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GEOGRAPHICAL INFORMATION SYSTEMS

Geospatial Analysis of Rainfall Variability Impacts on Crop Yield in the Guinea Savanna Ecological Zone of Nigeria

Année universitaire :

JUNE, 2008

GEOSPATIAL ANALYSIS OF RAINFALL VARIABILITY IMPACTS ON CROP YIELD IN THE GUINEA SAVANNA ECOLOGICAL ZONE OF NIGERIA

BY

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SSP03/04/H/1130

A THESIS SUBMITTED TO THE DEPARTMENT OF GEOGRAPHY, OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING.

JUNE, 2008

CERTIFICATION

We certify that this research work was carried out by AYANLADE Ayansina, in the Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria.

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DEDICATION

This thesis is dedicated to the Almighty God through my Lord Jesus Christ who saved me and gave me direction in life.

ACKNOWLEDGEMENTS

I want to first of all thank the Almighty God for His faithfulness and mercy over my life during the period of this study, for it is not of him that runs, but of God that shows mercy. I wish to express my sincere gratitude to all those who have in various ways contributed to the success and completion of this project.

Special thanks to my amiable and humble supervisor, Dr. T.O Odekunle and co-supervisor, Dr. A.A. Omitogun (of Regional Center for Training in Aerospace Survey (RECTAS), whose fatherly pieces of advice greatly helped me on this research project. Thanks to my erudite and resourceful Head of Department, Dr. A. Adediji for his commitment which has greatly moved the Department forward. I cannot forget the Dean of my Faculty, Prof. Oluwole Aloba and my special academic guardian, Prof. Olusegun Ekanade, for their intellectual ideas, spiritual and fatherly advice.

My special thanks go to my lovely and understanding wife- Mrs Oluwatoyin Ayanlade, for her full support during this research work. You are not just a wife but virtuous partner and mother.

I thank the coordinator (Prof. A.T Salami) of Space Application and Environmental Science Laboratory of Institute of Ecology, Obafemi Awolowo University, Ile-Ife, Nigeria, for the scientific contribution to training activities and fellowship grant support.

Above all, this study is part of a research project funded and supported by CODESRIA (Council for the Development of Social Science Research in Africa).

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ABSTRACT

The study developed a GIS database on inter-annual rainfall variability and crop yield in the Guinea Savanna ecological zone of Nigeria; mapped inter-annual changes in crop yield as a response to inter-annual rainfall variability in the study area. It also related the spatio-temporal variability in rainfall with crop yields; and model future scenario of the impact of rainfall variability on crop yields. This was with a view to evaluating the spatio-temporal impacts of rainfall variability on crop yields in the area.

Secondary datasets were used for the study. These included annual crop yield and rainfall data from 1970 to 2000 and topographical maps of the study area. Data on crop yield were obtained from the Annual Abstracts of Statistics of the National Bureau of Statistics, Abuja while rainfall data were collected from the Nigerian Meteorological Services, Oshodi Lagos. Spatial datasets were prepared as a base data for the analyses. Three spatial interpolation methods: Inverse Distance Weighting (IDW); Spline and Kriging were used for the spatial analysis. Also, correlation and regression analysis were carried out on the dataset.

The results showed spatial relationships between crop yield and rainfall variability for the period of study. Also, coefficient of variation showed that rainfall variability was high in most of Northern Guinea Savanna with values ranging from 21% to 49% (e.g. Yola 21% and Minna 29%) while it was low in the Southern Guinea Savanna especially, with values ranging from 8% to 9% (e.g Shaki 8% and Enugu 9%). The spatial variability in rainfall fluctuated from one year to the other (550mm to 2987mm). The results showed that there were significant positive relationship between crop yield and total rainfall (r=0. 68, at

$p<0.05$ for millet; $r= 0.62$, at $p<0.05$ for maize; $r= 0.68$, at $p<0.05$ for cassava; and $r= 0.62$, at $p<0.05$ for yam). The results further showed that the quantity of rainfall in April and May were the most important for maize and millet yield in most of the stations considered. This indicated that in a "normal" year, farmers in the Guinea Savanna should not plant maize and millet earlier than the month of April.

The study concluded that geospatial techniques are powerful tools that should be explored further for realistic assessment of the effects on climate of farming activities.

CHAPTER ONE

INTRODUCTION

1.1 General Background of the Study

Climate is the characteristic condition of the atmosphere near the earth's surface at a given place or region over a considerable period of time, usually 35years and above (The Intergovernmental Panel on Climate Change (IPCC), 1992). Tim (2000) defines inter-annual climate variability as the observed inter-annual difference in value of specific climate variables within an averaging period (typically 30 years). Thus, climate variability can be regarded as variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Rainfall variability impact analysis is a way of looking at the range of consequences of a given rainfall event or change on given spatial phenomena (Chiew, 2002). Inter-annual rainfall variability impact assessments begin by mapping out direct physical consequences of rainfall event or change on such as variability in crop yields. (UNEP, 2001b).

The scientific evidence of rainfall variability impacts on crop yield is now stronger than ever (Hare, 1985; Hulme, 1994; Ribot, et al 1996; WMO, 2000; IPCC, 1998; 2000; 2004a; Adejuwon, 2004). One undisputable cause of 'famine' in Guinean Savanna ecological zone of Nigeria is the failure of crops resulting from insufficient or untimely rainfall (Anuforom, 2004). IPCC (2004a) has studied the inter-annual variability in the climate of West African countries, particularly the magnitude of rainfall variability impact on human activities, including crop production. However, the recent impacts of rainfall variability on crop yield in Nigeria raise the question as to whether there will be enough food in Nigeria in the next century (IPCC, 2000).

