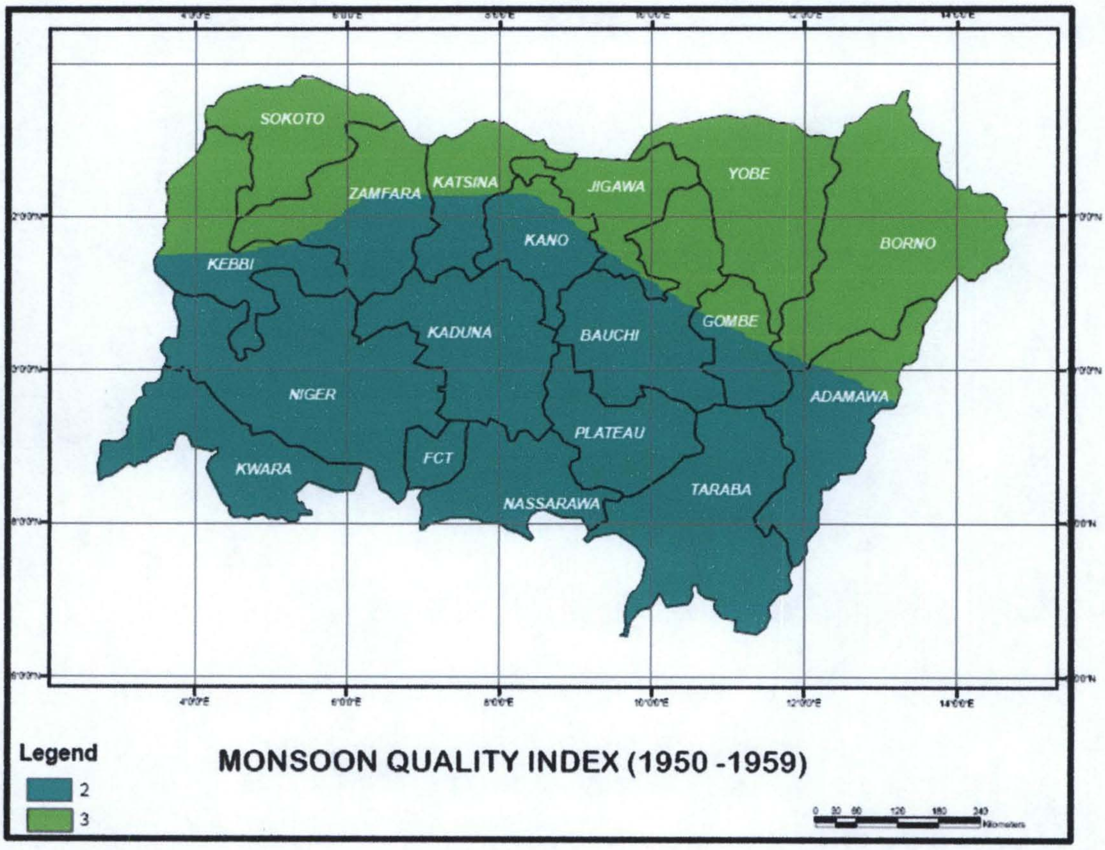
Fig. 44: Decadal Real Monsoon Onset Moisture Effectiveness Zones Comparison

4.4.33 Monsoon Quality Index Spatio-temporal Trend

Decadal monsoon quality like any other eco-climatic factor is highly variable across northern Nigeria, this signals short, middle and long-term moisture stress in the region.

4.4.34 Monsoon Quality Index 1950s Decadal MEZs

In the 1950s the moisture quality was adequate across southern and central States. Deficient moisture zone was dominant in the extreme northern States, Sokoto, Jigawa,Yobe, Borno, and parts of Kebbi, Zamfara, Katsina, Gombe, and Adamawa States Figure 4.42.

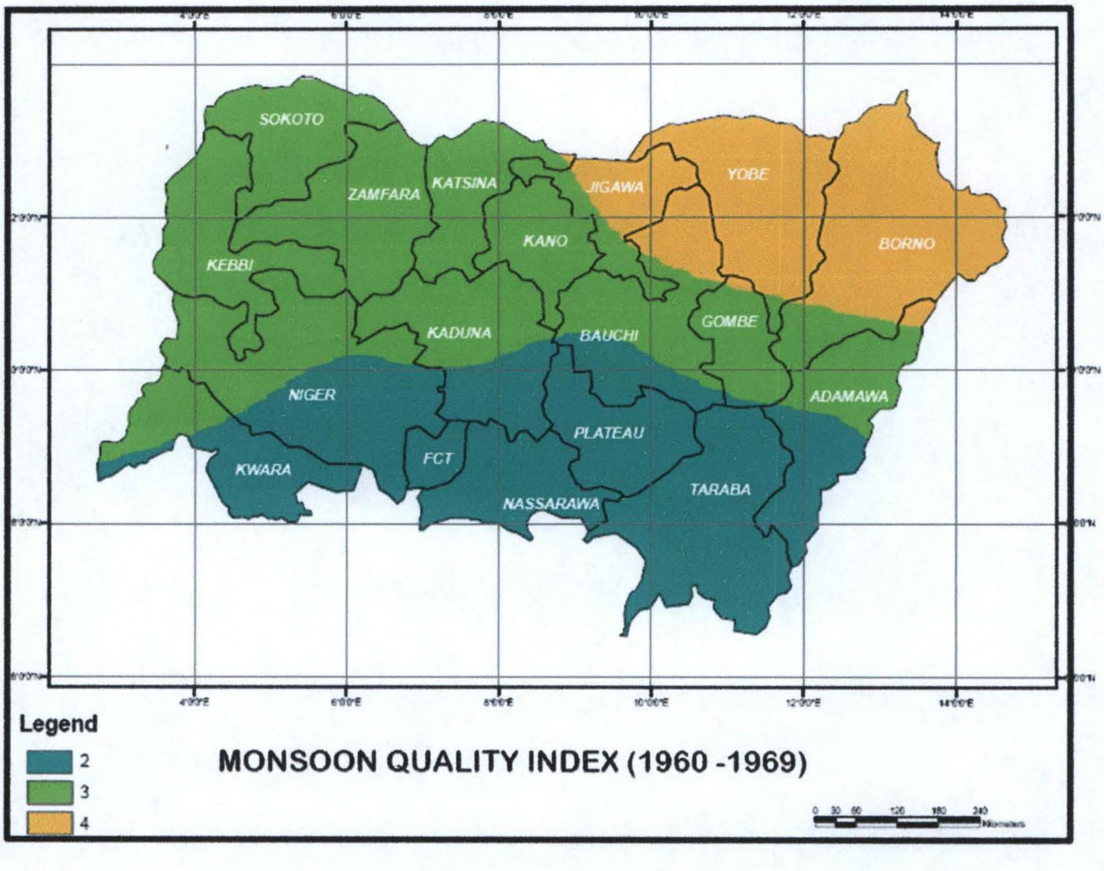


3 & 2=, Deficient & Adequate

Fig. 4.42: Monsoon Quality Index 1950s Decadal MEZs

4.4.35 Monsoon Quality Index 1960s Decadal MEZs

Also in the 1960s, adequate moisture zone skewed towards the southeast encompassing Taraba, Nassarawa, FCT, Plateau States and southern parts of Kwara, Kaduna, Bauchi and Niger States. Vast northwest States and central States were characterized by deficient moisture quality, very deficient moisture zone was apparent in the Northeast encompassing Jigawa, Yobe and Borno State (Figure 4.43).

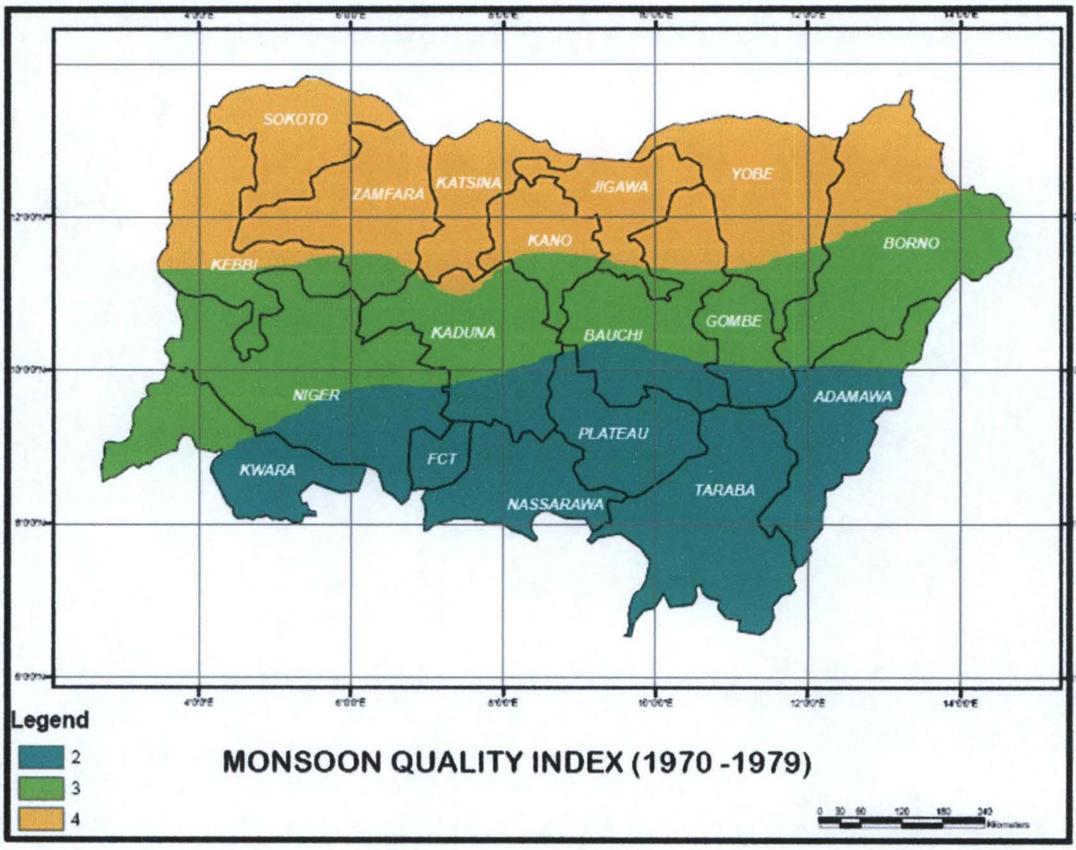


4, 3& 2 = Very Deficient, Deficient &Adequate

Fig. 4.43: Monsoon Quality Index 1960s Decadal MEZs

4.4.36 Monsoon Quality Index 1970s Decadal MEZs

The 1970s MQI decadal map recognized moisture stress distinctive of drought decades. Deficient moisture zone spread across the extreme north and area adequate moisture zone depreciated Figure 4.44.

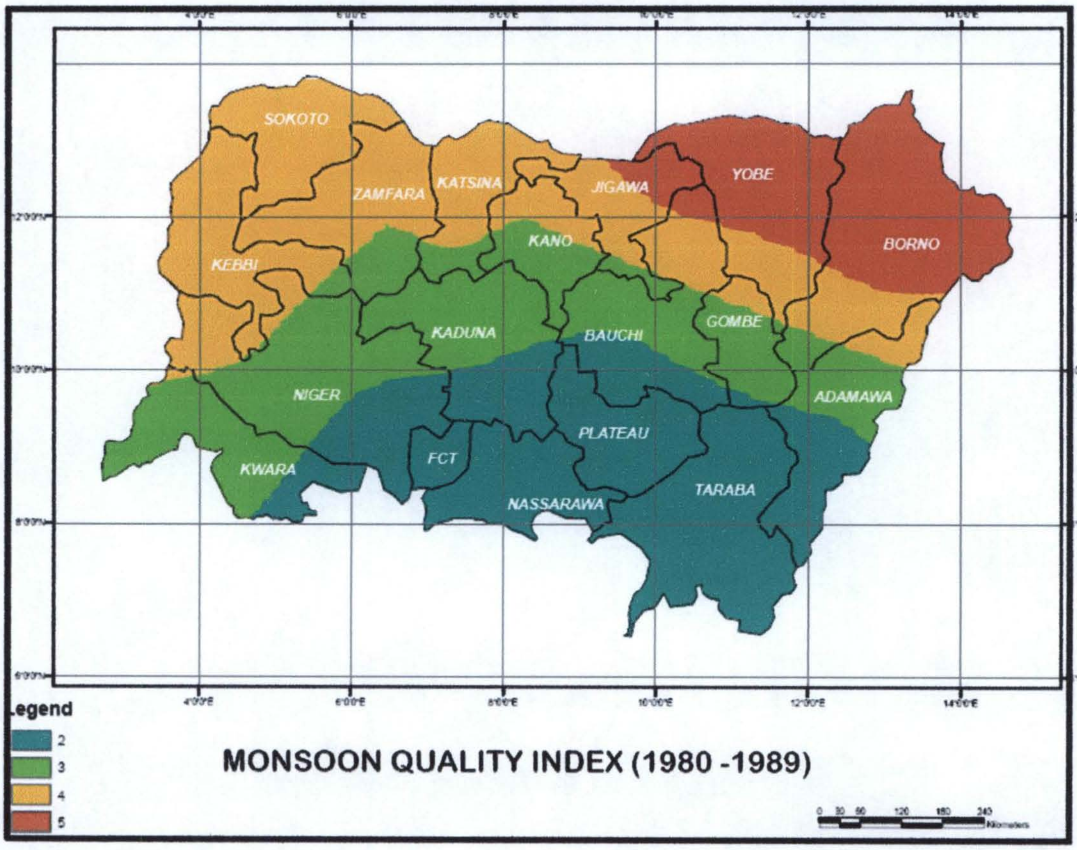


4, 3& 2 = Very Deficient, Deficient &Adequate

Fig. 4.44: Monsoon Quality Index 1970s Decadal MEZs

4.4.37 Monsoon Quality Index 1980s Decadal MEZs

The moisture quality stress intensified in the 1980s as extremely deficient moisture quality spread across the northeast. Northern Niger and Kebbi through Sokoto, Jigawa, Katsina to southern parts of the northeast were zones of very deficient moisture quality (Fig.4.45).

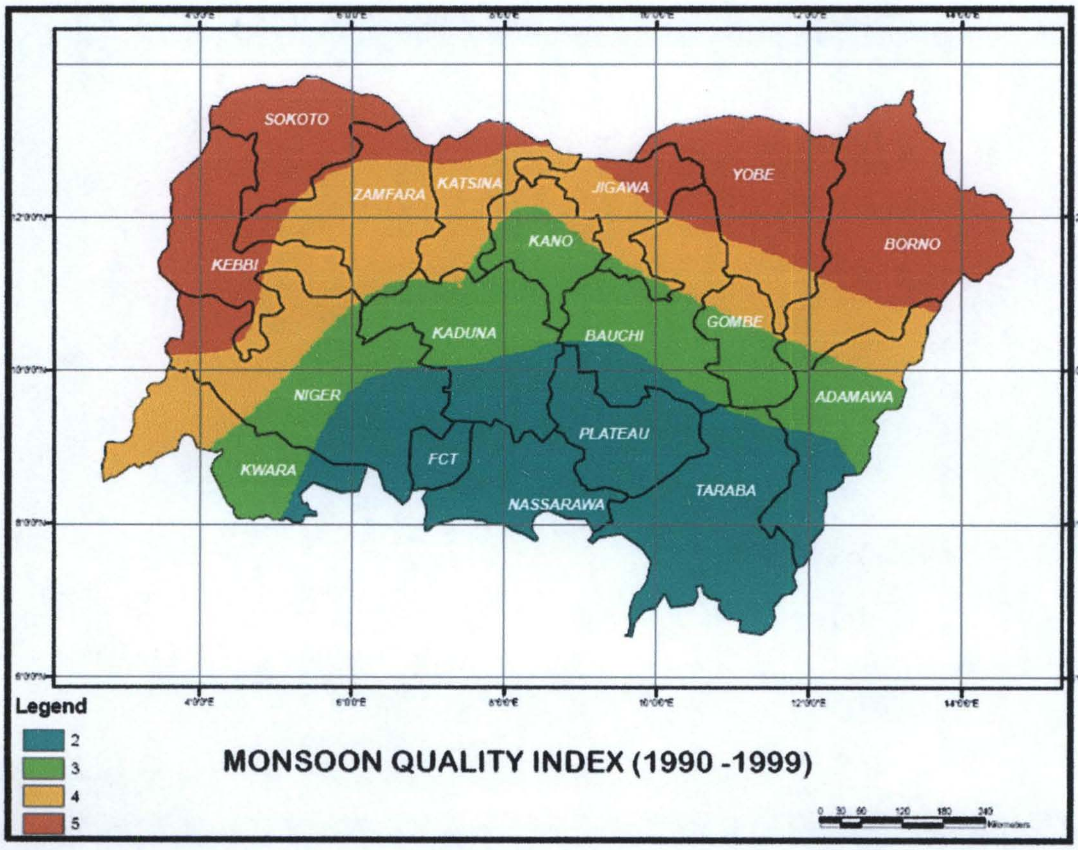


5, 4, 3& 2 = Extremely Deficient, Very Deficient, Deficient & Adequate

Fig.4.45: Monsoon Quality Index 1980s Decadal MEZs

4.4.38 Monsoon Quality Index 1990s Decadal MEZs

Despite, the moisture effectiveness appreciation in the 1990s, moisture quality was stressful across the extreme north. Adequate moisture zone declined southwards with the extreme northwest and northeast being dominantly areas of extreme deficient moisture quality (Fig. 4.46).