Various studies on the impacts of rainfall variability on crop yield have been carried out in different parts of the world and well established through decades of field experiments, statistical analyses of observed yields and monitoring of agricultural production by IPCC and other scholars. Prominent among these are the works by Aronoff (1989), Rosenzweig and Hillel (1995), Tim (2000), FAO (2001), Chiew (2002), Haimson and Ennis (2004) and Adejuwon and Odekunle (2006). Some of these studies have shown significant impacts of climate variability on agricultural activities, especially during the last 40-year period. Different techniques, such as parametric and non-parametric tests, are used for testing whether there have been significant impacts. For example, Tim (2000) observed that over the period 1961 to 1990 the north east arid zone of Nigeria experienced a decline in annual rainfall which led to a decline in millet yield. The zonal variability of rainfall is observed to bring about not only the differences in the types of crops cultivated but also the rate of yield of such crops (Osagie, 2002). However, modelling with a Geographical Information Systems (GIS) offers a better mechanism to integrate many scales of data developed for agricultural research. GIS emerges as a promising tool in mapping and modeling rainfall impact on crop yield. GIS tools also enable the easy calculation and display of the area under pacified rainfall conditions and the display of maps for rainfall/crops impacts monitoring purposes.

Generally, rainfall regime is the most important climatic factor influencing agricultural activities particularly in the tropical region. Rainfall can vary considerably even within a few kilometres distance and on different time scale. This implies that crop yield is exceedingly variable over space and time. It has biggest effect in determining the crops that can be grown, the farming system, the sequence and timing of farming operations (Adejuwon, 2006). Rainfall can also be seen as the supplier of soil moisture for crops. The soil moisture supply, however, does not depend on rainfall alone, but also on various other factors concerned in the hydrological equation, such as evapotranspiration and surface run-off (IPCC, 2000). In many areas with alternating wet and dry seasons, the annual rainfall is less than the amount of the water that a crop well supplied with water would transpire during the growing season. In such circumstances, a fair depth of soil may be at field capacity fairly frequently during the immature phase of the crop, but later the mature crop may dry out the soil to the full depth of its rooting system, or a little deeper. This can have two effects on crops. First, during the latter part of the growing season, insufficient soil moisture may restrict transpiration to well below the potential rate, with corresponding reduction in growth and yield. Second, after harvesting the crop, there will be a deep layer of soil which must be recharged to something approaching field capacity early in the following rains before satisfactory growth of the next crop can occur. Surprisingly, little systematic research has focused on the distribution patterns of the impacts of rainfall variability in terms of mapping its spatiotemporal impact using the modern GIS techniques such as Kriging interpolation technique. There is need, however, for an integrated type of this GIS modeling system, to allow agricultural producer as well as policy makers to know the impact of spatio-temporal variation in rainfall on crop yield for better management, productivity and profitability.

Therefore, this study aimed at using GIS Kriging interpolation technique together with correlation and regression methods to examine and map the spatiotemporal impact of rainfall variability on crop yields in the Guinea Savanna Ecological Zone of Nigeria. Kriging technique is employed for this research work because primary information in respect of rainfall variability is often collected in respect of widely scattered points known as meteorological stations. One major problem is how to estimate values for the other locations in respect of which the primary data are not available. Scholars have been using Climate Models such as General Circulation Models (GCM) and these are capable of generating primary data in respect of the nodes of grids of widely spaced longitudes and latitudes (Adejuwon, 2005). Problems also often arise as to what values to attach to weather or climatic variables at points other than these nodes. There are now available standard techniques for solving these problems.

Guinea Savanna Ecological Zone of Nigeria was selected for this research work because the area intensely produces staple crops such as yam, millet, cassava and maize. Further, the large inter-annual variability of rainfall subjects the area to frequent dry spells that sometimes result in severe and widespread drought that can impose serious socio-economic constraints (Buchanan and Pugh, 1955). Farming is generally rainfed and has the subsistence variety. The crops grown include grains such as rice, wheat, soybeans, beans, maize and millet and tuber crops such as yam and cassava. However, the present study is interested in crops like maize, millet, cassava and yam. Although the area is rich in culture, history, and natural resources, it is often remembered more for its disastrous droughts and floods, starving population, and struggling economy. Its heavy reliance on agriculture, combined with its susceptibility to frequent rainfall extremes, has left it in a precarious position, striving to not only stay on par, but to prevent vast numbers of people from falling deeper into disparity (Anuforom, 2004). With 85 percent of the population living in rural areas, agriculture plays an important role in physical and economical survival (National Population Commission (NPC), 2006).

1.2 AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to examine and map the spatiotemporal impact of rainfall variability on crop yields in the Guinea Savanna Ecological Zone of Nigeria using GIS Kriging interpolation technique together with correlation and regression methods. The specific objectives of this study are to:

i. develop a GIS Database for inter-annual rainfall variability and crop yield in the study area between 1970 and 2000;
ii. map inter-annual changes in crop yield as a response to inter-annual rainfall variability in Guinea Savanna Ecological Zone of Nigeria;
iii. relate the spatio-temporal variability in rainfall with crops yield in the study area; and
iv. model future scenario for rainfall inter-annual variability impact on crops yield.

1.3 RESEARCH QUESTIONS

To achieve the above objectives, the following two research questions were addressed:

i. Does rainfall and crop yield vary from year to year?

ii. Is crop sensitive to rainfall variability experienced in the zone?

iii. Is crop yield venerable to rainfall variability in the study area?

iv. Could GIS procedures developed for interpolating from data collected at meteorological stations be logically employed for assessing rainfall and crop yield variability?

1.4 JUSTIFICATION OF THE STUDY

During the past three decades, inter-annual rainfall variability impacts on crop yield have resulted in increasingly serious agricultural loss in Nigeria, which in some cases have led to unprecedented famine (WMO, 2000). Resent studies have indicated inter-annual rainfall variability as a major factor affecting the yield of crop in Nigeria (Adejuwon, 2004). It affects the various aspects of plant growth and yields; consequently, alter crop productivity. Although, it may appear that little or nothing could be done to improve variability in rainfall since most of its causes are natural. Thus, there is need for in-depth study and understanding of spatio-temporal rainfall variability as well as its significant impacts on crop yield. There is no doubt that an in-depth understanding of rainfall variability as well as a broad knowledge of its spatio-temporal pattern using GIS would be very useful in the monitoring strategies which should improve the crop yield in Nigeria.

However, it is important to note that in spite of great advance that has been made in understanding and dealing with the problem of rainfall variability impact on crop yield at the international level, awareness and the concern for the problem at national and local levels remain poor or in some cases non-existent (Anuforom, 2004). This research work, therefore, attempts to look at the rainfall variability impact on crop yield with particular reference to the Guinean Savanna Ecological Zone of Nigeria. The results of the GIS spatial analysis, Java Script Models and the maps produced will show inter-annual variability of rainfall that brings about the spatio-temporal differences in the rate of some crop yield in Nigeria. There is no doubt that farmers increasingly need detailed models and maps of this kind to plan crops planting schemes and to monitor the rate of yield. This technique is known as “precision agriculture” (FAO, 2001). Above all, the selected crops are vital components of food security not only in the study area but also in all parts of Nigeria and they will remain largely associated with the food security of drought-prone areas such as Guinea Savanna part of Nigeria. But yield is lagging because of the severity of the rainfall variability and pressure of human population growth on traditional land extensive fallow system. Correspondingly, this research will contribute most directly to the alleviation of poverty and food security problem in the area and add to knowledge of assessing rainfall-crop yield relationship for the benefit of mankind.

1.5 STUDY AREA

1.5.1 Location and Size

The study area is Guinea Savanna Ecological Zone of Nigeria. The area lies between the semi-arid north and the wet southern part of the country. The area lies approximately between longitudes $3.^0$ and 14^0E and latitudes 6^0 and 10^0 36'N (see Figure 1.1). The region is sometimes referred to as the middle belt and has a land extent of about 323,569 square kilometers and a west-east breadth of about 800 km (Buchanan and Pugh, 1955). The enumerated total population of the entire study area was put at 88, 257, 112 with male totaling 53, 623, 124 and female 34, 633,988 (NPC, 2006).

1.5.2 Climate

Rainfall is the key climatic variable in the study area. Rainfall in the zone is largely seasonal and highly variable from year to year, with mean annual rainfall of between 1500 mm and 1800 mm in north and south respectively. The delineation of the Guinea Savanna Zone is based on the mean annual rainfall as well as the severity of the dry season. The southern limit of Guinea Savanna zone is based on a mean annual rainfall of at least 1600 mm and lowest mean monthly relative humidity at 9 a.m of not less than 70%.