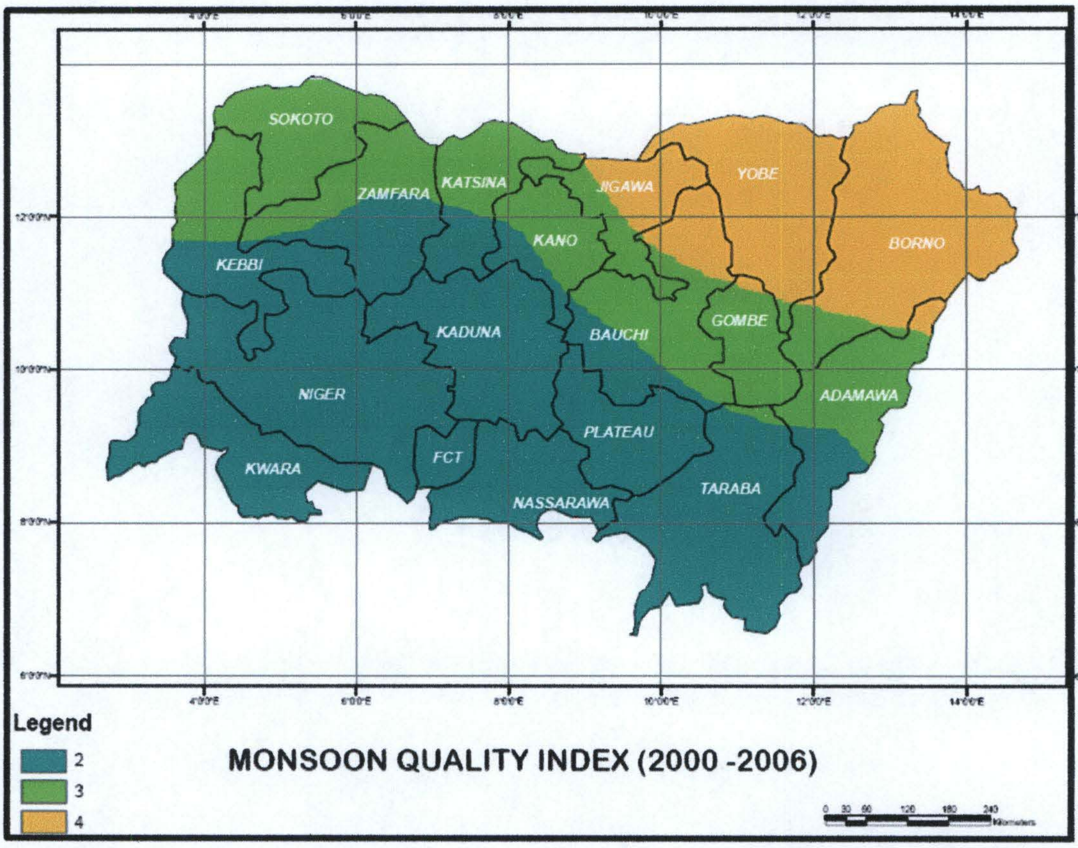


5, 4, 3 & 2 = Extremely Deficient, Very Deficient, Deficient & Adequate

Fig. 4.46: Monsoon Quality Index 1990s Decadal MEZs

4.4.39 Monsoon Quality Index 2000s Decadal MEZs

Also by 2000s the moisture quality appreciated was evident; three moisture zones were evident; adequate, deficient and very deficient. The moisture effectiveness skewed westwards across the region, however the north east was dominated by very deficient moisture zone (Fig. 4.47).



4, 3 & 2= Very Deficient, Deficient &Adequate

Fig. 4.47: Monsoon Quality Index 2000s Decadal MEZs

4.4.40 Monsoon Quality Index MEZs Decadal Comparison

A comparison of decadal MQI moisture quality trend confirms the decline of the adequate and deficient moisture zone with no zone dominated by abundant moisture quality for the entire decades across the region. In general, there was an increase in the area extent of very deficient and extremely deficient moisture zone (Fig. 4.48).

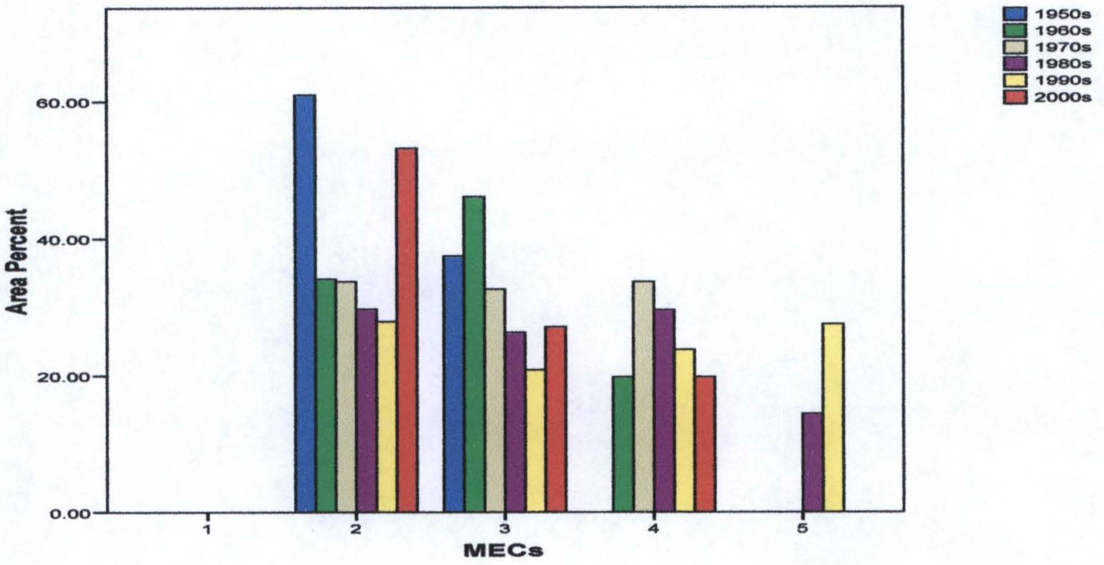


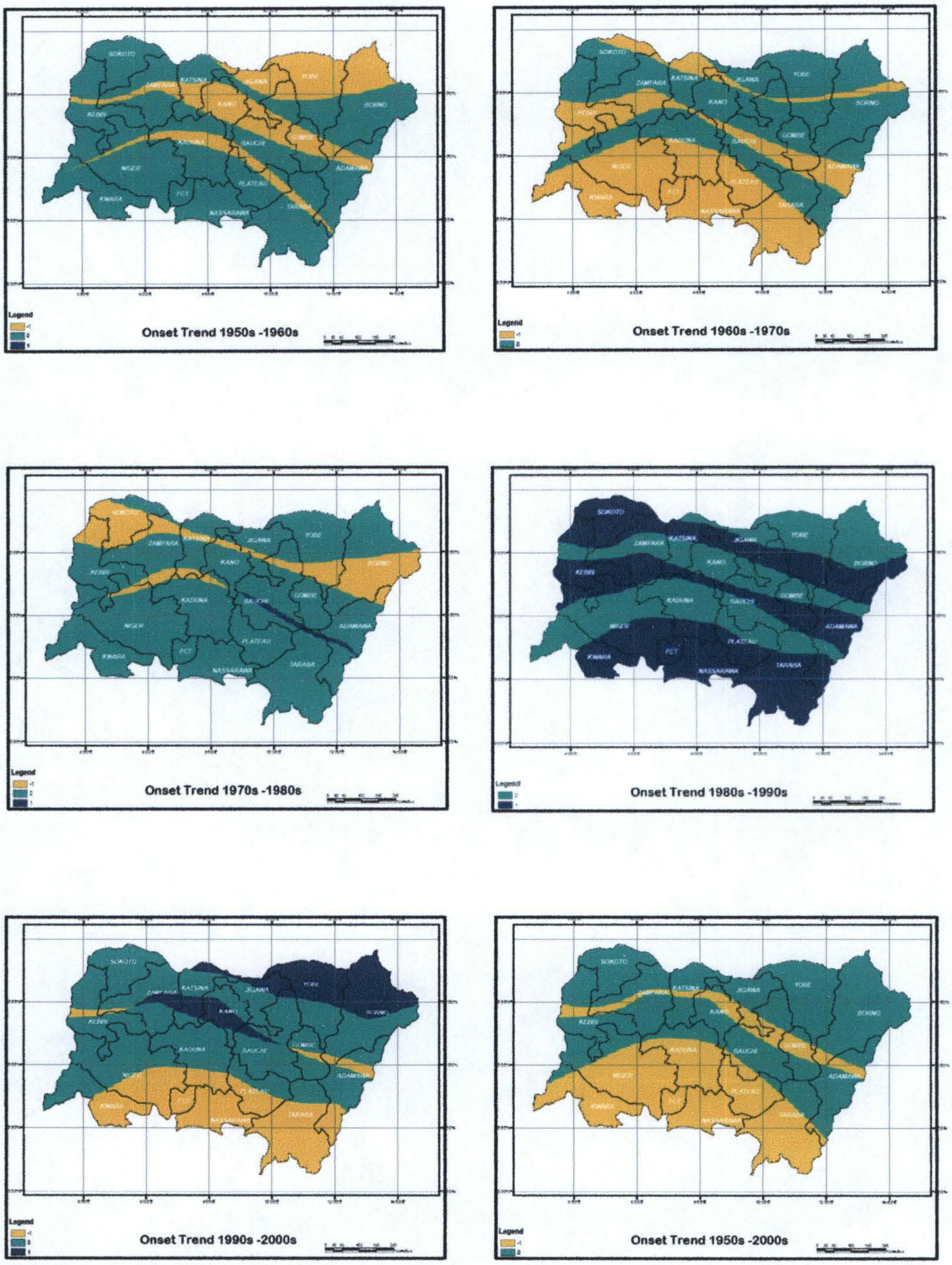
Fig. 4.48: Monsoon Quality Index MEZs Decadal Comparison

4.4.41 Geo-spatial Decadal Moisture Effectiveness Comparison

Decadal Image differencing confirms the spatio-temporal variability associated with the entire moisture effectiveness classes. The recorded image differencing values confirm this trend (using earlier minus later) with negative values indicating areas where the later year is greater and positive values implying area of the earlier year is greater and zero indicates no difference. Consequently, it is possible to conclude that decadal gradual and middle-term variability in moisture effectiveness have triggered aridity in northern Nigeria (Fig. 4.49-4.53).

4.4.42 Onset Decadal Image Difference (1950-2000)

Gradual delay in rainfall onset between 1950s - 1960s and severe delays between 1960s - 1970s, and 1970s - 1980s was evident in Figure 4.49.


Onset Trend 1950s -1960s

Onset Trend 1960s -1970s

Onset Trend 1970s -1980s

Onset Trend 1980s -1990s

Onset Trend 1990s -2000s

Onset Trend 1950s -2000s

Fig. 4.49: Onset Image differencing (1950 -2006)

4.4.43 Cessation Decadal Image Difference (1950-2000)

Furthermore, there was a spread in areas dominated by early cessation between the 1960s and 1980s and areas of late cessation appreciated during the late decades (Fig. 4.50).

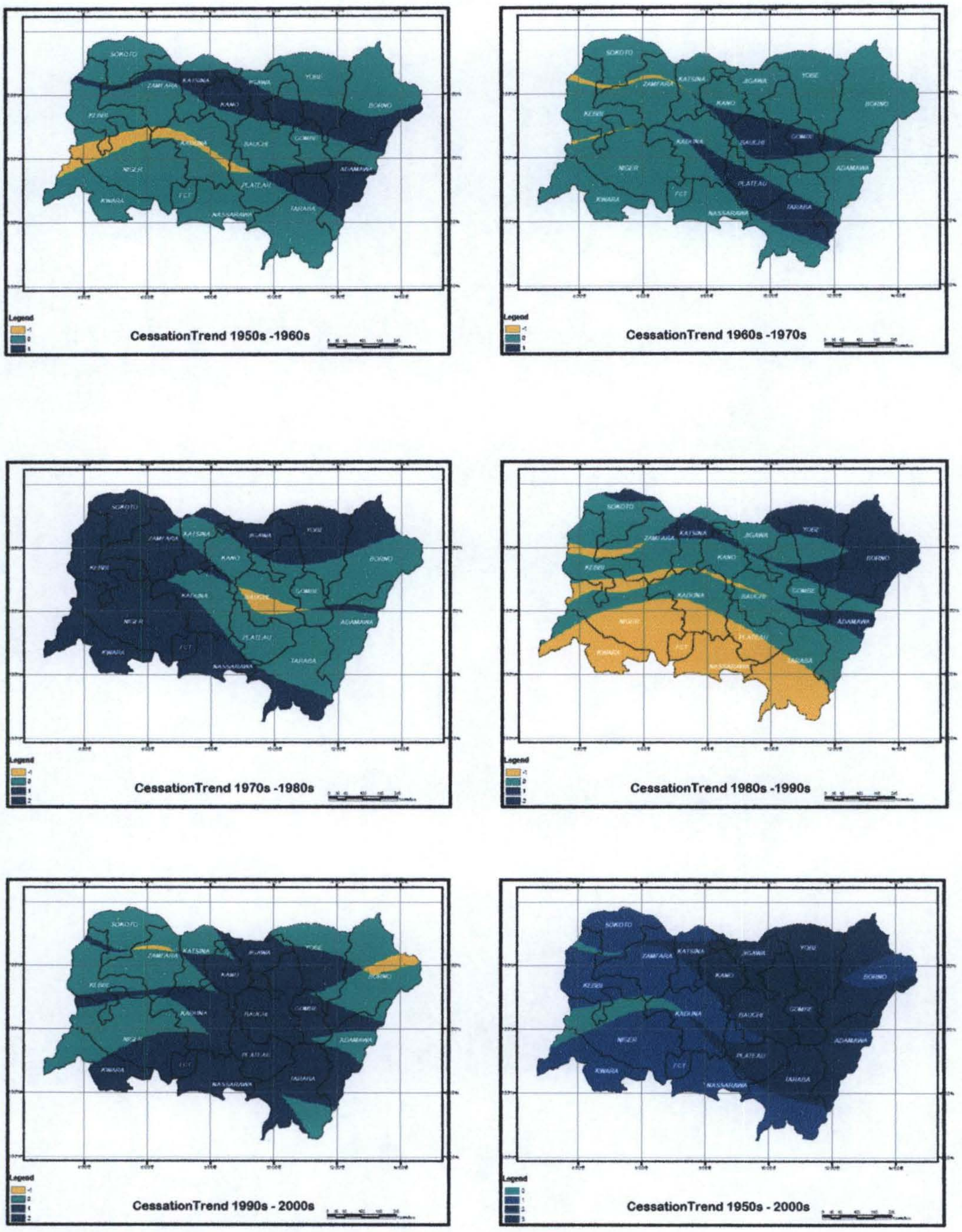


Fig. 4.50: Cessation Image differencing (1950 -2006)

4.4.44 HGS Decadal Image Difference (1950-2000)

Similarly, HGS declined gradually in the early decades and drastically within the middle decades. In the later decades there was increase in areas of shortest HGS (Fig. 4.51).

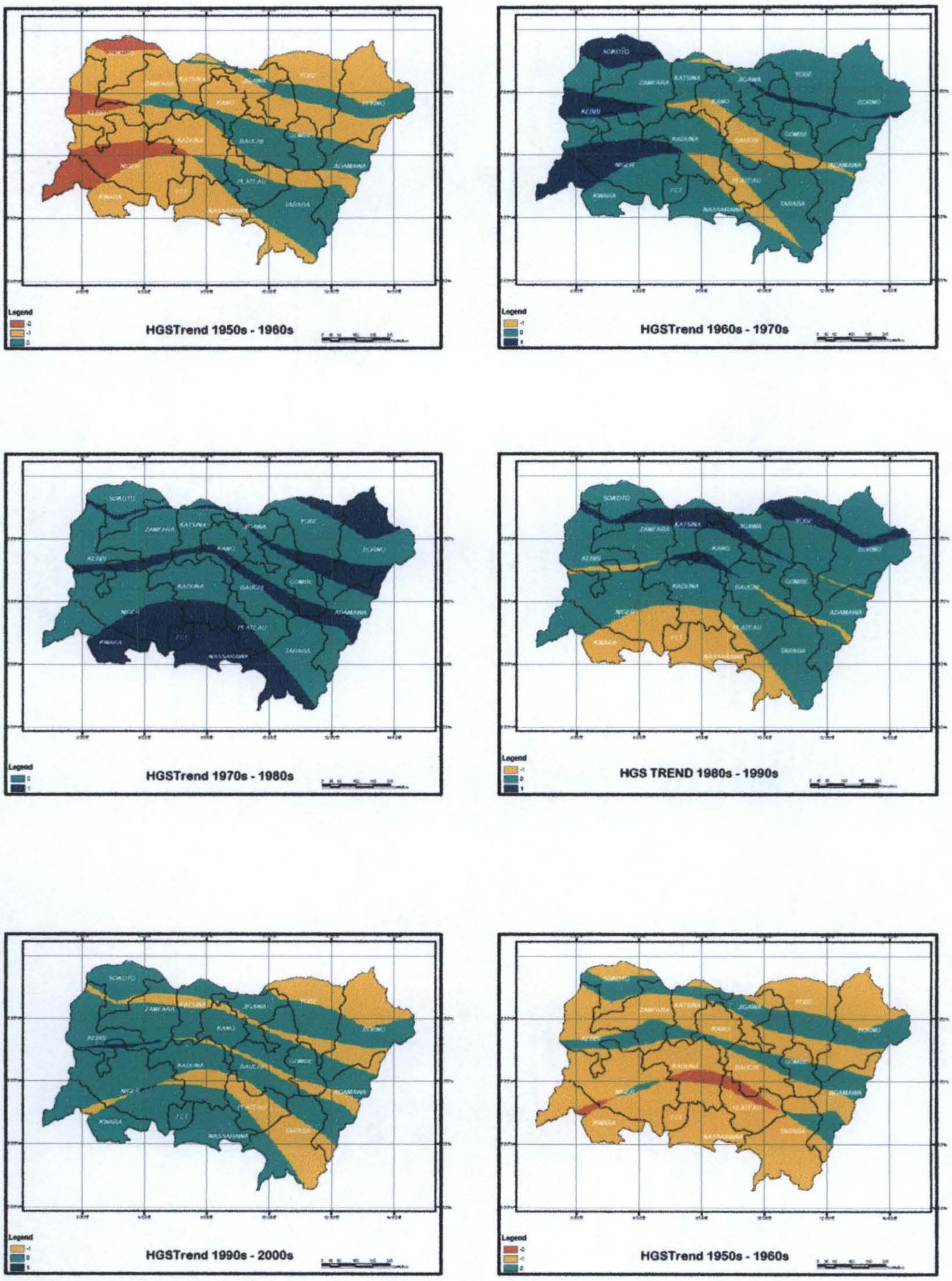


Fig. 4.51: HGS Image differencing (1950 -2006)

4.4.45 Aridity Index Decadal Image Difference (1950-2000)

Figure 4.52 shows that areas of high aridity appreciated slowly between 1950s – 1960s and severely in the middle decades. An appreciation in areas of low aridity was apparent in the later decades.