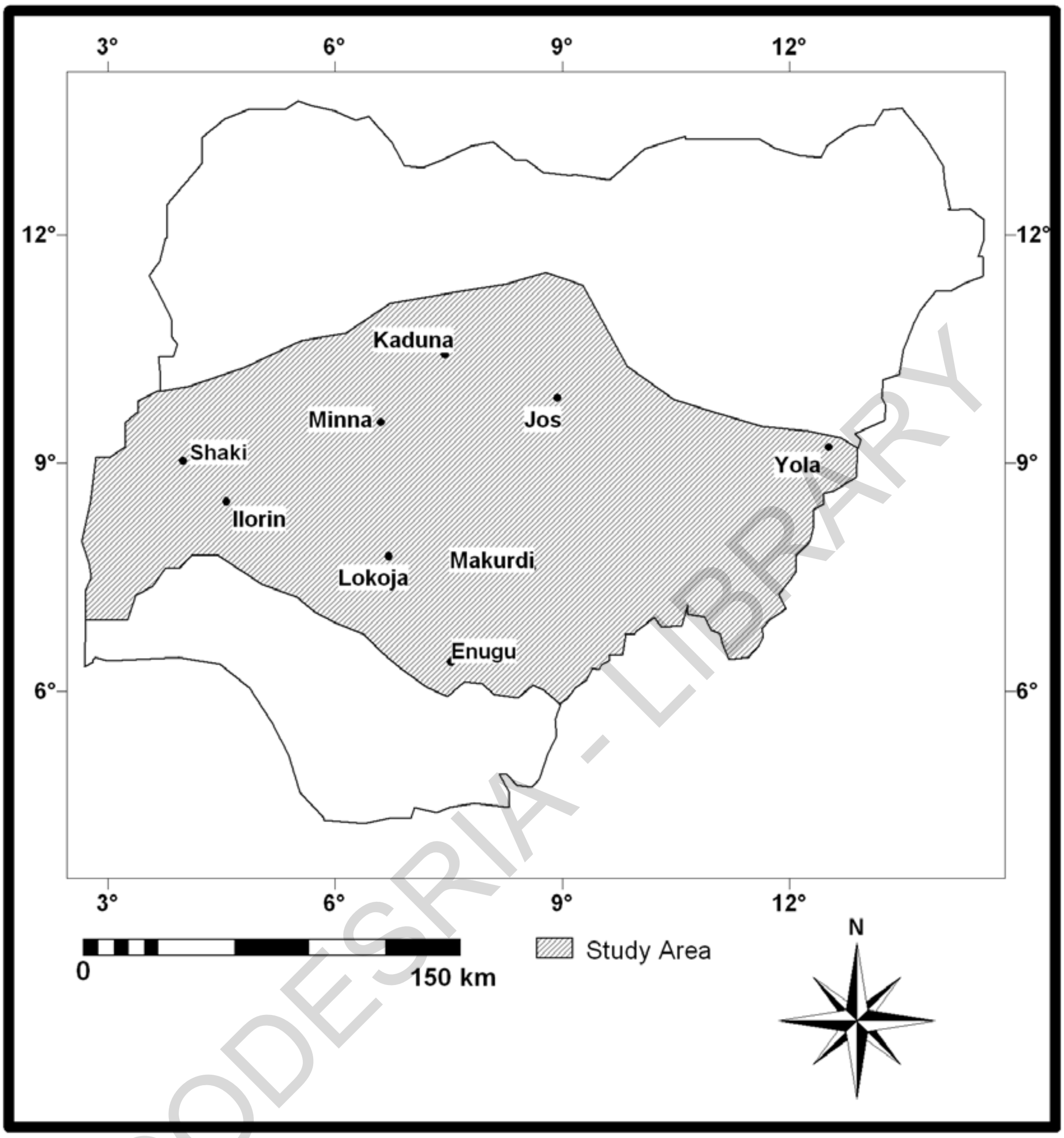


Figure 1.1: The Study Area within Nigeria

The northern limit of Guinea Savanna zone is at approximately 1550mm mean annual rainfall, with the lowest mean monthly relatively humidity at about 29%. By April or May the rainy season is underway in most areas south of the Niger and Benue river valleys. Farther north of Guinea Savanna, it is usually June or July before the rains really commence. The peak of the rainy season occurs in August, when air from the Atlantic covers the entire country. From September through November, the northeast trade winds generally bring a season of clear skies and lower humidity for this area. From December through February, however, the northeast trade winds blow strongly and often bring with them a load of fine dust from the Sahara. These dust-laden winds, known as the Harmattan, often appear as a dense fog and cover everything with a layer of fine aerosols and dust particles. The harmattan is more common in the Guinean Savanna but affects the entire country. (Anuforom, 2004).

The dry season extends over a period of about 6-7 months, from October/November to March/April, while the remaining months are wet. The climate of the study area is characterized with relatively high temperatures throughout the year. The average annual maximum temperature varies between 35ºC and 31ºC throughout the year while the average annual minimum temperature is between 23ºC and 20ºC (FAO, 2001). On the Jos plateau and the eastern highlands, altitude makes for relatively lower temperatures, with the maximum temperature of 28ºC and minimum temperature of 14ºC (FAO, 2001). Frequent drought periods have been among the most notable aspects of Guinean Savanna climatic attributes in recent years. Climatologists regard the twentieth century as one of the driest periods within the last several centuries. The well publicized droughts of the 1970s and 1980s were only the latest several significant of such episodes to affect West Africa (FAO, 2001). At least two of these droughts have severely affected large areas of the Guinea Savanna Ecological Zone.

1.5.3 Vegetation

The Guinea Savanna ecological zone is characterized by patches of woodland, consisting of both fire-tolerant and fire-tender trees, but over large areas the vegetation has been degraded by fire and farming (Owonubi, 1997). This vegetation region covers about one-half of Nigerian land area and it is characterized by tall grasses and scattered trees. The typical vegetation is open woodland with tall grasses in open areas and trees, usually with short boles and broad leaves. Fierce fires burn this vegetation almost annually in the dry season; therefore fire-resistant species predominate (Obasi, 2001a). Many of the species in the southern areas of the Guinea Savanna zone are closely related to high forest species. Such species as *Lophira Lanceolata* and *Terminalia glaucescens* are good examples. Other typical species are *Opilia celtidifolia*, *Gardenia spp*, *Protes elliottii*, *Uvaria chamae*, *Daniellia oliveri, Hymenocardia acida, Vitex doniana, Detarium microcarpum, Isoberlinia doka, I. dalzielli, Monotes kerstingii, Uapaca togoensis* and *Afzelia africana*. All these species have thick bark capable of resisting grass fires, and they typically send up a dense sucker growth after the fires have passed.

1.5.4 Geology and Soil

Geology is virtually entirely sedimentary except in South East Kwara, northern part of Oyo, west of Kogi and eastern Adamawa and Taraba states where the soils are underlain by the basement complex rock (Buchana and Pugh, 1955). The sedimentary areas typically consist of flat-topped ridges and dissected plateaus and a characteristic landscape of extensive plains and no major rocky outcrops (Odunze et al, 2005). The landscape of the study area is generally true of the basins of the Niger and Benue rivers in the far northwest and northeast of the Nigeria, respectively. The most dramatic of the sedimentary landscapes are in southeast, where thick sedimentary beds from the Abakaliki Uplift to the Anambra Basin have been tilted and eroded. This process has resulted in rugged scarp land topography with east-facing cliffs as in the Udi Hills, north of Enugu, and in the area around Nanka and Agulu (Buchana and Pugh, 1955). The elevational pattern of the study area consists of a gradual rise from the coastal plains to the Guinean savanna regions and generally reaching an elevation of 600 to 700 meters. Higher altitudes, reaching more than 1,200 meters in elevation, are found only in isolated areas of the Jos Plateau. The Niger and Benue basins are the broad, stepped plateau and Granite Mountains that characterize much of the study area (Buchana and Pugh, 1955).

Soils in the Northern Guinea Savanna Zone of Nigeria are lighter in colour usually called “Nupe Sands” (Buchana and Pugh, 1955). Although, rainfall is still considerable, they are leach to lesser extent which make longer fallow period possible. Nevertheless, fertility in the area can be classed as more than medium. Soils in this area are continually being degraded. Soil erosion by water is a major factor degrading soils of the zone (Odunze et al, 2005). Soil erosion in the zone is prominent during the early part of the rainfed-cropping season, when the soil surfaces are largely bare.

1.5.5 Agricultural Practices and Crop Production

Until the independence in 1960, agriculture (most especially from Guinean Savanna) was the most important sector of the economy, accounting for more than 50% of GDP and more than 75% of export earnings (NEST, 2003). The Guinea Savanna ecological zone represents a rich agricultural area of Nigeria that accounts for about two-thirds of the nations total agricultural production (Anuforom, 2005). The area is made up of traditional small-holder farmers, who use simple techniques of production and the bush-fallow system of cultivation.

Subsistence food crops (i.e mainly sorghum, maize, yams, cassava, rice and millet) are grown in the area and are traded largely outside the area. The most significant commercial crop of the area are sesame (or benniseed) and millet. Agriculture employs the larger percentage of the working population in the area, but agricultural landholdings are generally small. The average number of farm plots per household ranges between 3 and 30 plots and between 0.4 and 4.0 ha (FAO, 2002b). Cropping systems across the zone are characterized by tremendous diversity. The predominant form of crop husbandry in the case study areas is the rainfed cultivation of annual cereal crops.

However, with the rapid expansion of the petroleum industry, agricultural development was neglected, and agricultural sector entered a relative decline. After independence, especially in the mid-1980s, Guinean Savanna part of Nigeria moved from a position of self-sufficiency in basic foodstuffs to one of heavy dependence on import goods (FAO, 2001).

CHAPTER TWO

LITERATURE REVIEW

2.1 CLIMATE VARIABILITY

Different scholars and organizations have carried out the climate/crop related research works in different parts of the world. Their studies have considered the relationship between climate variability and agricultural productivity in order to establish the impact of the former on the latter. Some of them are: Ojo and Oni 2001; IPCC, 2001; 2004b; Chiew 2002; Okpara, 2003; Adejuwon, 2004; among others. IPCC (2001) gives a clear difference between climate variability and climate change. Climate fluctuates naturally on all time scales from days, years and few decades (climate variability proper) to many decades - climate change. Thus, climate variability is short-to-medium term fluctuations around some mean climate state on time scales, varying from less than annual to multi-decadal time scales such as 30 years. Climate change, on the other hand is a fundamental shift in the mean state of climate. It pertains generally to longer-term trends than that of climate variability (Okpara, 2003; IPCC 2001; 2004b). In other words, climate variability is the fluctuations of climate naturally on a time scale ranging from days, weeks and year to few decades, including altered frequencies of extreme events while climate change is a longer term fluctuation from decades to centuries.

Climate variability has been, and continues to be, the principal source of fluctuations in global food production, particularly in the semi-arid tropical countries of the developing world, Nigeria inclusive (Sivakumar, 1997;

Adejuwon, 2004). It determines not only where and when to plant a crop but also whether the crop will yield effectively or not

Theoretically, there are three different forms of rainfall variability: (a) spatial (b) inter-annual (c) intra-annual variability (NEST, 2003). Spatial variability has to do with differences in total rainfall received between places structurally located within a given region. Inter-annual rainfall variation can be defined as the annual deviation from long-term averages or the differences in rainfall between years. Intra-annual rainfall variability refers to the distribution of rainfall within a year (Obasi, 2003b). In the last decade, inter-annual rainfall variations are causes of great stress to the farming activities, crop production and crop yield in the Guinea Savanna of Nigeria (Adejuwon, 2004).

2.2 RAINFALL AS THE MOST IMPORTANT DETERMINANT OF CROP YIELD

Rainfall has been the most important determinant of the climate and crop yields in Nigeria as well as in other part of West Africa (Awosika et al 1994; Adejuwon and Odekunle, 2006). Inter-annual variability in rainfall has been the key climatic element that determines the success of agriculture in the sub-region. As observed by Awosika et al (1994), the aggregate impact of drought on the economy of Nigeria in 1992 was between 4% and 6% of the GDP. The rainfall of the region has changed substantially over the last 60 years (Awosika et al, 1994). Adejuwon (2004) observed that rainfall anomalies such as decline in annual rainfall, change in the peak and retreat of rainfall and false starts of rainfall are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season. Rainfall variability in actual fact affect crop yield, photosynthetic rate, plant growth, and it could also affect the incidence of pest and disease outbreaks and mortality, which in turn will affect crop yield and production (Haimson and Ennis, 2004).

From an analysis of recent rainfall conditions in West Africa, FAO, (2001) concluded that a long-term change in rainfall has occurred in the semi-arid and sub-humid zones of West Africa. Rainfall during the last 30 years (1968- 1997) has been on average some 15% to 40% lower than during the period 1931-1960. It has been observed that the most important climatic element is rainfall, particularly seasonal drought the length of the growing season and the distribution of rainfall within the growing season. The rainfall characteristics may affect crop yields in the sub-region. (IPCC, 2000; 2004a; 2004b).

2.3 THE IMPACTS OF RAINFALL VARIABILITY ON CROP YIELD

The impacts of rainfall variations on crop yields have been well documented through decades of field experiments, statistical analyses of experiment yields and monitoring of agricultural activities (IPCC 2000). The total rain and distribution of rains at any location determine the frequency and intensity of drought and flooding as well as the length of the growing season in that location (Owonubi, 1997).

WMO (2000), discussed the impacts of rainfall variability on agricultural productivity in Asia, Africa and Latin America with suitable examples. In tropical Asia and Africa, agricultural productivity is sensitive to rainfall variability that eventually causes environmental and social stresses. The arid and semi-arid tropics of Africa are already having difficulty in coping with environmental stress (WMO, 2000). Inter-annual rainfall variability is resulting in increased frequencies of drought and poses the greatest risk to crop yield.

According to FAO, (2001), extremes of heat and cold, droughts and floods, and various forms of violent weather phenomena have wreaked havoc on the agricultural systems in these regions. Climate variability and change contribute immensely to vulnerability to economic loss, hunger and famine. Hence, it is imperative that these aspects are well understood in order to formulate more sustainable policies and strategies to promote food production in Nigeria. In the report titled “Climate Variability and Change: A Challenge for Sustainable Agricultural Production”, FAO (2001) examined the effects of rainfall variability on food production and concluded that there are many interactions between climate variability and agriculture. Although agriculture is affected by the vagaries of climate, it also contributes to increasing climate variability and change through emission of greenhouse gases, land degradation, deforestation, etc. However the effects of rainfall variability on all forms of agricultural production are of major concern in the report. The study shows that rainfall variability is one of the main determinants of agricultural production in both developing and developed countries. The loss of agricultural production associated with background variability of rainfall is significantly higher than those associated with spectacular but localised weather-related hazards like cyclone and flooding. In fact, 10% to 100% of the short-term variability of production can be ascribed to rainfall variability depending on the level of development and technical influences (FAO, 2001).