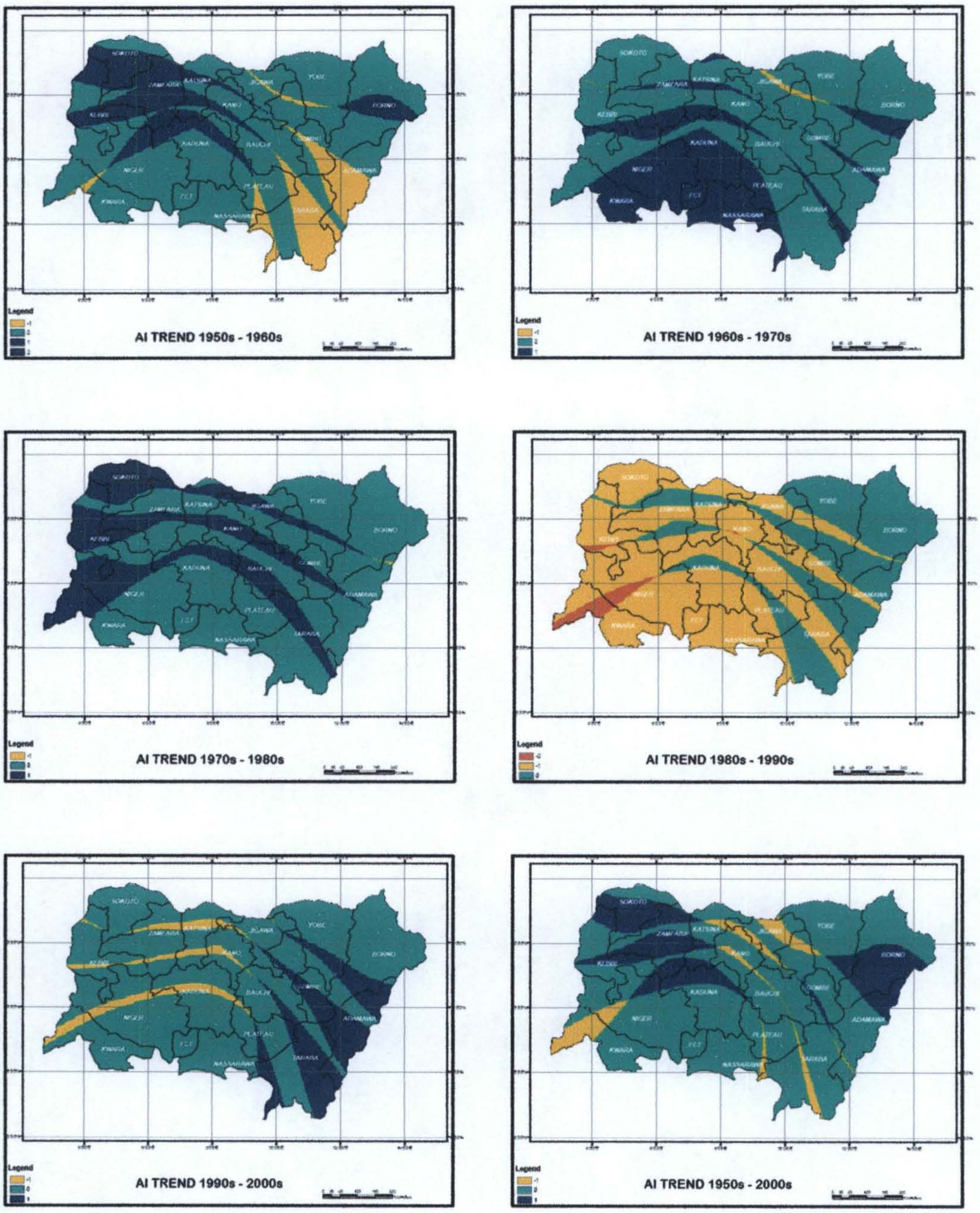


Fig. 4.52: AI Image differencing (1950 -2006)

4.4.46 Moisture Quality Index Decadal Image Difference (1950-2000)

Increase in areas of deficient and very deficient moisture quality was evident, particularly in the early and the middle decades while areas of abundant and adequate moisture appreciated during the later decades (Fig. 4.53).

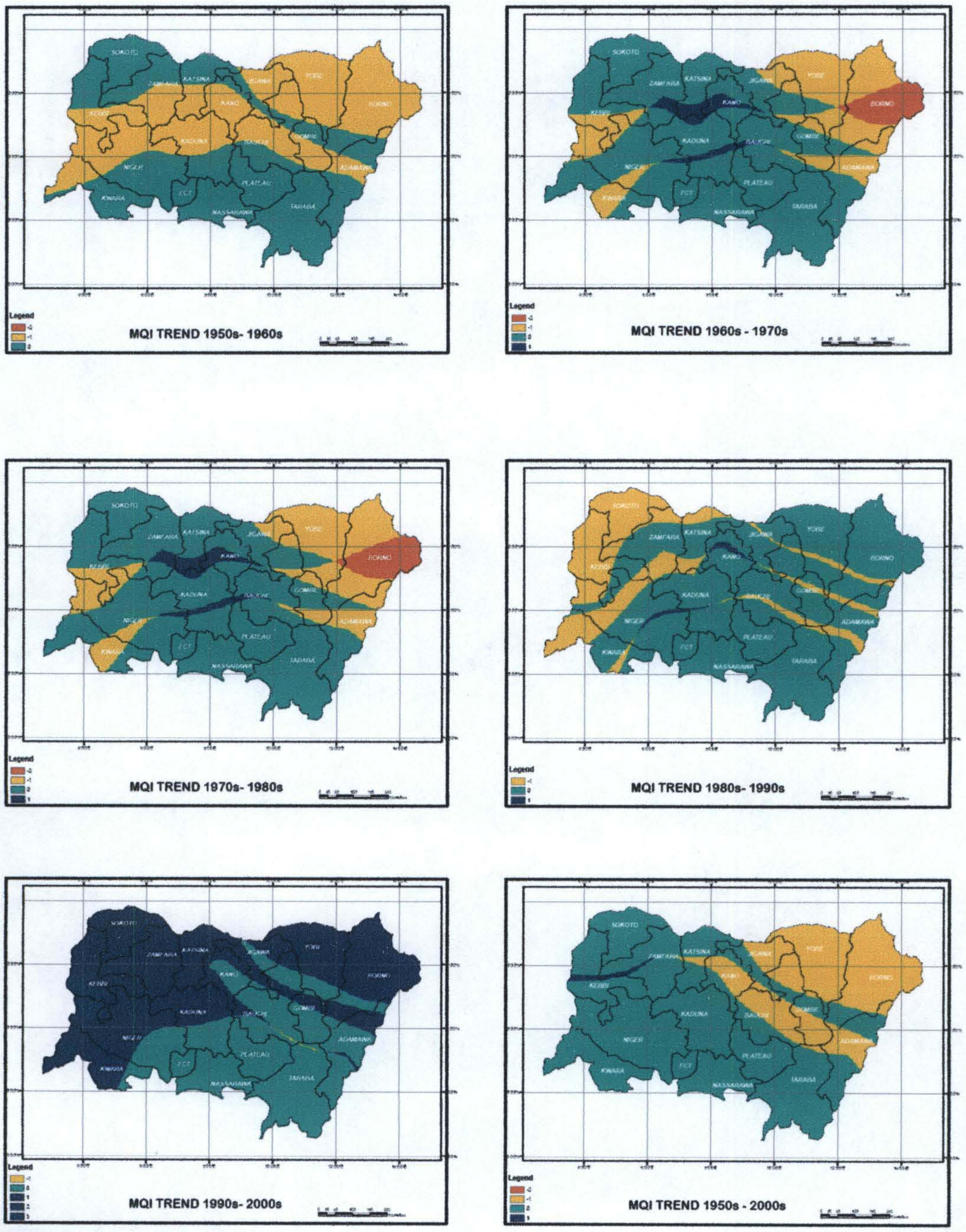


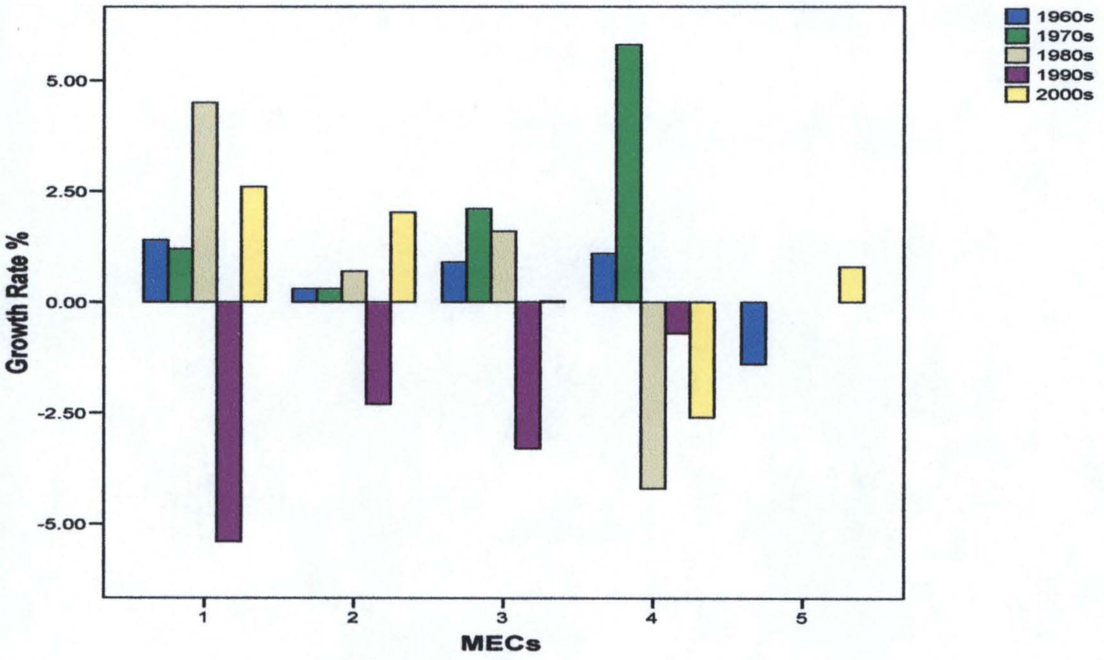
Fig. 4.53: MQI Image differencing (1950 -2006)

4.4.47 Spatio-temporal Aridity Growth Rate

Spatio-temporal aridity growth rate does confirm fundamental degradation of the northern Nigeria though; this has been most severe in the drought decades of 1970s and 1980s as seen for the entire factors (Fig 4.54 – 4.59b). It was obvious from the figures that the growth rate is irregular; slow between 1950s & 1960s, drastic within 1970s and 1980s and gradual between 1990s and 2000s though moisture appreciation during this period does not imply that moisture effectiveness returned to normal. The progressive moisture stress does constitute a source of adverse effects on plants and animals across the belt. Moreover, these variability rates confirm short, middle and long term southward shift of moisture zones thus, indicating continued degradation of the classic climatic zones across the region is inevitable.

4.4.48 Aridity Index Aridity Growth Rate

Aridity Index growth confirmed the gradual desertification in the belt; increase in area of high aridity (1, 2 and 3) and decline in spatial extent of low aridity (4&5).

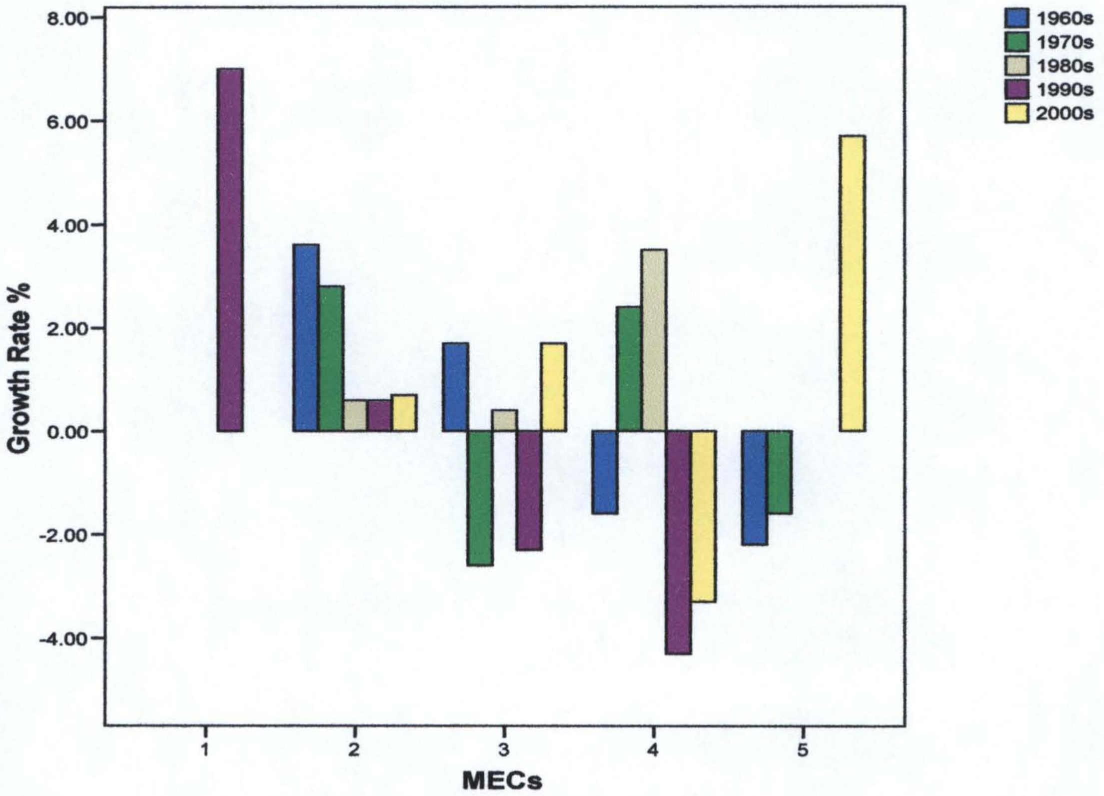


5,4,3,2 &1 = Lowest, Low, High, Very High & Extremely High

Fig.4.54: Aridity Index Aridity Growth Rate

4.4.49 Hydrologic Growing Season Aridity Growth Rate

Similarly, HGS attested desertification in the belt as there is spatial increase of shortest and short HGS zones (1& 2) as well as decline longest and long HGS zones (4&5).

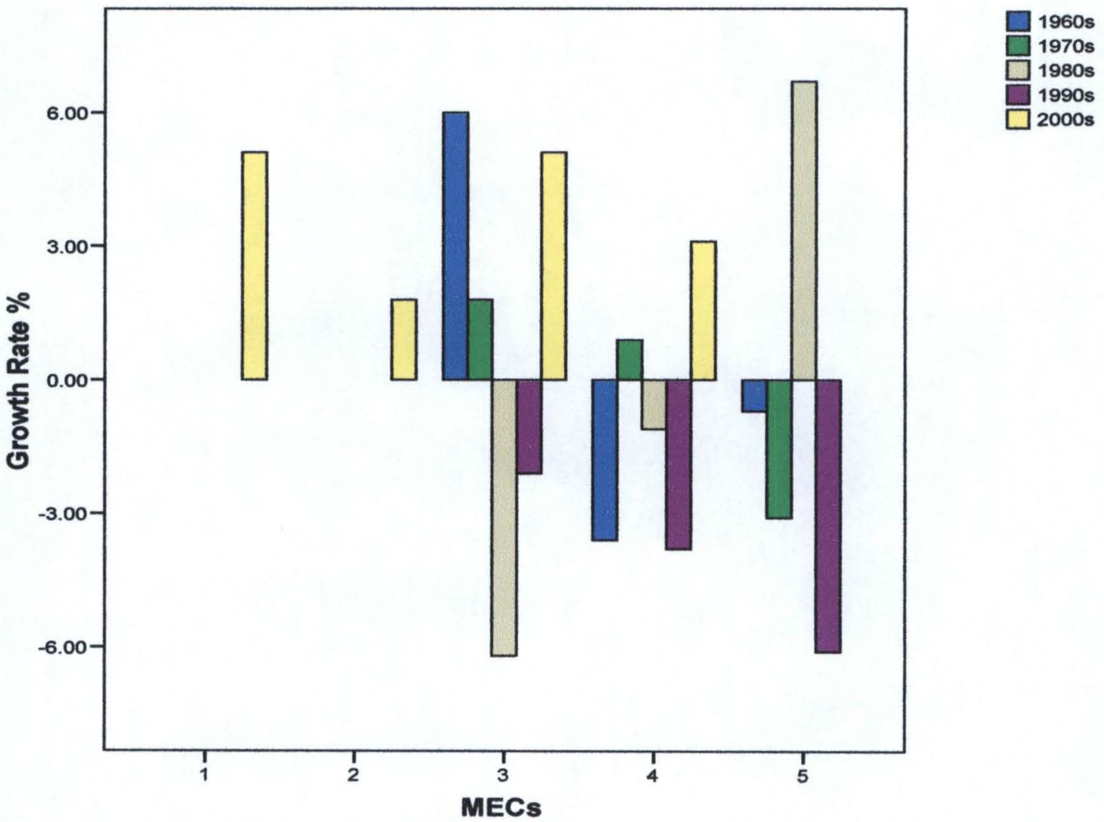


5, 4, 3, 2, & 1 = Longest, Long, Short, Very Short, Extremely Short HGS

Fig.4. 55: Hydrologic Growing Season Aridity Growth Rate

4.4.50 Cessation Aridity Growth Rate

Furthermore, desertification in the belt is affirmed by the appreciation in areas of early and very early cessation zones added to depreciation in areas of late and latest cessation zone.

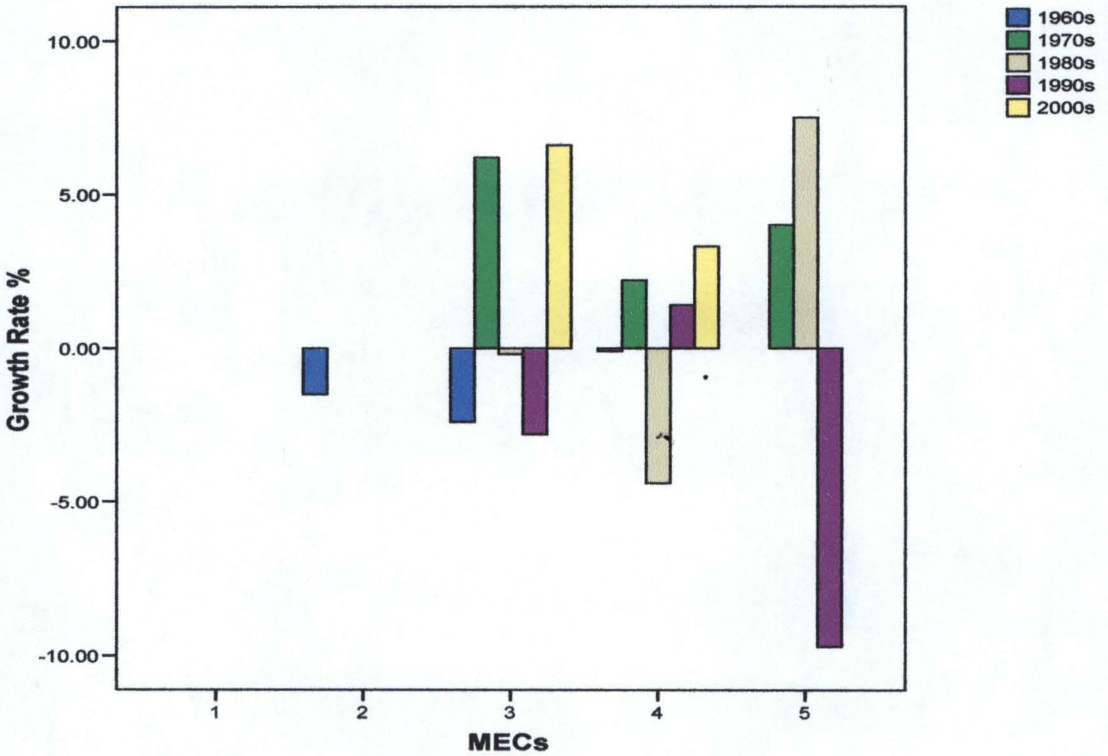


5, 4, 3, 2& 1 = Latest, Late, Early, Very Early & Extremely Early

Fig. 4.56: Cessation Aridity Growth Rate

4.4.51 Real Monsoon Onset Aridity Growth Rate

This unveil the severity of desertification in the belt; absence of earliest onset zone and disappearance of the early onset zone coupled with increase in areas of late, very late and extremely late RMO zones.

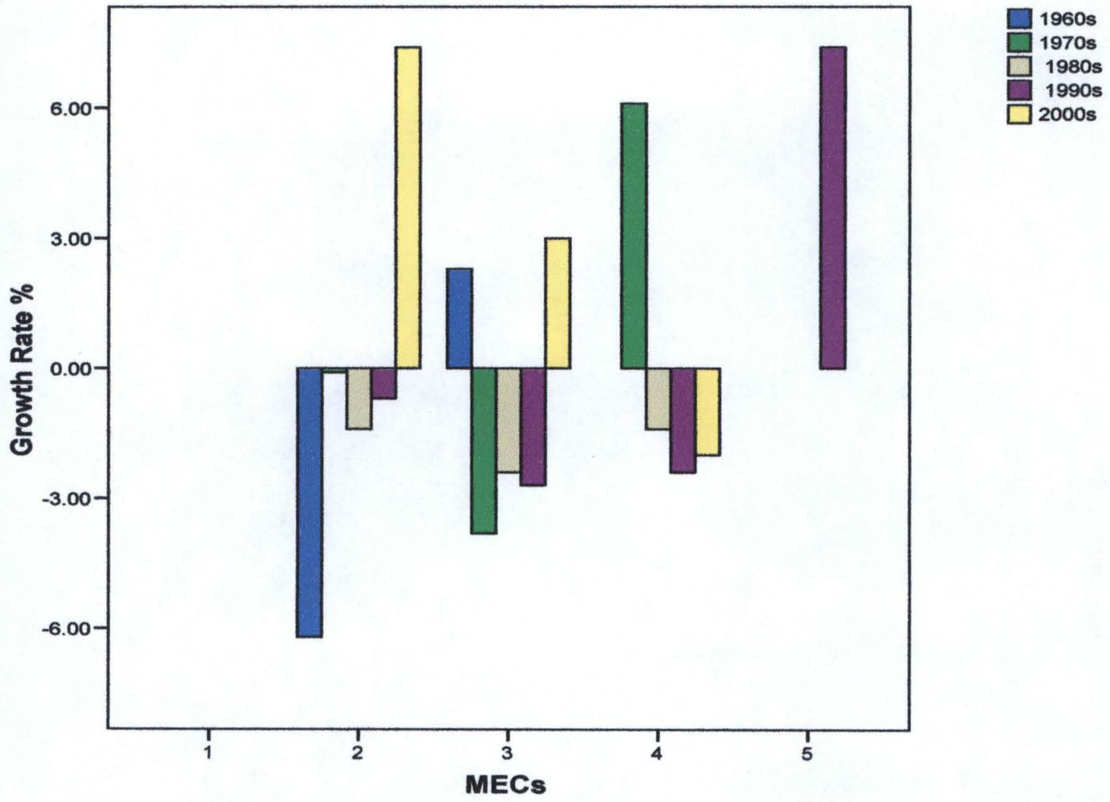


5, 4, 3, 2 &1 = Extremely Late, Very Late, Late, Early & Very Early

Fig. 4.57: Real Monsoon Onset Aridity Growth Rate

4.4.52 Monsoon Quality Index Aridity Growth Rate

Decline in adequate moisture zone in addition to appreciation in deficient, very deficient and extremely deficient moisture are indication of desertification in northern Nigeria.



5, 4, 3, 2 &1 = Extremely Deficient, Very Deficient, Deficient, Adequate &Abundant

Fig. 4.58: Monsoon Quality Index Aridity Growth Rate

4.4.53a Long –Term Cessation, HGS & AI Aridity Growth Rate

Long-term trend (AI, HGS and Cessation) reaffirmed desertification in the region; increase in areas of deficient moisture and reduction in spatial coverage of adequate moisture zone.

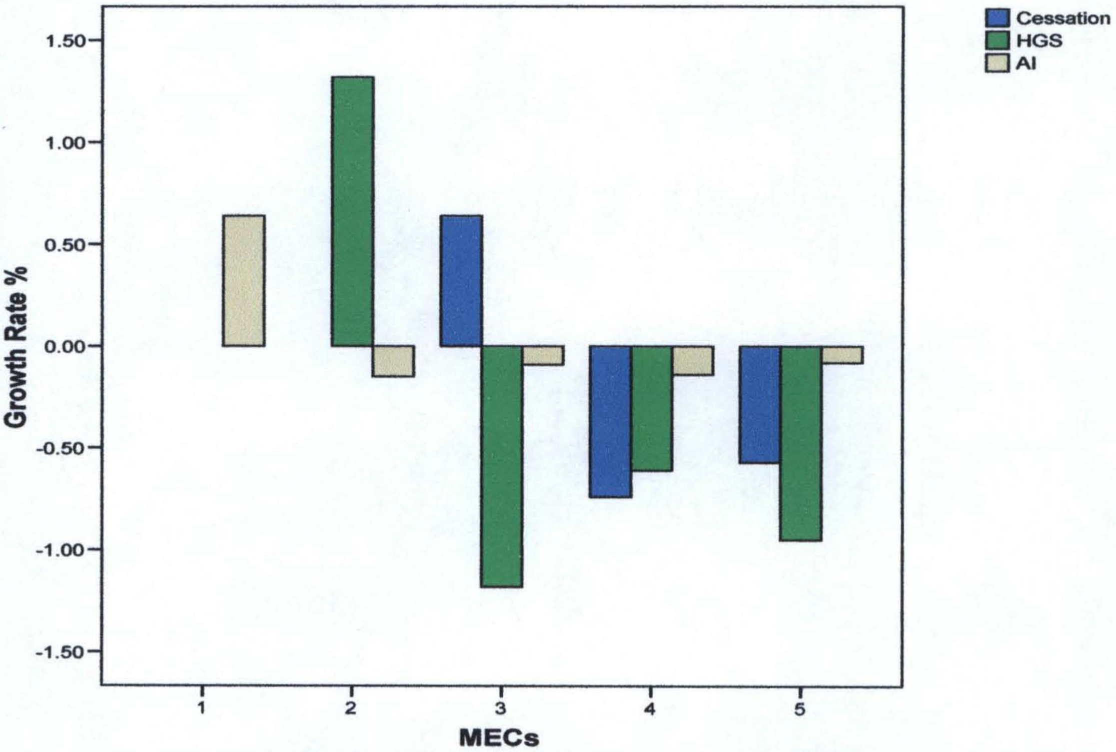


Fig. 4.59a: Long –Term (Cessation, HGS & AI) Aridity Growth Rate Graph

4.4.53b Long -Term Onset & MQI Aridity Growth Rate

Correspondingly, RMO and MQI long-term trend ascertained desertification in the northern Nigeria as there are depreciation in areas of adequate moisture with appreciation in the spatial extents of deficient moisture zones.

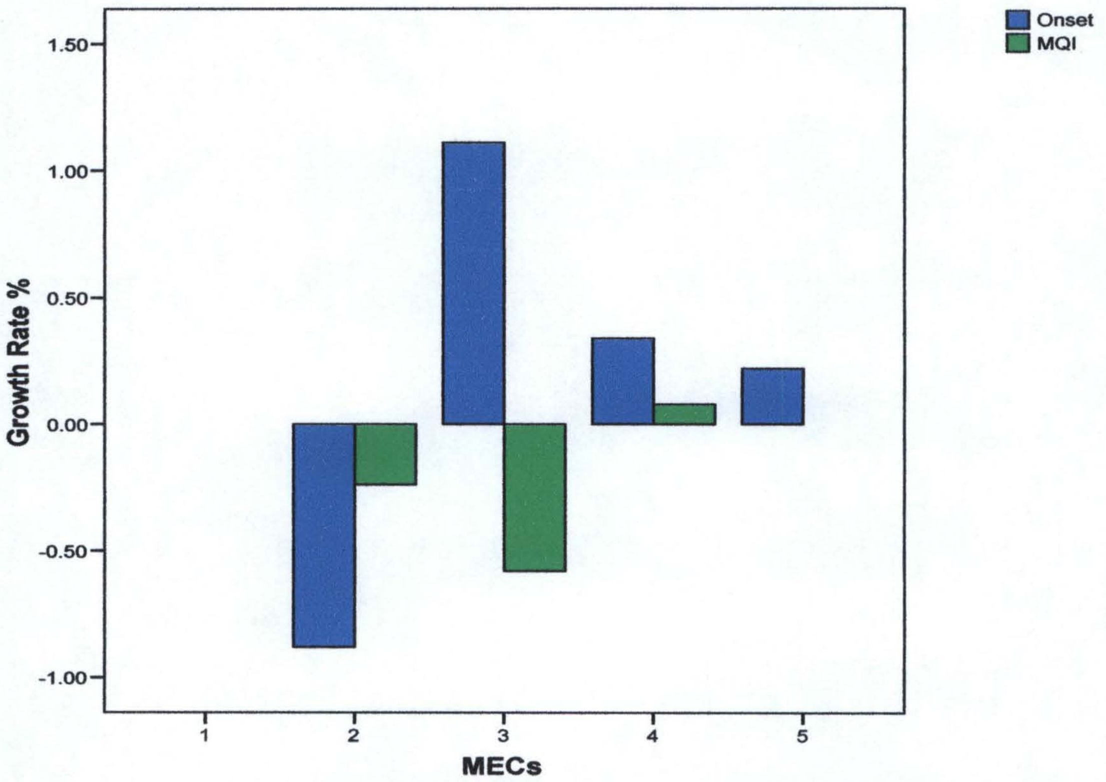


Fig. 4.59b: Long -Term (Onset & MQI) Aridity Growth Rate Graph

4.5 Vegetation Index

The result of SAVI vegetation index depicts the vegetation features over the entire northern Nigeria; the vegetation biomass (tall trees and grasses) is dominant to the south and around water bodies. Similar to other eco-climatic factors, vegetative biomass decreases northwards as the lowest values were recorded along the extreme north and parts of the north east (Fig. 4.60). SAVI unveil the vegetation biomass distinctive of the region (-0.33 – 0.71).

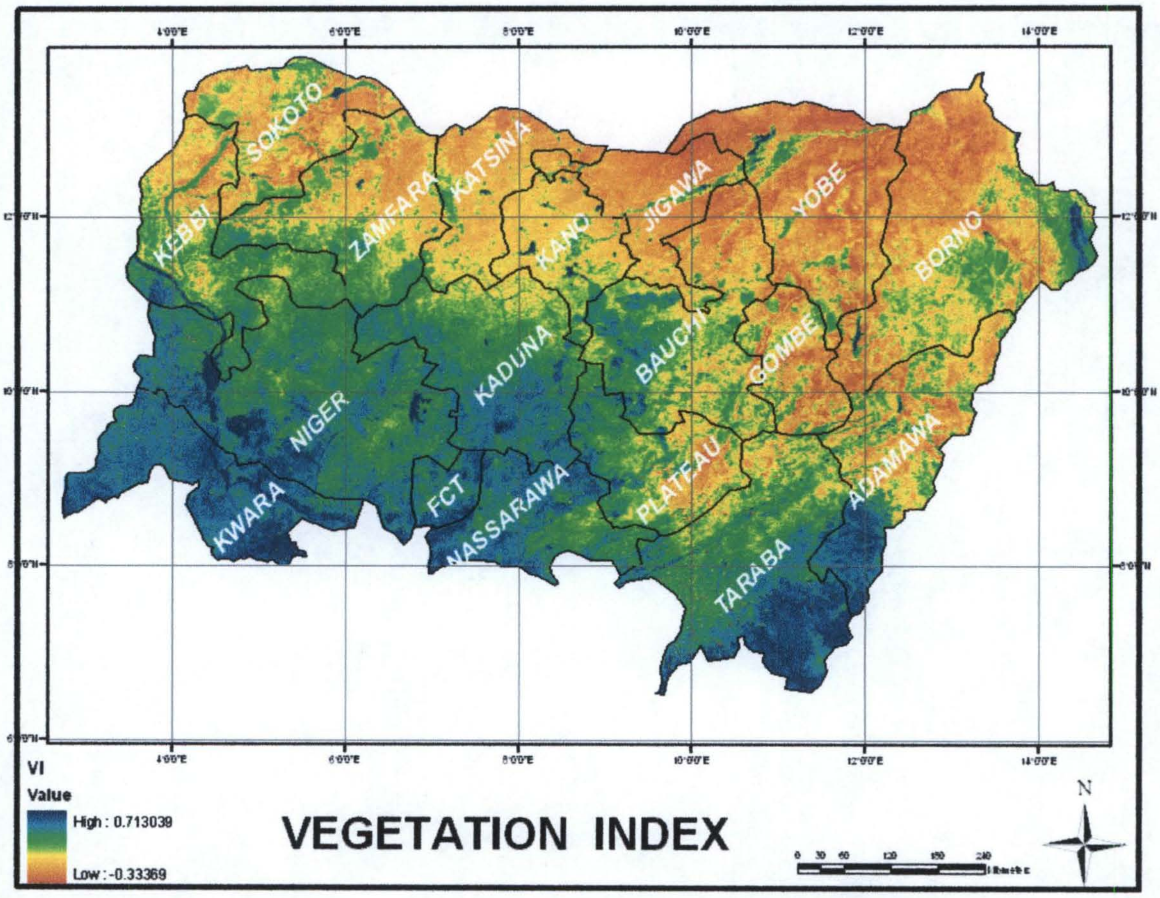
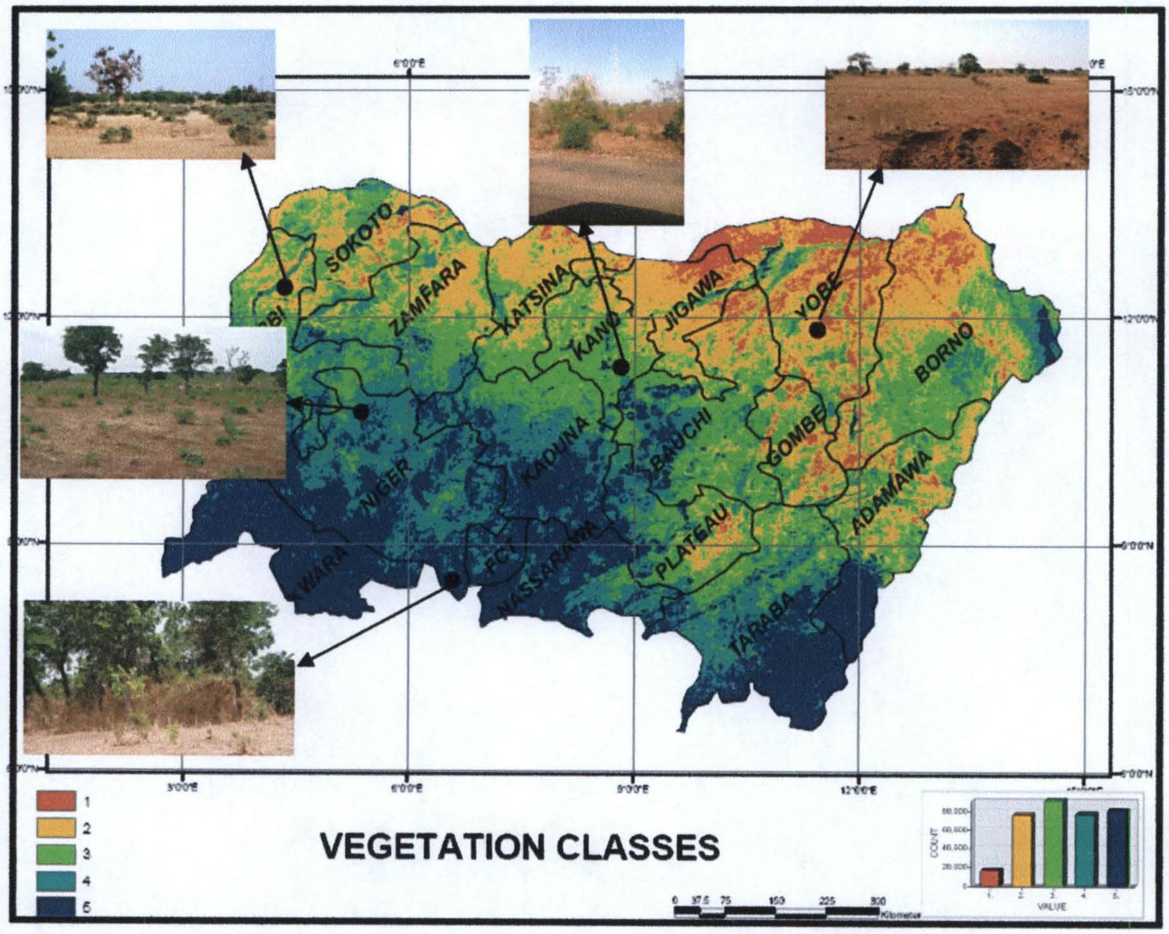


Fig. 4.60: Vegetation Index

4.5.1 Vegetation Classes

The SAVI vegetation values were quantitatively reclassified into five classes 1,2,3,4, and 5 representing bare ground, drought resistant species, scattered trees/shrub, Short trees/grasses and Tall trees/grasses. In response to the vegetation biomass, five vegetation classes were vegetation identified numerically, these unveiled that the tall trees and grasses are widespread to the south, while the drought resistance and bare ground are to the extreme north. Ground truthing using specific geographic location confirmed the depicted pattern of the vegetation classes' dominant in the region (Fig.4.61).