Maize, Millet, Cassava and yam production in particular are mainly affected by the vagaries of rainfall due to the fact that they are mostly grown on marginal lands (Sivakumar,1997). Precipitation and temperature anomalies often result in huge cereal yield reduction and consequently, economic losses for farmers. Aina and Adejuwon (2004) pointed out that rainfall variability becomes critical for cereal crop production when moisture availability drops below the optimal level required for biomass growth during different stages of the agricultural cycle, resulting in reduced yield, and it also becomes critical in economic terms when a shortfall in water availability is beyond the recurrent seasonal rainfall pattern.

In general, changes in rainfall variability as well as in the mean value of climate variables influence the yield of cereal crops, but because the pattern of rainfall variability is not necessarily harmful, the problems arise from extreme events and the uncertainty which derives from the difficulty of predicting weather beyond a week or so (FAO, 2001). It is essential to note that although these extreme events are inherently abrupt, random and disastrous, the risks can be reduced through improved preparedness and planning, better information, stronger institution and new technologies to minimise human and material losses (FAO, 2001). Agricultural productivity in Nigeria is strongly linked to rainfall variability because farmers rely on rain-fed agriculture. Therefore, water scarcity is a major constraint to cereal production, especially millet that is grown on the marginal lands in the northern part of the country where other crops generally fail.

Rainfall variability affects crop yields greatly and indirectly influences the population living standards. Adejuwon (2005) observed that rainfall anomalies such as decline in annual rainfall, change in the peak and retreat of rainfall and false starts of rainfall are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season. IPCC (2004b) provided evidence of some increasing climate variability and showed that climate variability particularly droughts, in the semi-arid regions of the developing countries, trigger frequent subsistence crisis-sharp increase in crop failure, dislocation, hunger, and famine. Owonubi (1997) also noted that changes in average rainfall conditions and climate variability will have significant effect on Nigerian agriculture since farmers depend on rain-fed agricultural systems. Particularly vulnerable is the northern part of the country where there has been a trend towards increasing aridity. If rainfall varies from the norm, both in terms of total precipitation and timing, food security will be greatly affected (FAO, 2001).

2.4 GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN AGRO-CLIMATOLOGY

Over the last decade, researches have greatly increased into the use of Geographical Information Systems (GIS) in a variety of applications that involve the processing of climatological and meteorological data. Recent efforts using GIS for applications in climate and meteorology include traditional GIS strategies for hydromet database analysis and management, and the fusion of hydromet data with traditional GIS applications (e.g Tveito et al. 2000; Tveito and Sch-oner, 2002; Daly et al, 2004; Zbigniew and Danuta, 2005). But new techniques are emerging which exploit GIS features and capabilities to support the analysis of hydromet data in the GIS operating environment. GIS have now become a very important and widespread tool serving a variety of functions in many environmental sciences including meteorology and climatology (e.g. Tveito et al. 2000). GIS techniques are also very helpful for climate monitoring, as it is easy to calculate and map the mean monthly or seasonal temperatures for specified periods and the deviations from the mean value. It is hard to imagine contemporary climate monitoring without GIS applications (Zbigniew and Danuta, 2005). GIS tools give very exact and detailed images of analyzed data more effectively than traditional – usually manual –techniques. GIS tools also enable the easy calculation and display of the area under specified climate conditions and the display of maps for climate monitoring purposes.

Well-constructed GIS maps allow presentation at a wide range of spatial scales and virtually unlimited regimens for data processing. At the same time, the construction of digital maps is now possible because of progress in computer science, data availability, exchange and access, and worldwide communication networks. Finally, the production of digital maps is much cheaper and faster than those produced using analogue technologies (Tveito and Sch-oner, 2002). GIS are unique because of their emphasis on providing users with a representation of objects in a cartographically accurate spatial system and on supporting analysis and decision-makings (Burrough, and Rachael 1998).

2.5 EVALUATION OF RAINFALL SPATIAL INTERPOLATION METHODS

Climate information is based on in-situ observations, and spatial interpolation schemes are used to establish fine-mesh grids of these variables over the model domain. Climatic elements can be spatially distributed by applying spatial interpolation methods. Interpolation is a systematic process of estimating the value of properties at un-sample sites within the area of study by existing observation (Burrough, 1990). Many different methods of spatial interpolation exist and they are widely described in the specialized literature. Perhaps the most widely adopted version of this technique is the one that adopts the data collected at the nearest weather station for the location of interest. There are a number of such methods available for rainfall variability assessment (Tveito and Sch-oner, 2002), but their application is restricted by theoretical assumptions that must be fulfilled as far as possible. These assumptions vary between the methods, and are discussed in detail by Tveito & Sch-oner (2002). The use of mathematical or geo-statistical methods can also be restricted by the use of extra information (co-variables), and the availability of such.