1, 2, 3, 4 &5 = bare ground, drought resistant species, scattered trees/shrub, Short trees/grasses and Tall trees/grasses

Fig. 4.61: Vegetation Classes

4.5.2 Vegetation Map

The derived vegetation map from spatial interpolation of vegetation index smoothen the variability that characterized vegetation biomass across the region. This depicts four vegetation zones, 2, 3, 4, and 5 with the tall trees/grasses prevailing along the south while resistant are dominant to the extreme north (Fig.4.62). Similarly, Maria *et.al* (1995) identified three different ecological characteristics in Niger Republic and Krishnaswamy et.al (2004), concluded that Satellite based vegetation mapping technique are relatively simple cost-effective alternative.

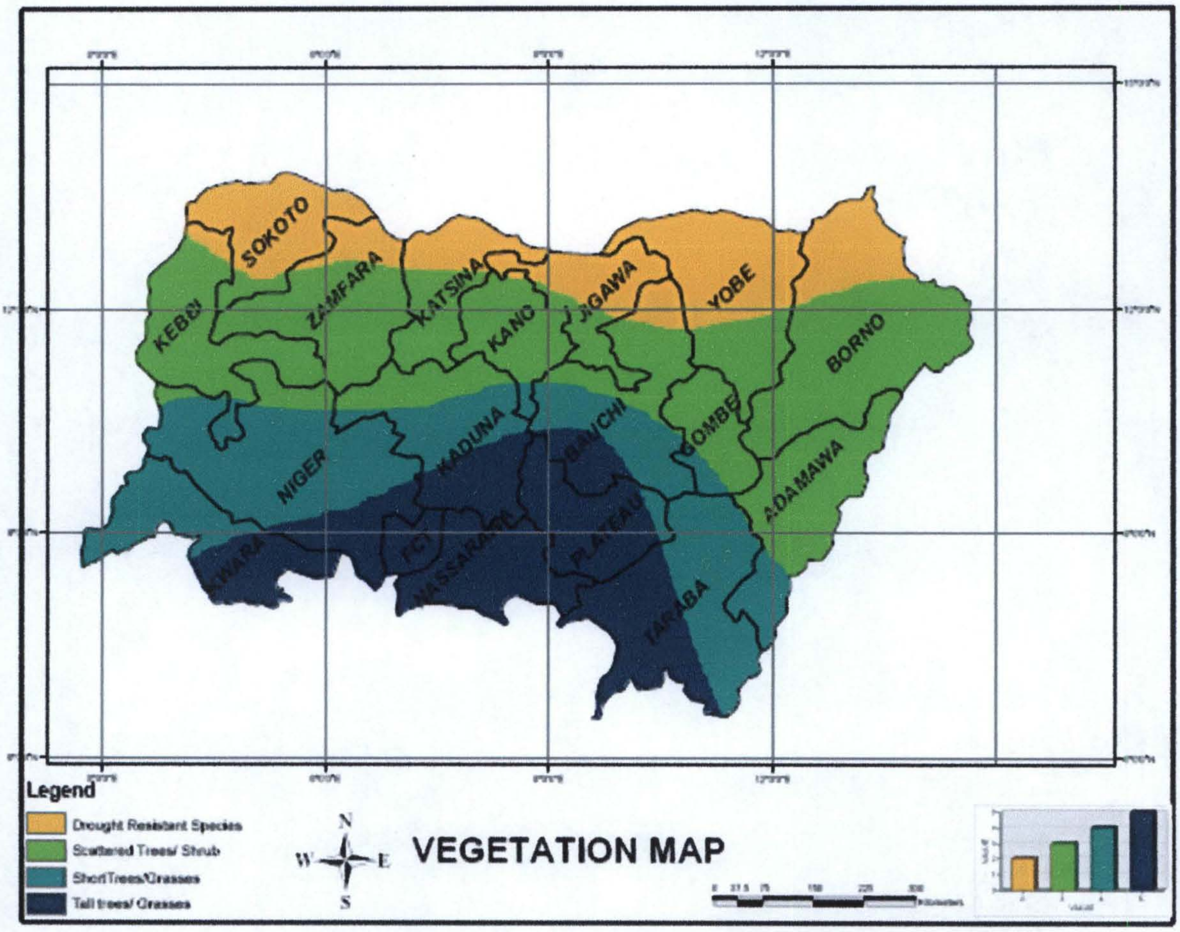


Fig. 4.62: Vegetation Zone

4.6 Geospatial Identification of Eco-climatic Zones

The eco-climatic index is derived from logical and theoretical grounds; using empirical relation (Eqn. 3.14). The integration of the entire factors using the empirical relationship reflected the moisture features typical of northern Nigeria. Eco-climatic index values decreased gradually from the south northwards, as was evident of all the factors signifying the accuracy of the index. The value ranged from 0.202 in the extreme north to 477.242 in the southern belt (Fig. 4.63).

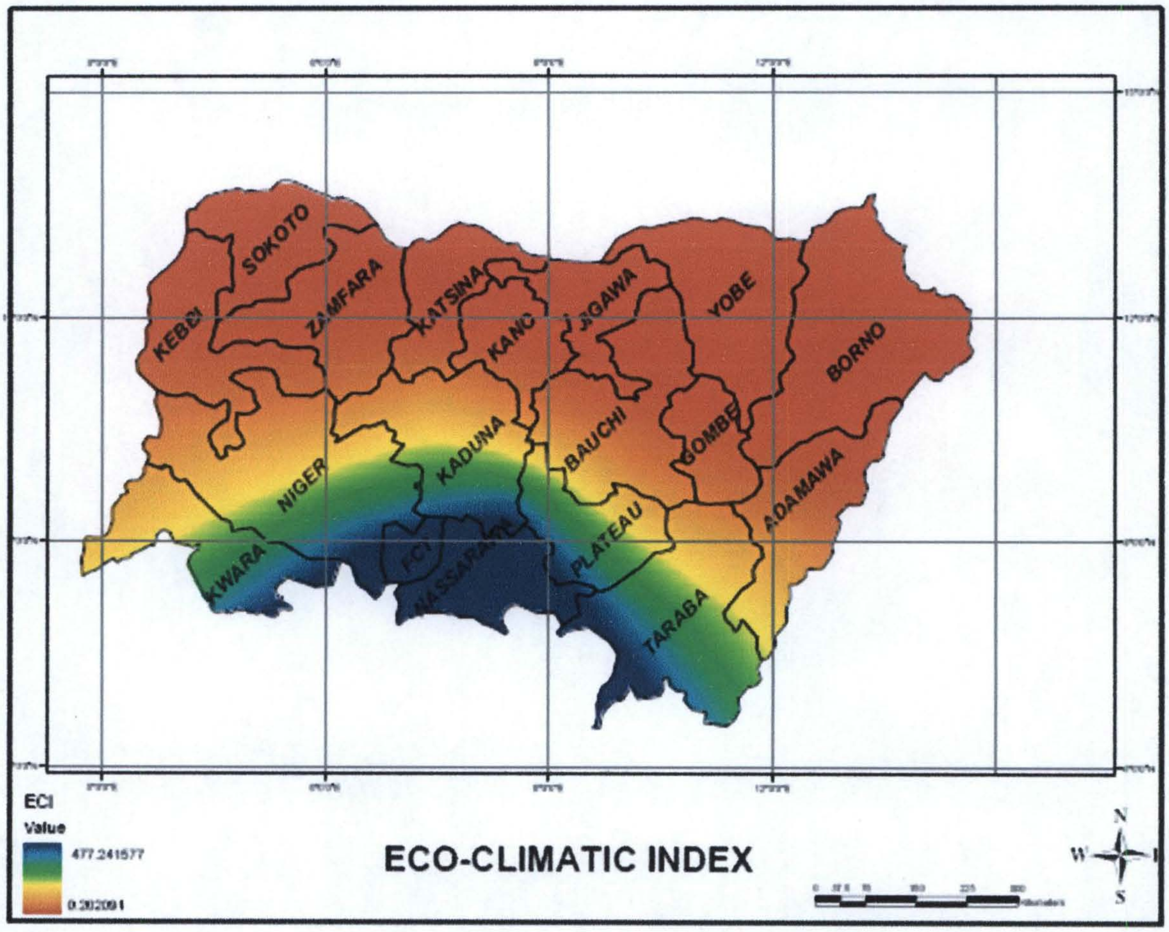


Fig. 4.63: Eco-climatic Index

4.6.1 Classification of the Eco-climatic Zones

The derived eco-climatic index was reclassified quantitatively using Table 3.5; consequently five eco-climatic classes were identified (Fig.4.59); **Semi-Arid/ Arid, Dry Sub-humid, Sub-humid, Humid and Wet** eco-climatic zones. Arid/Semi-Arid eco-climatic zone is most wide spread in the northern Nigeria; this stretches from northwest about (Lat. $10^0 20^1$N) through the central portion (Lat. $11^0 12^1$N) to about Lat. $9^0 27^1$N along the northeast. This eco-climatic condition covers the entire Sokoto, Zamfara, Katsina, Kano, Jigawa, Gombe, Yobe, Borno, and northern parts of Bauchi and Adamawa States. Moisture stress is homogeneous in this zone as evident in the eco-climatic index as it has the least eco-climatic index value (ECZ< 50), since all the eco-climatic factors are poorest in this zone. Southwards, eco-climatic zones are heterogeneous reflecting different levels of moisture effectiveness.

Dry Sub-humid climate extends from southern board of semi arid/arid zone to Long.4^0 E10^1 Lat. 8^0N 40^1 through Long.8^0 E9^1, Lat.10^0N16^1 to Long.11^0 E 46^1 Lat.7^0N 8^1. It spread across northern Niger, Kaduna, Plateau and Taraba States, in addition to southern parts of Bauchi, and Adamawa States. This zone is characterized by low eco- climatic index ($50 \leq$ ECZ ≤ 150).

Three varying strips of humid zones are identified; Sub-humid consists of a narrow zone stretching from the southern margin of Sudan climate to Lon.4^0E 53^1 lat.8^0N 7^1 through Lon.8^0 E 30^1 lat. 9^0 N 32^1 to Lon.10^0 E 35^1 lat.7^0 N 12^1. This is found across the central portion of Kwara, Niger, Kaduna, Plateau and Taraba States with eco-climatic values $150 \leq$ ECZ ≤ 250. Humid ($250 \leq$ ECZ ≤ 350) spreads from the southern boundary of the Sub-humid zone to Lon.6^{0}E 31^{1}Lat.8^{0}N26^1 and Lon. 9^{0}E 7^1 Lat.7^0 N 53^1 covering southern parts of Kwara, Niger, Kaduna, Plateau and Taraba States as well as, northern parts of FCT and Nassarawa State. The Wet eco-climatic zone is found mainly in parts of FCT, Nassarawa and the extreme fringe of Niger and Taraba south. The highest eco-climatic index ($350 \leq ECZ \leq 448$) is recorded in this zone.

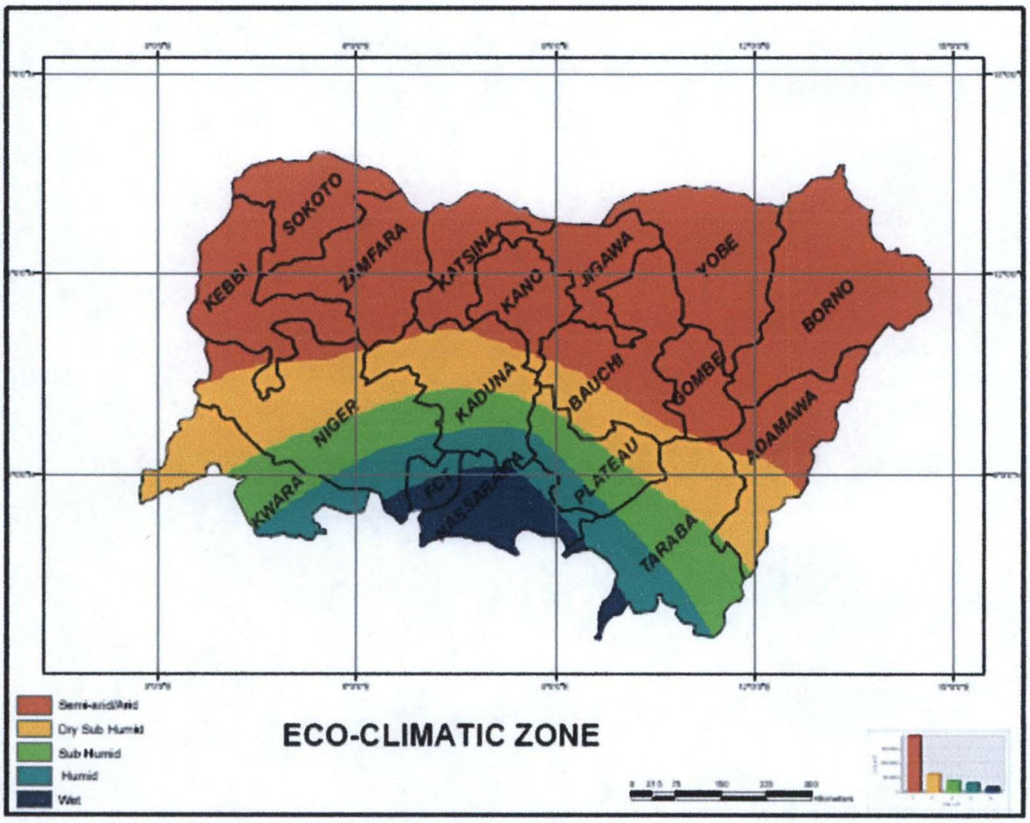


Fig: 4.64: Eco-climatic Zones

4.7 Comparison of Eco-climatic Zones and Climatic Regions

Iloeje (1976) identified four climatic regions in Nigeria; Subequatorial South, Tropical Hinterland, Tropical Continental North and High Plateaux climate (Fig: 4.65). This climatic classification was based on precipitation, temperature and relative humidity annual means values and totals. Centre for Climate change and Fresh water Resources Eco-climatic Atlas only plotted States and regional eco-climatic parameter maps for the six geo-political zones other than climatic or eco-climatic map. Furthermore, Nigeria Meteorological Agency produce annual rainfall prediction maps using derived rainfall parameter. However, all these do not integrate ecological parameter (vegetation biomass) with derived climatic parameter.

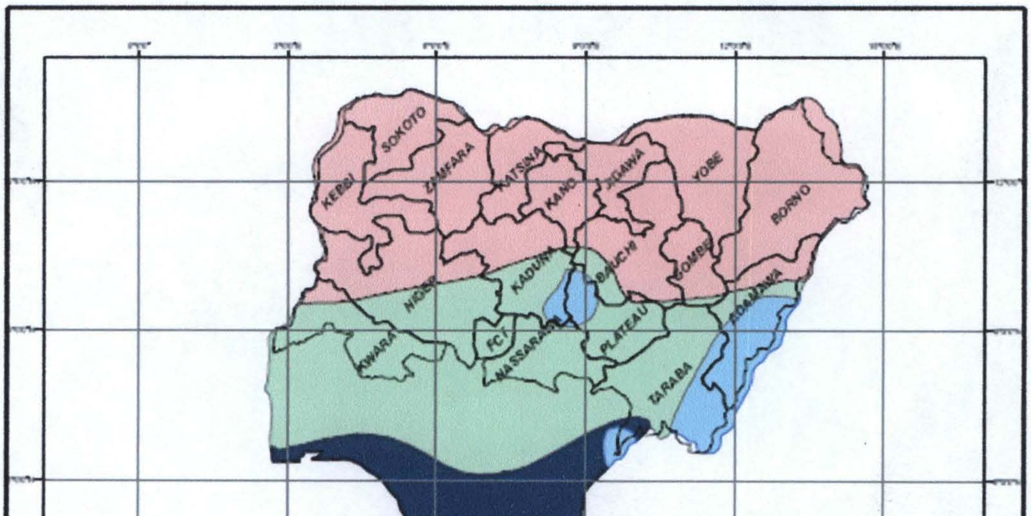


Fig: 4.65 Climatic Regions (Source: Iloege, 1976)

In contrast the current eco-climatic zone map is based on the integration of derived precipitation and vegetation data using Geospatial technique and empirical relationships to distinguish eco-climatic sub-units. As against Iloeje's classification that was based on broad regional levels and traditional vector map overlay. This does not identify micro variations in the ecological and climatic zones for planning purposes across the region. This study identified five eco-climatic zones; Semi-arid /Arid, Dry Sub-humid, Sub-humid, Humid and Wet eco-climatic zones with underlying implication of drastic transformation of the regional climatic zone; Tropical continental north to Semi-arid /arid and Dry sub-humid. The classical Tropical hinterland shows actual characterization of varying humidity levels; Dry Sub-humid, Sub-humid, Humid and Wet eco-climatic zones (Fig: 4.66)

4.7.1 Eco-climatic and 1976 climatic Zones Comparison

Comparison of the regional climatic and eco-climatic maps revealed significant transformation of the regional climatic zones.

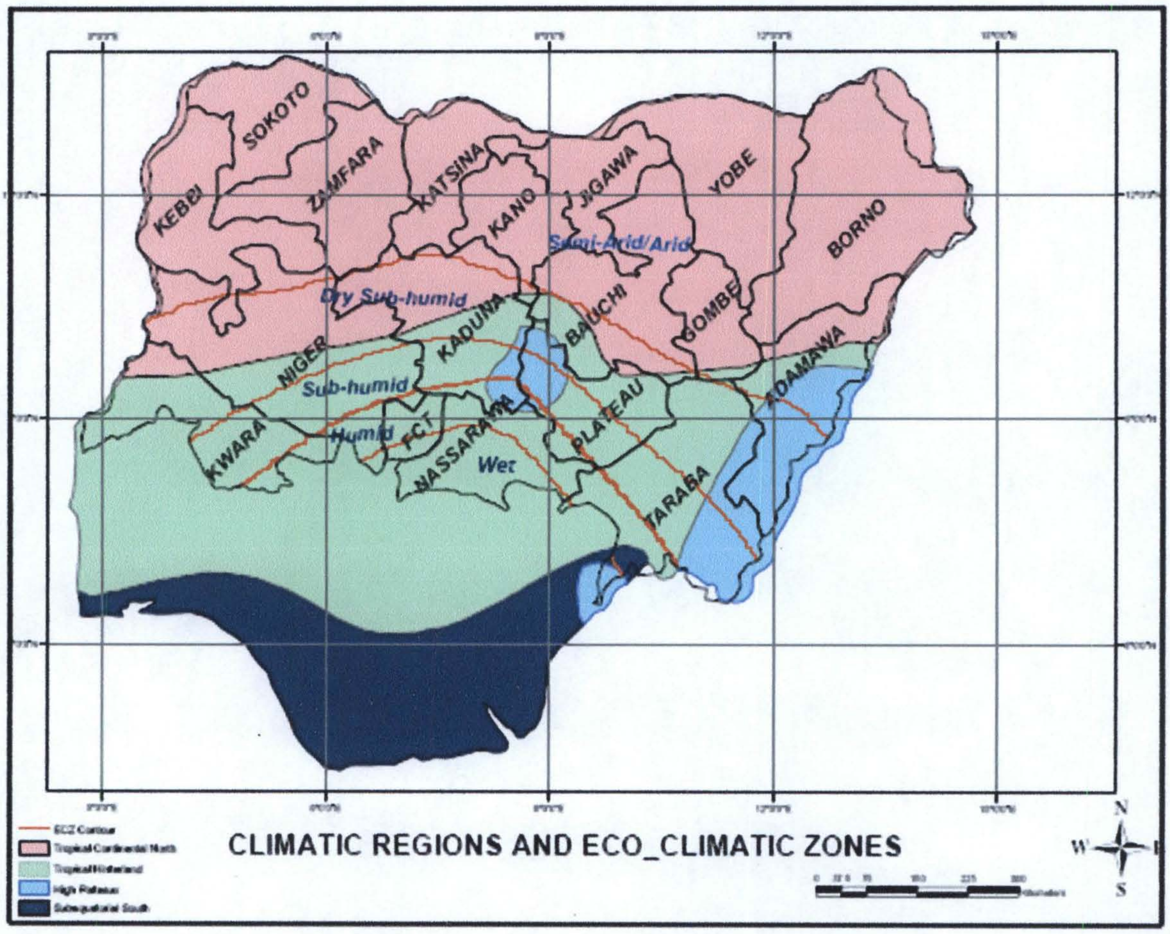


Fig: 4.66: Eco-climatic and 1976 Climatic Zones Comparison

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion

The results of eco-climatic parameters, spatio-temporal trend of the factors, geo-spatial identification of the eco-climatic zones, eco-climatic classification and comparison of the ECZs and the regional climatic maps are discussed.

5.1.1 Eco-climatic Parameters

The factors moisture effectiveness indices and maps (figures 4.1 - 4.10) illustrate the spatial extents of each factor moisture effectiveness classes throughout northern Nigeria and the challenges for the sustainability of the physical environment. The physical consequences of moisture deficit and steady deterioration of the physical environment has dictated the need to provide accurate information designed towards the achievement of sustainable development. By this result, the entire northern Nigeria is vulnerable to crop failures as vast proportion of the region is characterized by vary levels of deficient moisture quality, late onset, early retreat of rainfall and shorter hydrologic growing season that were hitherto obvious. Srikantha and Uditha (2004) identified decline in the numbers of rainy days.

These are disastrous to agriculture, as delayed onset often leads to late planting of crops, while premature cessation and shorter HGS leads to wilting and dryness of the crops before maturity and consequently, poor yield. Onset, cessation and length of the Hydrologic Growing Season (HGS) are more critical plant (Adefolalu, 1986a). High aridity index and moisture quality reduce bio-productivity and all these endanger food security. Generally, the entire surface map affirms that the eco-climatic features are extremely variable and potentially associated with different forms of economic and environmental disruption (stress). The scenario calls for identifying reliable and adequate information on the state of the environment.

The Principal Component Analysis (PCA) carried out spelt out the union between the features of the best and worst MEZs with the intersection between the various classes defining the relationship between the various factors. The lack of union particularly between the intermediate MEZs and the intersection between these classes also signals the fact that all the factors have certain unique features and have some relationship as evidenced in the overlap of the MEZs. Leonard and Felix (1998) showed that temporal and spatial characteristics are vital in change detection and mapping. Thus, necessitate the use other available techniques for smoothening this variability to provide adequate information on the state of the environment. Generally, MEZs do not vary in the same way. Specifically very early onset does not necessarily imply very good moisture quality or aridity index. As a result, integration of all the factors with biophysical state of the environment (derived from satellite images) using empirical relations should be the basis for improved management of the vital resources (land & water).This will give an insight into specific management actions that will minimize the progressive ecological degradation and enhance food security in the region and the county at large.

The derived Moisture Effectiveness Map (MEM) indicates that moisture effectiveness across the belt decreases progressively northwards as expected (Fig. 4.13). Underscoring why the extreme north is characterized by extremely deficient moisture and very deficient moisture zone this extends to about Lat. 12^0N and Lat. 10^0N in the northwest and northeast respectively. To provide fundamental information for moisture stress and adaptation strategy in the region, the strong positive correlation between the factors and MEM along with a regression analysis returning R^2 to 90%, was used to integrate these eco-climatic characteristic using GIS. Since climatic variation is fundamental to environmental quality and food security in the zone, such information will enhance the sustainability of biotic and the abiotic resources and provide an optimal environment for sustainable agriculture. Furthermore, general positive relationships that exist between the factors and moisture effectiveness map confirm that all these factors are fundamental in the identification of soil moisture stress in the zones.

5.1.2 Spatio-temporal Trend of the Eco-climatic Parameters

Trend and aridity growth rate analysis of the entire factors unveils short, medium and long term moisture quality dynamics that characterise northern Nigeria. High frequency climatic variability changes are driven by climate change (Stenphenne 2004 & Kiunsi and Meadows 2006). The short-term changes are distinctive of inter-annual variability in moisture effectiveness and the middle term changes are indicative of drastic decadal changes noticeable of the drought decades (1970s and 1980s) that generally exaggerate moisture stresses in the region. Zeewdu and Peter (2004) stated that (1982-1983) *karent* onset was later than normal. The long term changes are suggestive of significant changes that occurred between 1950s and 2000s, in which abundant and adequate moisture zones decline, skewed to southwest and central portions. Desertification is driven by a limited suite of recurrent core variables (Helmut and Eric 2004). Furthermore, deficient, very deficient and extremely deficient moisture supplies typical of northeast, spread to the northwest and extreme north central. This trend confirms the steady desertification process and south wards shift of eco-climatic zones.

The general appreciation of moisture effectiveness in the 1990s and 2000s does not imply moisture effectiveness normalized or that there was ecological stress recovery. The enhanced moisture could not be adequate to reverse the gradual moisture stress for two decades (1950 – 1970) and severe stress that characterised the 1970s and 1980s. Drought resulted in broad scale plant die-offs in shrublands, woodlands, and forests and accelerated shrub invasion of grasslands (Thomas and Julio 1998). Moreover, long-term changes are evidenced in the general increase within the areas of deficient, very deficient and extremely deficient moisture zone across the region along with decline of adequate and abundant moisture zone to the south.

In general, the spatial increase in the spread of areas of deficient moisture within 1950s to 2000s signals the migratory trend of the eco-climatic characteristics resulting in the apparent ecological stress in the zone. Decreased amount of vegetation have been identified between 1973 and 2001 (Susana and Keller, 2006; and Hahn *et al.*, 2005). The aridity growth rate analyses (1950 -2006) of (AI, C, HGS, MQI and Ø) signalling rapid advancement of desert condition in response to short, middle and long- term climatic fluctuations. Consequent on the above, the potential of persistent/recurring drought in radically aggravating aridity is reaffirmed and could easily be aggravated by climate change.

Also noteworthy is the spatio- temporal moisture effectiveness analysis reveals a negative moisture trend which confirms drastic degradation and southward shift of the eco- climatic zones in the last four decades (figure 4.14- 4.54b). Planners are therefore required to identify ways of coping with the current eco-climatic zones using significant approaches tied to the carrying capacity of the natural environment. Critical nature of the rains over the Sahel with respect to its impact on agriculture makes it mandatory that effective means are evolved for the assessment of the problems of drought and mitigation planning Usman (2000b). Specifically, the 1970s and 1980s generally reflect the period of agrarian economic stagnation, as evident in the disappearance of the country's agricultural crop export and the decline agricultural production obvious in the country to date. During these periods the extreme north stretching from Maiduguri through Katsina to Sokoto was under extremely deficient moisture condition. Maiduguri and Nguru onset records actually indicate some years without effective rainfall onset implying HGS was zero. This trend portrays the fact that the climatic conditions in the study area have changed due to the complex drought and climate change making this belt to be highly vulnerable to irreversible ecological degradation.

These decadal derivative maps of moisture effectiveness classes portray the belt's vulnerability to desertification. Visualization of the eco-climatic characteristics illustrates drastic deterioration of moisture effectiveness and migration of moisture effectiveness southwards (Fig. 4.14 – 4.48). The areas of deficient moisture zones are grew significantly; AI appreciated from about .3 to 4.5%, MQI 2.3 to 6.1%, HGS .4 to 7%, onset 1.4 to 7.5% and cessation 1.8 to 6%. In addition, good moisture zone declined AI at about -1.4 to -4.2%, MQI -.7 to -6.2%, HGS -1.6 to -4.3%, onset -.1 to -1.5% and cessation -.7 to -6.3%

(Fig.4.49 - 4.54b). Of particular concern are potential increases in tree mortality associated with climate-induced physiological stress, Craig *et. al* (2009). Also, Musa and Bukar (2010) showed a noticeable significant decrease in vegetation fraction in 1973, 1986, and 2006. These analyses confirm the anticipated eco-climatic shift in the zone, virtually, all the moisture zones shifted southward but most drastically during the drought decade. Furthermore, these unveil the creeping rate of desertification in the region. These trends depict the potential decline in moisture effectiveness that could trigger a worsening of the negative socio-economic conditions which threaten political stability, environmental sustainability and the general quality of the biotic and abiotic life in the region.

In addition, during these extended dry condition temperatures are high and evapo-transpiration is high thereby leading to high potential evapo-transpiration as a result aridity index is declining. Rainfall amount is concentrated in few days and moisture quality is getting poorer. Consequently, desertification is a threat to the majority of the population who derive their livelihood from subsistence agriculture. As Nsofor (2003) rightly put it, we are in a crisis of survival for aridity or desertification is a reality. Thus, the challenges of environmental sustainability lie on adequate information on the State of the environment. Also, the ultimate goal for the achievement of sustainable development and food security lies on accurate and up to date information.

5.1.3 Geo-spatial Identification of Eco-climatic Zones (Eco-climatic Index)

The mathematical combination of various layers to derive eco-climatic index and map of the northern Nigeria illustrate moisture variability typical of the region. Andrade *et al.* (2005) observed that spatial and temporal rainfall variability scenario is more compatible to the physical reality. The derived climatic and ecological variables are the building block for defining the zones in quantitative terms. The derived maps show clearly the vulnerability of the entire belt to drought, desertification and crop failure. In addition, they identified the fundamental moisture condition patterns that could fill the gap of inaccurate and out-dated information evident of the developmental processes in the country. Reliable and sufficient geo-spatial information is shown here to be vital for sustainable development of any nation, since adequate, accurate maps and geo-spatial data base can provide basis for any developmental decision. As a result, these eco-climatic indicators and map are crucial environmental indicators and fundamental tool for natural resource management in this belt.

The homogeneous moisture stress identified in the Arid/ Semi-Arid zone beyond Latitude 10^0N is an indication of drastic desertification in northern Nigeria. Desertification is a serious threat to arid and semiarid environments—which cover 40% of the global land surface and are populated by approximately 1 billion humans (Veron *et.al.*, 2006). This trend is disastrous to the agricultural sector, rural livelihood and can escalate food insecurity.

5.1.4 Eco-climatic Classification

These derived eco-climatic indices provide detailed and accurate information on the eco climatic zones. Furthermore, the derived eco-climatic map depicts the present State of eco-climatic zones in the region. Designation of tension zones is an important prerequisite for formulating national polices that address land degradation and desertification (Eswaran, *et al.* 1998b). The derived eco-climatic map reveals that the eco-climatic index is fundamental for identifying, delimiting, and describing the major types of eco-climatic conditions in quantitative terms; moreover, it is sensitive to climatic variation across the region.

The most important point which emerges from the study is the need to identify the heterogeneity in the eco-climatic zones across the belt in the national planning policy. In addition, designs a tool for enhance agricultural productivity, poverty alleviation and environmental sustainability. The sustainable management of environmental resources is not possible until their worth is appreciated and an appropriate price is paid for the benefits received (Soussan 1992). The identified variability in the derived eco-climatic zone are of tremendous importance for farmers and, indeed, all the inhabitants, because agricultural productivity to large extent is a function of eco-climatic condition. Therefore, identification of these zones could enhance crop suitability planning across northern Nigeria. It is inevitable from the resultant map to promote water control and conservation particularly, in areas beyond Latitude 10^0N. The irrigation schemes will minimize the effect of drought, augment all year round cultivation, ensure enough pasture and water for livestock and lessen the dangers of flooding downstream as already evident in the region. Moreover, in severe drought years that onset dates and HGS are insignificant (especially around Nguru and Maiduguri) irrigation agriculture will minimise the effect and reduce southward migration that usually characterized such years.

The apparent and widespread desertification across the northern region could result to meteorological changes will reduce rainfall effectiveness. By inference, the identified changes imposed localised impacts on regional circulation system and super-imposed global variability pattern, indicating drought and crop failure are inevitable in the region.

The spatio-temporal trend indicated that the belt will become drier as such that the dwindling availability of the vital natural resources required for survival will be aggravated. Suggesting, food insecurity, famine, loss of biodiversity, poverty, women and children labour and socio-economic instability will be severe in the region. Accurate assessment of the status, change, and trend of desertification will be instrumental in developing global actions to prevent and eradicate the problem (Yang *et.al* 2005). The majority of the population in this belt live in rural areas where the primary occupation is agriculture (rainfed), so the identified trend is a threat to economic growth. Consequently, identification of the current eco-climatic zones provide accurate and adequate information fundamental for the achievement of food security and sustainability of the physical environment in the belt where most economies are mostly agro-based.

5.1.5 Comparison of Climatic Regional and Eco-climatic Zone Maps

Iloeje (1976)'s climatic map identified four climatic zones over the whole of Nigeria; high plateaux, subequatorial south, tropical hinterland and tropical continental north. This classification was based on quantitative definition of temperature and precipitation values [Koppen 1918 method-strahler (1969)]. Generally, Köppen's limits are basically simple averages of the directly observed values of the climatic elements. It has been evident for a while (Usman et.al. 2005) that these parameters alone cannot explain conditions pertinent to environmental sustainability in dry and dry sub-humid environments. The challenge therefore, is to use accurate and reliable methods to compute the derived parameters (onset, cessation, HGS and MQI) with little or no generalization. For example, NIMET (2008) prediction delineated the north eastern zone as a zone with 80 – 120 days of HGS and CCCFR (2005) also classified north western zone with 100- 120 HGS days. How these days of potential plant growth and development will be distributed throughout the season and how the rainfall receipt could be translated into actual moisture available to plants is not considered. This has remained the single reason why despite apparent seasonal improvements in the total rainfall receipt, crop failure has remained an issue across the belt. Consequently, the present study captured the moisture stress across the belt, better identifying the extreme northeast as a zone with less than 60 days of HGS, the northwest extending to the northeast with less than 90 HGS days signifying that crop failure is inevitable across the zone. Similarly, NIMET's 2008 rainfall prediction long-term mean onset forecast dates was 15 – 30th March for most State in the middle belt of Nigeria as against 10 – 25th May using IRMI that considers both cumulative totals and temporal spread.

Generally, the country's climatic classification is based on broad regional levels which do not identify sub-units for the purpose of landuse planning and other practical purposes. In addition these classifications are based on methods that are about two centuries' old or cumulative values despite the growing level of knowledge and technology. Above all, researches have attested to the fact that mean and total rainfall figures are irrelevant for plant growth and development. Thornthwaite (1948), Denton and Barness (1988), Andrade *et.al* (2005) and Dantas *et.al* (2007) identified precipitation effectiveness and plant growth as fundamental in climatic classification. Consequently, climatic classification on the basis of mean temperature and precipitation values is not crucial for plant requirement as does the classifications based precipitation effectiveness and vegetation biomass. It identifies the remarkable evidence of progressive transformation of tropical continental north to Arid/ Semi-Arid eco-climatic condition and Dry Sub-Humid eco-climatic condition is the transition zone between the dry north and the humid south. Tropical hinterland shows diversified level of humidity; Sub-humid, Humid and wet eco-climatic zones. Ecosystems are liable to undergo sudden discontinuous transitions from a vegetated to a desert State Sonia *et al.* (2007), these necessitate the re-appraisal of the broad regional classification that has been in use and the need to capture the variation within the topical areas for developmental policy.

5.1.6 Implication of the Observed Trend

The spatial spread (lat 9^0 -$14N^0$) of northern Nigeria justified the eco-climatic range that is evident of the entire factors across the region. The early effective onset of rain, late cessation, longest HGS, lowest aridity index values and adequate effective moisture zone to the south, is an indication that southern belt may support cultivation of most crop species in the zone. The gradual moisture stress northwards could be use to identify crop suitability for each eco-climatic zones base on moisture effectiveness across the region. Similarly, John and Barry (1998) recognized the characteristics of climatic events, the ecological properties of systems which mediate effects, and the distinctions which are possible among different types of adaptation. Furthermore, the decline trend of moisture effectiveness (intensification of moisture stress) in the region, necessitate the need for the development and adoption of drought resistant species across northern Nigeria, as this will minimize the recurring crop failure that characterized the region.

The spread and intensity of drought in the region signals variability and transformation of the regional climatic zones. Understanding of the nature and future climate change has led to a realization that significant future impacts are inevitable and increased efforts towards understanding the process of adaptation to the threatened impacts are required (Adger 2001). Consequently for the attainment of food security and sustainability of the physical environment, identification of micro-sub eco-climatic zones is inevitable. The southward migration that is typical of 20th century to date is only in response to the southward migration of the climatic, eco-climatic and agro-climate zones. In response the quantitative designation of eco-climatic index at pixel level will enhance crop suitability decision at specific location across the region. The drastic reductions in rainfall effectiveness and the identification of long-term changes in eco-climatic parameter in northern Nigeria may have huge potential in mitigating the impact of climate related disaster and minimizing the recurring crop failure.

By inference trend analysis and eco climatic map indicate drought severity in the region is a function of negative trend in rainfall effectiveness. The negative trend of eco-climatic factors explains the impact of climate change on the natural environment that adversely intensifies drought and recurring crop failure widespread in the region. Peter (1998) states that a wide range of ecological and human crises result from inadequate access to, and the inappropriate management of the resources. The eco-climatic parameters trend is fundamental for the identification of adaptive measure that may boost the efficiency of food production. Particularly the varying levels of late effective onset, earlier cessation, shorter HGS, higher aridity and deficient moisture quality trend of rain can be use to develop cropping calendar to enhance agricultural productivity. The decline in the hydrologic growing days may be use to selected appropriate species that will grow to maturity within the HGS across the region, semi-desert and desert species should be adapted in the semi-arid/arid zone. In addition the identified eco-climatic condition suggests that effort should be channelled towards recovery of the natural environment. Adaptation to climate variability and change is important both for impact assessment and for policy development (Kenny et.al 2000). Thus, for agricultural and natural resource sustainability these declining trends should be incorporating in the regional policy.

The integration of the derived eco-climatic parameters are crucial for identifying the state of the environment in quantitative term, at micro / pixel level and this will enhance decision making regarding crop suitability and sustainability of the natural environment. The quantitative description of the eco-climatic condition provides an indicator of natural environment sensitivity to climate change and climatic vulnerability that will enhance management of natural resources and lead to the attainment of sustainable development. David and Chasca (2005) considered climate change as 'special' amongst livelihood disturbing factors in the developing world. The eco- climatic factors trend have depicts shift of the climatic zones to lower latitudes, necessitating the adaptation of high latitude species in the lower latitude for enhanced livelihood. Furthermore, all measures should be towards reducing this southward shift and the impacts of the shift by proper resource management strategies. Thus, the derived eco climatic map will enhance crop sustainability decision, increase food production and sustainability of the physical environment.

Homogenous moisture stress identified north of latitude 10^0 (Sudano-sahelian states) reveals that drought severity is mainly a function of the changes that are evident in the region. Consequently the derive map confirms that Sudano-sahelian states (sokoto, Kebbi, Katsina, Kano, Jigawa, BOrno, Yobe Bauchi and Gombe has now been transformed to semi arid and arid environment and this is important for any planning on natural resource management. Climate forecasting is not the panacea to all our problems in agriculture; instead, it is one of many risk management tools that sometimes play an important role in decision-making Holger and Roger (2005). Consequently, the derived eco-climatic map constitutes proactive approach in the region sustainability decision particularly, those regarding resource deficits. As a result the current eco-climatic condition and map of northern Nigeria is crucial for enhance food security and sustainability of physical environment.

5.2 Summary

The post independence recurring drought across the Sudano-sahelian belt coupled with a dwindling precipitation effectiveness trend; despite increase in general annual rainfall totals, is a threat to food security and sustainability of the physical environment. Hence, the need to respond to the vacuum created by a lack of an existing eco-climatic map of Nigeria (leading to the use of obsolete climate information of Nigeria), has directed the focus of this research that used derived eco-climatic parameters to define the micro eco-climatic zones in northern Nigeria.

The variability associated with the entire factors is an indication that the adoption of one factor for identification of the eco-climatic zones may be grossly inadequate. The variability that characterized the eco-climatic parameters was apparent. The factors depicted the moisture stress of the sub-humid and dry ecosystem at different levels such that the uncertainties in the quality of the biological and economic resources are evident. Furthermore, this variability within the factors necessitates the use of empirical relations for integrating the factors in a GIS environment to smooth out the variability and identify the current State of the environment.

The spatio-temporal trend analysis of the eco-climatic factors reveals the drastic eco-climatic changes, southward shift of the eco-climatic zones and the progressive northward decrease of moisture effectiveness. These indicators are also relevant in identifying changes that can be relevant in the management of fragile eco-systems and for long term monitoring programmes in the belt. The general trend indicate the exposure of people to disaster risk (drought and desertification) due to growing aridity as indicated by the derived spatio – temporal trend maps. Spatio-temporal moisture effectiveness identified moisture effectiveness as the prime factor of desertification, an indication of progressive decline in moisture effectiveness northward, in addition to increase in spatial and temporal spread of drought, which aggravates aridity. The major cause of this is evident in decreased environmental quality, climate variability and change.

The eco-climatic index identified moisture condition typical of northern Nigeria at varying levels. The quantitative reclassification of the eco-climatic index values identified five sub-units of eco-climatic zones in the belt; Arid/ Semi-Arid, Dry Sub – Humid, Sub – Humid, Humid and Wet, the noting of which is fundamental for the achievement of food security and provision of adequate information on the State of the environment. The apparent negative rainfall effectiveness trend coupled with confirmed transformation of the broad level 1976 climatic boundary across the region, Signifies the need to develop and adopt current and accurate maps as baseline for all planning and resource management policies if the future must be sustained.

5.2.2 Conclusion

The integration of meteorological and remote sensing data in GIS environment provides the fundamental indicator of moisture effectiveness in northern Nigeria. The derived eco-climatic classification integrated climatic and vegetation indices and therefore better related to sustainable agricultural productivity and food security as against climatic classification based on mean temperature and rainfall values. The resultant parameter maps after applying the kriging geo-statistical technique provided fundamental information for visualizing the typical eco-climatic characteristics in the region. Integration of meteorological and remote sensing data using empirical relationship in GIS environment has the capability of providing pointers to best possible sustainable solutions to the critical environmental issues.

In conclusion, the study showed evidence that eco-climatic dynamics in northern Nigeria is mainly a function of rainfall variability aggravating desertification in the region. Consequently, sustainability of agricultural productivity and other socio-economic activities is primarily a function of accurate, up-to-date and adequate eco-climatic information on the state of the environment.

5.3 Recommendations

The rapid aridity, prolong drought and perennial crop failure typical of northern Nigeria is primarily a function of inaccurate and non-operational information that dominate the national planning programmes and policies. To reclaim and ensure sustainability of the Sudano-sahelian belt, there is no alternative to accurate, adequate and functional information on the State of the physical environment. Defining arid/semi-arid environment as tropical continental north, using irrelevant parameters in a dominantly agricultural environment, etc, can only be misleading and disastrous to the agricultural sector. The eco-climatic map provided fundamental information for combating desertification, or dryland degradation, minimizing rate of drought and mitigating adverse effects of drought, with a view of achieving food security and sustainable development in the belt. Consequently, the following sustainability issues are recommended;

- Relevant ministries such as ministries of Environment, Agriculture, Water resources and Forestry and agencies for instance Agricultural Development Project (ADP) and National Emergency Management Agency (NEMA) should incorporate ecological and climatic consideration in resource management policy. The eco-climatic index has demonstrated huge potential as an efficient measure of eco-climatic variability in time and space. It is therefore a tool for producing accurate maps necessary for agricultural risk reduction and management planning.
- The index could be adopted for mapping and early warning of resource deficits and trends, especially those tied to developmental challenges and resource conflicts. The eco-climatic map produced by the study provides information that is crucial in national planning and for raising awareness on the stage of the environment to

reduce vulnerability and risk at local levels. Generally, proactive approaches to drought and ecological stress should be based on accurate eco-climatic maps to minimize vulnerability to natural hazard (drought, flood and desertification) and recovery of the affected areas.

- Perennial drought is inevitable in the arid/semi-arid zones of the Sudano-sahelian belt. As a result, adequate and accurate information using derived parameters should be used in developing Early Warning Systems (EWS) for early detection of drought and aridity for immediate mitigation measures as against current weather prediction procedures and practices that are based on single parameter and not tailored to the specific needs of the agricultural sector. Drought resistant and short term maturity variety crops and tree species should be introduced and propagated for adaptation. There should be a shift from aggressive political tree planting campaigns and promotion of community-based participatory approaches tied to livelihood advancement; for more sustained tree planting approach where economic tree species will be highly subsidised and made accessible for farmers. Water conservation should be government priority (small & middle scale) and subsidies for farmers and nomads; in addition all year round cultivation should be introduced.
- Desertification is apparent in northern Nigeria, justifying the need to check over grazing and minimize the effects of drought and desertification on the physical environment. In addition, the need exists to check southward migration to minimize socio-political and socio-cultural crises across the country. Long-term measures and programmes are required to address the issue of grazing reserves:
    I. Need to investigate factor militating against the development and utilization of permanent grazing zones.

II. Socio-econo-cultural measures to transform nomadism into more sustainable means of livestock production.

- It is necessary to subscribe to the principle of sustainable agriculture as a strategy for the logical use of biophysical resources. Specifically, sustainable use of the current state of physical environment should be in a manner that will be environment-friendly; in a way adding value to the environment.
- Accurate eco-climatic maps are crucial to the sustainability of the physical environment, agricultural productivity and food security. It is a prime input into understanding of the State of the environment, decision making and policy in a belt where over 90% of the rural population depends on agriculture for livelihood. Thus, environmental awareness programmes should be promoted and all geography text books and other applied social and environment management text books must contain eco-climatic maps of Nigeria to increase awareness on the State of the environment.
- As a result of the vacuum created by inadequate Environmental Education, it should be embedded not only in our secondary school curriculum, but also at the foundation level, as part of general studies in the tertiary institutions and included in our radio and television programmes using local languages at the community level. Understanding the State of the environment is crucial to the achievement of sustainable development. Furthermore, environment awareness aimed at good environmental practices and long-term environmental management strategy of eco-climatic zones will check further degradation and hence ensure sustainability of the physical environment.

- The present research has provided an insight into rainfall variability typical of this belt and recognized the current eco-climatic zones. It should be extended to cover the whole of Nigeria and Sub-saharan West Africa. A detailed research should be undertaken to identify rainfall variability factors in northern Nigeria and measures put in place to institutionalize timely provision of sectors specific early warning forecast product in aid of economic development. Long-term multi-temporal images should be used to develop composite data set for the identification of vegetation cover in the region Also, factors militating against the development and utilization of permanent grazing reserves should be investigated.

REFERENCES

Achard, F., and Estreguil, C., (1995) Forest Classification of Southeast Asia using AHVRR data. *Remote Sensing of Environment, 54, Pp 198 – 209*

Adefolalu D.O. (1988) Precipitation Trends, Evaporation and the Ecological zones of Nigeria. *Theoretical & Applied Climatology Vol. 39. Pp 81 – 89.*

Adefolalu D.O. (2003) The impact of climate Change on the Savannah Environment in Africa: Its Impacts on Water Resources Management. *Paper presentation at UNESCO Sponsored Multi-stake Holder National Workshop Minna, Nigeria.*

Adefolalu, D.O. (1986a) Further aspects of Sahelian drought as evident from rainfall regime of Nigeria. *Meteorology and Atmospheric Physics, Volume 36, no 3-4 Pp 277-295*

Adefolalu, D.O. (1986b) Rainfall Trends in Nigeria. *Theoretical & Applied Climatology Vol. 37. Pp 205 – 219*

Adetoro J.E. (1982) *A Geography Course for Junior Secondary School.* Nigeria, Macmillan LTD

Adger, W. (2001), Scales of governance and environmental justice for adaptation and mitigation of climate change. *Journal of International Development, 13: 921–931.*

Afolabi O. (1974) *Study Map Notebook: West Africa.* Second Edition, Ibadan, Collins and Glasgow.

Ali-Akbar S. and Hoossein T. (2010) Regional Estimation of Reference Evapotranspiration in Arid and Semiarid Regions. *J. Irrig. and Drain. Engrg. Volume 136, Issue 10, pp. 724-731*

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998) Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. *FAO Irrigation and Drainage Paper No.56. FAO, Rome. pp 300.*

Amadou, T., and Ronald J. E. I. (2006) Andes Guide to GIS and Image Processing manual version 15.00 *Pp* 218 – 229

Anderson, M.C., Neale, C.M.U., Li F., Norman, J.M., Kustas, W.P., Jayanthi H. and Chavez J. (2006) Upscaling ground observations of vegetation water content, canopy height, and leaf area index during SMEX02 using aircraft and Landsat imagery. *Remote Sensing of Environment. Vol. 92, Issues 4. Pp 447-464*

Andrade J.A.S.de, Bastos E.A., Barros A.H. C.,Silva C. O .da, Gomes A.A. N.(2005) Climatic Classification and semiarid zone regionalization of the Piauí State, Brazil, under distinct rainfall scenarios. *Revista Ciência Agronômica, (Vol. 36) (No. 2) Pp 143-151*

Andrew T. H. and Carol A. W. (2000) Deforestation in Mwanza District, Malawi, from 1981 to 1992, as determined from Landsat MSS imagery. *Applied Geography, Volume 20, Issue 2, Pp 155-175*

Begue T.and Myneni C. (1996) Operational relationships between NOAA-advanced very high resolution radiometer vegetation indices and daily fraction of absorbed photosynthetically active radiation, established for Sahelian vegetation canopies. *Journal of Geophysical Research, Volume 101, Issue D16, Pp 21275-21290*

Carl J. S. III., and Fredrick H. M. S. (2003) An investigation of variability of the climate of East Africa during the recent decades. *CLIVAR Exchanges, 27, Pp 58-61*

Centre for Climate change and Fresh Water Resources (2005) *Eco-climatic Atlas*. MINNA FUTMIN consult

Cottton, W.R; Pieike, R.A.(1995) *Human impacts on weather and climate*. New York, Cambridge University Press. *Pp* 288

Craig D. A., Alison K. M., Haroun C., Dominique B., Nate M., Michel V., Thomas K., Andreas R., David D. B., Hogg E.H. (Ted), Patrick G., Rod F., Zhen Z., Jorge C., Natalia D., Jong-Hwan L., Gillian A., Steven W. R., Akkin S. and Neil C. (2009) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Journal of Environmental Management Volume 60, Issue 4, Pp 267-288*

Dantas, A. A. A., Carvalho, L. G.de and Ferreira E. (2007) Climatic classification and tendencies in Lavras region, MG. *Ciênc. agrotec., vol.31, no.6, Pp 1862-1866. ISSN 1413-7054.*

David S.G.T. and Chasca T. (2005) Adaptation to Climate Change: Perspectives Across Scales. *Global Environmental Change, Part A, Vol. 15, Issue 2, Pages 115-124*

Denton S. R., and Barnes B. V; (1988) An Ecological Climatic Classification of Michigan: A Quantitative Approach. *Forest Science, Volume 34, Number 1, PP. 119 - 138 (20)*

Donald A. D. (2002) The Assessment of Land Resources: *Achievements and New Challenges Australian Geographical Studies Volume 40 Issue 2 Pp 109-128, July 2002*

Dregne, H.E. and Chou, N.T., (1992) Global desertification dimensions and costs. *In:* Degradation and restoration of arid lands. *Texas Tech University, Lubbock. [http:// www.ciesin.org/docs/002-186/002-186.html* 27th Oct., 2007]

Driss H., John R. M., Elizabeth P., Pablo J. Z.and Ian B. S. (2004) Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. *Remote Sensing of Environment. Volume 90, Issue 3. Pp 337-352*

El-Beltagy, A. (1997) Land degradation: a global and regional problem. *ICARDA, Aleppo. [http;//www.unu.edu/millennium0el-beltagy* 10 March, 2007.]

Eswaran, H. and Reich, P. (1998a) Desertification: A global assessment of land quality. *Proc.of 16th Intl. Congr. Soil Science, Montpellier, France.*

Eswaran, H., Reich, P.F. and Beinroth, F. (1998b) Global Desertification Tension Zones. *Proc. of Intl. Soil Conservation Conference. Purdue University.*

Fabio M. (2001) Definition of Spatially Variable Spectral Endmembers by Locally Calibrated Multivariate Regression Analyses. *Remote Sensing of Environment, Volume 75, Issue 1, Pp 29-38*

Fitzpatrick E.A. and Stern W.R. (2003) Estimates of potential evaporation using alternative data in Penman's formula. *Agricultural Meteorology. Volume 3, issues 3-4 Pages 225-239*

Gavilán P., Lorite, I.J., Tornero S., and Berengena J. (2006) Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment. *J. Irrigation and Drainage. Volume 55 Issues 2, Pp 201- 215*

Geneviève R., Michael S., Frédéric B. (1996)Optimization of soil –adjusted vegetation indices *Remote Sensing of Environment, Volume 55, Issue 2, Pp 95-107*

Gilabert M. A., González-Piqueras J., García-Haro F. J .and Meliá J. (2002) A generalized soil-adjusted vegetation index. *Remote Sensing of Environment. Vol. 82, Issues 2-3 Pp 303-310*

Gunston, H. and Batchelor, C. H. (1983) A comparison of the Priestley- Taylor and Penman methods for estimating reference crop evapotranspiration in tropical countries. *Agricultural Water Management, Volume 6, Issue 1, Pp 65-77*

Hahn B.D. , Richardson F.D., Hoffman M.T., Roberts R. , Todd S.W. and Carrick P.J. (2005) A simulation model of long-term climate, livestock and vegetation interactions on communal rangelands in the semi-arid Succulent Karoo, Namaqualand, South Africa. *Ecological Modeling, Volume 183, Issue 2 – 3, Pp 211 – 230*

Hanafi A. and Jauffret S.A.(2008) Long-term vegetation dynamics useful in monitoring and assessing desertification processes in the arid steppe, southern Tunisia . *Journal of Arid Environments, Volume 72, Issue 4, Pp 557-572*

Hansen M., Defries, R.S., Townshend, J. R. G., and Sohlberg, R.(2000) Global Land Cover Classification at 1km Spatial Resolution using a tree classification approach. *International journal of remote Sensing, 21, Pp 1331- 1364.*

Hargreaves, G.H., and Samani, Z.A. (1985) Reference crop evapotranspiration from temperature. *Appl. Eng, Agric. 1 2 (1985), Pp 96–99.*

Harold F. (1976*) Modern College Atlas for Africa. 14th Edition,* George Philips and Sons.

Haruna D. M. and Bukar S. (2010) Integrated Remote Sensing Approach to Desertification Monitoring in the Crop-rangeland Area of Yobe State, Nigeria. Journal of Sustainable development in Africa. Vol.12, No.5. Pp 236-250

Helmut J. G. and Eric F.L. (2004) Dynamic Causal Patterns of Desertification. *BioScience, Volume 54, Issue 9, Pp 817–829*

Henry N. L. H. (1996) Climate Change, drought and desertification. Journal of *Arid Environments, Volume 34, Issue 2, Pp 133-185*

Holger M. and Roger C. S. (2005) Seasonal and Inter-Annual Climate Forecasting: The New Tool for Increasing Preparedness to Climate Variability and Change in Agricultural Planning and Operations. *Climate Change, Vol.70, Numbers 1-2 Pp 221-253*

Huang S. and Siegert F. (2006) Land cover classification optimized to detect areas at risk of desertification in North China based on SPOT VEGETATION imager. *Journal of Arid Environments, Volume 67, Issue 2, Pp 308-327*

Huete A. R. (1988) A soil – adjusted vegetation index (SAVI*), Remote Sensing and the environment, 25: Pp 53 – 70*

Iloeje N. P.(1979) *A New Geography of Nigeria.* Nigeria, Longman Limited ISBN 0 582 65510 2

Jabloun, M. and Sahli, A. (2008) Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data Application to Tunisia. *Agricultural Water Management, Volume 95, Issue 6, June 2008, Pp 707-715*

Jason E. and Roland G. (2004) Discrimination between climate and human-induced dryland degradation. *Journal of Arid Environments, Volume 57, Issue 4 Pages 535- 554*

Jeremy L. W. , David S. G. , Julia E. A. C. and Clifford N. D. (2004a) Seasonal and inter-annual relationships between vegetation and climate in central New Mexico, USA. *Journal of Arid Environments, Volume 57 Issues 4, Pp 507 – 534*

Jeremy L. W., David S. G., Julia E. A. C. and Clifford N. D. (2004b) Long – term Vegetation Monitoring with NDVI in s Diverse Semi- arid Setting Central New Mexico, USA. *Journal of Arid Environments, Volume 58, Issue 2, Pp 249-272*

John S. and Barry S. (1997) Human adaptation to climatic variability and change. *Global Environmental Change, Vol. 7, Issue 2, Pages 129-146*

Jude H. K., Terry L. K., Dietrich L.A. K., Kevin P. P., Edward A. M., and Re-Yang L.(2005) Image masking for Crop Yield Forecasting using AVHRR NDVI Time Series Imagery. *Remote Sensing of Environment, Volume 99, Issue 3, 30 November 2005, Pp 341-356*

Kenny G.J., Warrick R.A. , Campbell B.D., Sims G.C. and M. Camilleri, et.al (2000) Investigating Climate change and Thresholds: An Application of the CLIMPACTS Integrated Assessment Model for New Zealand Agriculture. *Climate Change, Vol 46, Number 1-2 Pp 91-113*

Kiunsi, R. B. and Meadows, M.E. (2006) Assessing land degradation in the Monduli District, northern Tanzania. *Land Degradation & Development. Vol. 17, No. 5, pp. 509-525*

Kogan F.N. (1995) Application of vegetation Index and Brightness temperature for Drought Detection. *Advances in Space Research, Volume 15, Issue 11, Pp 91-100*

Köppen, W. (1918) "Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf." *Petermanns Mitt., Vol. 64, Pp 193-203.*

Krishnaswamy J.; Kiran M. C.; Ganeshaiah K. N. (2004) Tree model based eco-climatic vegetation classification and fuzzy mapping in diverse tropical deciduous ecosystems using multi-season NDVI. *International journal of Remote sensing, Volume 25, Issue 6, Pp 1185 – 1205*

Kufoniyi O., Aliyu Z. O., and Momodou S. (2003) The Application of Remote Sensing and GIS in Ecosystem and Water Resources Management; *Paper Presentation at UNESCO Sponsored Multi Stake Holder National Workshop Minna , Nigeria.*

Kumar J. P.K., Roy P.S., Sarnam S., Shefali A. and Deepshikha Y. (2006) Vegetation cover mapping in India using multi-temporal IRS Wide Field Sensor (WiFS) data .*Remote Sensing of Environment, Volume 103, Issue 2, Pp 190-202*

Lambin E. F., and Ehrlich D., (1995) Combining Vegetation Indices and Surface Temperature for Land-cover Mapping at Broad Spectral Scales. *International Journal of Remote Sensing, 16, Pp 573 – 579.*

Lázaro R. R. .L. , Gutirrez F. D. and Puigdefabregas J. (2001) Analysis of a 30-year rainfall record (1967–1997) in semi–arid SE Spain for implications on vegetation .*Journal of Arid environments, Volume 48, Issue 3, Pp 373 – 395*

Leonard S. U. and Felix N. K. (1998): Drought Monitoring Corn Yield Estimation in South Africa from AVHRR Data. *Journal of Arid Environments. Volume 57, Issue 4, Pp 507-534*

Leprieur C., Kerr Y. H. and Pichon J. M. (1996) Critical assessment of vegetation indices from AVHRR in a semi-arid environment. *International Journal of Remote Sensing, Volume 17, Issue 13, Pp 2549 - 2563*

Liu H., Zhou C., Cheng W., Long E., and Li R.(2008) Monitoring sandy desertification of Otindag Sandy Land based on multi-date remote sensing images. *Acta Ecologica Sinica, Volume 28, Issue 2, Pp 624 - 635*

López B, C., Holmgren M., Sabate' A. and C.A. Gracia (2008) Estimating Annual Rainfall Threshold for Establishment of Tree Species in Water-limited Ecosystems Using Tree-ring Data. *Journal of Arid Environments, Volume 72, Issue 5, Pp 602-611*

Malinigreau, J.P., Tucker, C. J ., and Laporte, N. (1989) AVHRR for monitoring global tropical deforestation. *International journal of remote of remote sensing, 10, Pp 855-867*

Maria A. G., Fabio M., Claudio C., and Marco B., (1995), Characterization of primary productivity levels of Niger by means of NOAA NDVI variations. *Geocarto International. Vol. 10, issue 4 Pp 31-41*

Martínez-Cob, A. and Tejero-Juste M. (2004) A wind- based qualitative calibration of the Hargreaves ET_0 estimation equation in semiarid regions. *Agricultural Water Management, Volume 64, Issue 3, 1 February 2004, Pp 251-264*

Maxwell S.K., Hoofer. R.M. and Chapman P. L. (2002) AVHRR channel Selection for land cover classification. *Int. J. Remote sensing, vol.23, No23, Pp 5061-5073*

Mechi, G.A. (1994) Influence of the Land Surface in the Asian Summer Monsoon: Extend Conditions Versus Internal Feedbacks. *J. Climate, Vol. 7, Pp 1033-1049.*

Michael A. S., Lars L. P., Steven W. R., and David L. P. (1990) The Seasonality of AVHRR Data of Temperature Coniferous: relationship with Leaf Area Index. *Remote Sensing of Environment, Volume 33, Issue 2, Pp 97-112*

Nemani, R., and Running, S., (1997) Land cover characterization using Multitemporal red, Near- IR and Thermal IR data from NOAA/AVHRR. *Ecological Application* 7, *Pp 79 -90*

Nicholson S. E. (1998) Desertification, Drought, and Surface vegetation: An Example from West African Sahel, *Bulletin of the American Meteorological Society Vol. 79, No. 5, Pp 815 – 829*

Nicholson S. E. (2003) LAND Processes in the Sahel. *Science Vol. 299. no. 5615, Pp 2005 – 2010*

NIMET (2008) Year 2008 Rainfall Prediction and Socio-economic implication for all parts of Nigeria. *Annual Bulletin,* Abuja Nigeria Meteorological Services,

Nsofor G.N (2003) Water resources and Environmental Management curriculum for the Nigerian Environment. *Paper presentation at UNESCO Sponsored Multi-stake Holder National Workshop Minna, Nigeria.*

Oboli.H.O.N. and Harrison C.R.J. (1974). *An Outline Geography of West Africa.* London Harrap LTD

Olu O.O. and Bogda P. (2002), Defining climatic Zones for Architectural Design I Nigeria: A Systematic Delineation. *Journal of environmental Technology Vol. 1, Issue 2 Pp. 1-14*

Omar A. L. and Norma C. R. (1999) Relationship between interdecadal fluctuations in annual rainfall amount and annual rainfall trend in a southern mid-latitudes region of Argentina. *Atmospheric Research, Volume 52, Issue 3, Pp 177-193*

Parinaz R. B., Ali A. D., Ali K., and Majid F. M. (2004) Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran. *Journal of Arid environments Volume57, Issues 4 Pp 507-534*

Peter H. G. (1998) Water in Crisis; Paths to Sustainable Use *Ecological Applications 8:571–579.*

Robert M. B. and Samuel W. C (1969) A Graphical Method Determining Thornthwaite Climate Classification. *Annâls of the Association of American Geographers. Volume 59, Issue 3, Pp 561 – 371*

Roy P. S., Joshi P. K., Singh S., Agarwal D. Y. and Jegannathan C; (2006) Biome mapping in India using vegetation type map derived using temporal satellite data and environmental parameters. *Ecological Modelling, Volume 197, Issues 1-2 Pp 148 – 158*

Sharma K. D. (1998) The Hydrological Indicators of Desertification. *Journal of Arid Environments Vol.39, Issue 2, Pp 121 – 132*

Shukla J. (1993) The Influence Of Land Surface Properties on Sahel Climate. Part 1, Desertification. *J Climate.6, Pp 2232-2245*

Sivakumar M.V.K.(2007) Interactions between climate and desertification. *Agricultural and Forest Meteorology, Volume 142, Issues 2-4, 12 Pp 143-155*

Sonia K., Max R., Minus V. B. and Michel L. (2007) Local facilitation, bistability and transitions in arid ecosystems. *Theoretical Population Biology, Volume 71, Issue 3, Pp 367 – 379*

Soussan J.G (1992) Sustainable development. *Environmental issues in the 1990s. John Wiley and sons. Pp20-33*

Srikantha H. and Uditha R.(2004) Monitoring rainfall trends to predict adverse impacts—a case study from Sri Lanka (1964–1993). *Global Environmental Change Part A. Vol. 14, Supplement 1, Pp 71 -82*

Stephenne N. (2004) Dynamic Simulation Model of Land- Use Changes in the Africa Manuscript Submitted to *"Agriculture, Ecosystem and Environment. Special Issue on" Current Progress in Land- Use Change Model.*

Strahler, A. (1969) *Physical Geography*, Third Edition. New York, John Wiley and Sons, Inc.

Sultan, B. and Janicot S. (2004) The Pre – Onset and Onset Monsoon Systems over West Africa. *CLIVAR Exchanges, 27. Pp 231- 242*

Susana B. A. and Kelley A. C. (2006) Aridity and desertification: Exploring environmental hazards in Jáchal, Argentina. *Applied Geography, Volume 26, Issue 1, Pp 61 - 85*

Tennant W.J. and Hewitson, B. C.(2002) Intra- Seasonal Rainfall Characteristics and their importance to the Seasonal Prediction. *International Journal of Climatology, vol. 22, Issue 9, Pp 1033-1048*

Thomas S. W. and Julio L.B. (1998) Mesoscale Disturbance and Ecological Response to Decadal Climatic Variability in the American Southwest. *Journal of Climate, Volume 11, Issue 12, Pp 3128–3147*

Thornthwaite, C. W. (1948) An approach toward a rational classification of climate. *The Geographical Review, vol. 38, 1948, Pp 55-94.*

UNCED. 1992. United Nations Conference on Environment and Development. Rio de Janeiro: UN.

UNEP (1984) General Assessment of Progress in the Implementation of the Plan of Action to Combat Desertification 1978-84, Nairobi Kenya

UNEP, 1992 *World Atlas of Desertification*. London, Publ. E. Arnold. *Pp* 69

Usman M.T. (1999) An operational Index for assessing Inter-annual, Rainfall, Variability and Agircultural droughts over the Nigeria Sahel. *African climatological research series, 3, Pp 22-32*

Usman M.T. (2000a) An Instability I ndex for monsoon onset characterisation over the Nigerian sahel .*Env. Rev. Vol. 3 No.2*

Usman, M.T. (2000b) An Operational Index for Assessing Inter annual Rainfall Variability and Agricultural droughts over the Sahel, *African Climatology Research Series, 3: 1, Pp 23-33.*

Usman, M.T. and Abdulkadir A. (2008) A methodology for determining The Real Onset Date of seasonal Rains in Semi – Arid and Dry Sub – Humid Areas of West Africa (Accepted for publication).

Veron S.R., Paruelo J.M., and Oesterheld M. (2006) Assessing desertification, *Journal of Arid Environments, Vol. 66, Issue 4. Pp 751-763*

Vicente-Serrano, S. M., Lanjeri, S. and Lopez-Moreno, J. I. (2007) Comparison of different procedures to map reference evapotranspiration using geographic information systems. *International Journal of Climatology 28(8): Pp 1103 - 1178*

Volcani A. and Karnieli A.T. (2005) The use of remote sensing and GIS for spatio-temporal analysis of the physiological State of a semi-arid forest with respect to drought years. *Forest Ecology and Management, Volume 215, Issues 1-3, Pp 239-250*

Willem J.D., Van L., Barron J. O., Stuart E. M., and Stefanie M. H. (2006) Multi-sensor NDVI data continuity: Uncertainties and implications for vegetation monitoring applications. *Remote Sensing of Environment, Volume 100, Issue 1, 15 January 2006, Pp 67-81*

Wu R. and Wang B. (2000) International Variability of summer monsoon onset over the western North pacific and Underlying processes. *Journal of Climate, 13: Pp 2483-2494*

Yang X. , Ding Z. , Fan X. , Zhou Z. and Ma N. (2007) Processes and mechanisms of desertification in northern China during the last 30 years, with a special reference to the Hunshandake Sandy Land, eastern Inner Mongolia. *CATENA, Volume 71 Pp 2 - 12*

Yang X., Zhang K., Jai B., and Ci. L. (2005) Desertification assessment in China: An overview. Journal of Arid Environment Vol. 63, Issue2. Pp 517-531

Yansui L., Jay G., and Yanfeng Y. (2003) A Holistic Approach Towards Assessment of Severity of Land Degradation Along the Great Wall in Northern Shaanxi Province, China. *Environmental Monitoring and Assessment* *www.ciesin.org/docs/002-186/002-186.html 27th Oct., 2007]*

Yaw A.T. and Edmund C. M. (2007) Using Remote Sensing and GIS in Analysis of Ecosystem Decline Along the River Niger basin: The case of Mali and Niger. *Int.J. Environ. Res. Public Health. 4(2), Pp 173-184*

Yufu C., John A. G., David A. F., Zhiyan M., Daniel A. S., Hong-lie Q., Helen C., Alfredo H. and Abdullah F. R. (2006) A multi-scale analysis of dynamic optical signals in a Southern California chaparral ecosystem: A comparison of field, AVIRIS and MODIS data. *Remote Sensing of Environment, Volume 103, Issue 3, Pp 369-378*

Zewdu T. S. and Peter J. L. (2004) Interannual variability of growing season over drought – prone areas of Ethiopia. *CLIVAR Exchanges, 27, Pp 52-55*

Zhang, K., Li, X., Zhou, W., Zhang, D., Yu, Z., (2006) Land resource degradation in China: Analysis of status, trends and strategy. *The International Journal of Sustainable Development and World Ecology, Volume 13, Number 5, October 2006 , Pp 397-408(12)*

Zhao H. L. , Zhao X. Y. , Zhou R. L. , Zhang T. H., and Drake S.(2005) Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of Arid Environments, Volume 62, Issue2, Pp 309-319s*

Zheng Y., Xie Z., Jiang L., Shimizu H. and Drake S. (2006) Changes in Holdridge Life Zone diversity in the Xinjiang Uygur Autonomous Region (XUAR) of China over the past 40 years. *Journal of Arid Environments, Volume 66, Issue 1, Pp 113 – 126*