Rainfall spatial interpolation methods range from simple estimations to complex procedures and can be gathered in many typologies. The one that are generally used by scholars is based on two categories; the determinist methods and the stochastic methods. The determinist methods gather the bary center techniques with Inverse Distance Weighting method. For example, the area division techniques like the Thiessen polygons method, and the spline techniques (regularized and tension). The stochastic methods include the classic regression techniques with amongst them the trend surface analysis technic, the local regression techniques, and the kriging techniques (Burrough, 1990). Efficacy of the various interpolators varies; depending on the variable, the physical environment and the sampling density. Most interpolation techniques give similar results when data are abundant. For sparse data, the underlying assumptions about the variation among sampled points differ and, therefore, the choice of interpolation method and parameters become critical. Kriging has the disadvantage of high computational requirements (Burrough and Rachael, 1998). However, several studies conclude that the best quantitative and accurate results are obtained by kriging (Burrough and Rachael, 1998). Comparing thin splines, inverse distance weighting and kriging, Cristobal-Acevedo (1993) for soil parameters, concluded that thin spline is the least efficacious of the three. Splining has the disadvantage of providing no error estimates and of masking uncertainty (Collins and Bolslad, 1996). Also it performs better only when dense data, regularly-spaced, are available; it is thus not recommended for irregularly spaced data. It is the view of Easterling, (1998), that there is no simple answer regarding choice of an appropriate interpolator. Method performance depends on the variable under study, the spatial configuration of the data, and the extent to which the underlying assumptions of the methods are met.

Today's most commonly used spatial climate data sets have been created through the process of statistically interpolating data values from irregularly spaced station locations to a regular grid (Daly et al, 2004). Most rainfall data sets in use today have been developed using one of six interpolation techniques: inverse distance weighting (IDW), various forms of kriging, ANUSPLIN tri-variate splines, local regression models Daymet and PRISM, and regional regression models. These six techniques represent a mixture of general numerical methods and specific models (Davey and Pielke, 2005). IDW and kriging are related formulations that have been implemented in a variety of models too numerous to discuss here, so they have been grouped together into one category. ANUSPLIN employs general cubic spline theory, but because this specific model is extensively used in the development of popular spatial climate data sets, it is not the focus of discussion here. Daymet and PRISM are specific models that both use local regression techniques and have been used extensively to develop popular spatial climate data sets, but are otherwise very different in their formulation. IDW is the simplest of the six interpolation techniques. It takes advantage of the well-known principle that as the distance between a station and a location to be interpolated increases, the influence of that station on the interpolated value is lowered (Burrough, 1999). However, even sophisticated interpolation schemes incorporate some form of IDW algorithm. IDW is also used quite often to interpolate deviations from a long-term mean in climate data interpolation schemes. It is worth mentioning, however, that future climate interpolation methods are likely to employ hybrid approaches that combine remote sensing, numerical models, and station data interpolation (Daly *et al*., 2002 and Smith *et al*., 2004).

2.6 GIS DATABASE SYSTEM

A database is a unified computer-based array of information, shared by authorized users, with the capability for controlled definition, access, retrieval, manipulation, and presentation of data within it. At the heart of any GIS is the database (Worboys, 1995). The design of the database, namely, the database model, is a critical factor in building a GIS database. The layer-based and tile-based GIS use relational database model. Relational data bases isolate the graphic data from the attribute data. It leads to myriad of linkages between data tables and between graphic and attribute data stored in different locations. This, however causes the consumption of much computer memory space and thus increases processing time (Johnston et al, 1996; Vergani et al, 2002).

Although data capture, manipulation, and management are important functions of GIS, most GIS is eventually used to support data analysis and decision-making. The literature in the management information systems field is rich with descriptions of various decision support technologies to which GIS can be applied. For example, Aronoff, (1989); Goodchild (1993), and some other researchers have provided useful frameworks for understanding the nature and role of GIS database as a means of decision support technologies. In particular, the framework proposed by Goodchild (1993) is quite useful for defining a practical framework for considering GIS. Using such a framework it becomes clear that GIS include all of the features that are in a Decision Support Systems (DSS). However, they also include several other components. For example, a DSS includes various subsystems including data management, model management, knowledge management subsystem, and dialog management subsystems. A GIS includes similar subsystems, albeit subsystems, which are spatially enabled (Kufoniyi, 1995; 1998; 2003). For example, a typical spatial DSS will include a data management subsystem designed to manage textual or, in some cases, object-oriented data. A GIS must not only be able to manage these types of data, but also manage and integrate spatial data (e.g., data which include cartographic coordinates).

A GIS is a system specifically designed to work with data referenced by spatial or geographic coordinates (Sogoh, 2004). It is therefore both a database system with specific capabilities for spatially referenced data, as well as a platform for analytical operations to work with the data (Kufoniyi, 2004). A model built with GIS tools usually refers to a spatial model.

2.7 GIS SPATIAL MODELLING

One of the strongest and most successful application areas of GIS has been in modelling spatial changes in environmental systems. The study of GIS has emerged in the last two decades as an exciting multi-disciplinary endeavour, spanning such areas as Geography, Cartography, Remote Sensing, Image Processing, Environmental Sciences and Computer Aspects of GIS (Goodchild, 1993; Worboys. 1995). A GIS model is an abstraction of the real world that employs a set of data that support map display, query, editing, and analysis.

Generally, there are three approaches to building GIS models: the layer-based approach, the tile-based approach and the Object-Oriented based approach (Heywood et al., 2002), which are depicted in the following sections. The most common method of structuring spatial information in the computer is to use a layered approach, through which the real world is dissected into a series of layers. Each layer is thematic and reflects either a particular use or a characteristic of the landscape (Olaf, 2001). The use of tiles is a logical extension to the layer concept. This approach breaks down geographic space into a series of regular or irregular units that can be reassembled through the use of a coordinate system. The main purpose of the tiling concept is to assist with the storage of information in the computer (NASRDA, 2003). The Object-Oriented (OO) approach structures geographic space into a set of individual objects or groups of objects, defined as a class. The concept of “Object-Oriented” is straightforward as it emulates the real world of objects, as opposed to layers or tiles. The term “Object-Oriented (OO)” comes from computer programming, as in “Object-Oriented Programming Language” (Lee and Tepfrenhart, 2001). The database design employs three major characteristics of the concept of “Object-Oriented (OO)”:

1 Encapsulation,
2 Inheritance, and
3 Polymorphism.

In the Object-Oriented design, according to Lee and Teprenhart, (2001), the real world is made up of objects which can be grouped into classes Individual objects are characterized as attributes and behaviours. Encapsulation is a system construct, which has a clearly defined protocol prescribed in the definition of the object. With encapsulation, the world external to an object is shielded from the internal nature of that object and only communicates with it via a set of predefined messages that the object can understand and handle (Lee and Teprenhart, 2001; Tan and Shibasaki 2001; 2002). An important benefit of encapsulation is that since the internal implementation is totally hidden within the class, the implementation of a class can be changed without affecting other objects in the system. In other words, the implementation can be extended and modified without affecting the users of the class. This leads to easy software extensibility and reusability (Khoshafian and Abnous, 1995). Inheritance allows the value to be reused and thus reduces the data storage in the computer. This concept is very influential, because it reduces information redundancy (Woelk, 1987 in Egenhofer and Frank 1992) and maintains integrity. Polymorphism allows the same operation to be implemented in different ways in different classes. Polymorphism makes it possible for two or more objects to respond to the same message differently (Worboys, 1995). The relationship between classes can be designed using a relationship class. This database logical model designed using the CASE tool and UML can be transferred into a physical model directly and can automatically generate codes without manual programming.

CHAPTER THREE

METHODOLOGY

3.1 DATA ACQUISITION

Crop yield and rainfall data for 1970 to 2000 were used in this study. The data are for nine stations located in the study area (Table 3.1). Data on annual crop yield were obtained from the National Bureau of Statistics, Abuja, which is the central organisation for data collection in Nigeria. The crops studied were millet, maize, cassava and yam. Rainfall data were collected from the archives of the Nigerian Meteorological Services, Oshodi Lagos. In this study, rainfall is considered as the primary input for crop yield. It was observed that the most important climatic element is rainfall; particularly inter-annual variation and the spato-temporal distribution of rainfall. They affect both crop yields and yield quality (Adejuwon and Odekunle 2006). Thus rainfall is probably the most determinant factor of crop growth, development and thus crop yield. The rainfall data used in this study consist of monthly and annual rainfall total for the period 1970 to 2000.

3.2 DATA QUALITY

The rainfall data used in this study were collected by the Nigerian Meteorological Services using Dines Tilting Raingauge and the British Standard Raingauge. Data collected using these equipment are samples in space and time, are thus subject to various errors, notably, instrumental errors, observer error and data in-homogeneity.

Table 3.1: Names and locations of the stations used in the study.

S/N	NAME OF STATION	LATITUDE (^{0}N)	LONGITUDE (^{0}E)
1	Enugu	6^0 27'	7^0 29'
2	Makurdi	7^0 50'	8^0 05'
3	Lokoja	8^0 02'	6^0 02'
4	Shaki	8^0 03'	3^0 05'
5	Ilorin	8^0 55'	4^0 11'
6	Yola	9.12'	12.30'
7	Minna	9^0 36'	6^0 34'
8	Jos	9^0 52'	8^0 54'
9	Kaduna	10^0 36'	7^0 27'

Source: GPS Data Acquisition during Field Work

Also, it facilitates the use of common concepts, definitions and the use of the same sample area from year to year.

3.3 DATA ANALYSIS

3.3.1 GIS Method

3.3.1.1 Geospatial Interpolation Techniques for Rainfall and Crop Yields Variables

Mean annual precipitation for the averaging period 1970–2000 was interpolated. Three spatial interpolation methods were chosen for this research work: Inverse Distance Weighting (IDW) method and the Spline (completely regularized) as the determinist methods; and Ordinary Kriging as the stochastic method. In order to analyze the interpolation quality, an evaluation by cross validation has been carried out. The three different spatial interpolation methods are then applied to estimate the missing value on the basis of the remaining observed ones. This process has been carried out on each rain station. For each interpolation test on the three methods, the rainfall observed values Z(x) have been considered, the estimated values Ž(x), and the errors e(x) = Z(x)–Ž(x). The mean of the errors and its standard deviation was then calculated for each interpolation method.

The IDW method was executed in Microsoft Excel spreadsheets for each of the nine rainfall stations. The interpolation method was carried out manually. After evaluation of a number of options, the program chosen for fitting thin plate smoothing splines was JAVA 2. That was developed to calculate and optimize thin plate smoothing splines to data sets of unlimited size and distribution. Other available programs include ArcGIS, which was used for the kriging method, with runtime advantages. ArcGIS Geostatistical Analyst was chosen as the tool to implement the kriging interpolation method. Geostatistical Analyst is an extension of ArcMap used to generate surfaces from point data. The software is a powerful, user-friendly package and is flexible for implementation. Surface fitting using Geostatistical Analyst involves exploratory rainfall and crop yields data analysis, calculation and modelling surface properties of nearby locations, and assessment of results.

Inverse Distance Weighting method and the Spline are the less efficient interpolation methods for this research work. On the contrary, Ordinary Kriging is the method that allows the sharpest interpolation rainfall data and is the most representative.

3.3.1.2 Database Management and Spatial Analysis

In this study, two phases of GIS database management were adopted. First, database design phase were executed, and the second phase is implementation (construction) phase (Kufoniyi1995). GIS database design phase (data Modelling) for this study was divided into four levels namely (See Figs. 3.1 and 3.2):

1 Reality Phase,

2 Conceptual Design Phase,

3 Logical Design Phase, and

4 Physical Design Phase.

Reality Phase is all about observing the study area as it naturally exist. These include all aspects that may or may not be previewed by man. This involves mental abstraction of the reality for a particular application or group of applications which guides the user's request. Generally, the reality for this study is the study area (See Figure 3.1) and this was viewed in terms of the impact of rainfall variability on crops. This is the basic requirement (user requirement) of this study. Conceptual Design Phase involves the choosing of a data model (Kufoniyi, 1995) that includes: Vector Database Model; Tessellation Database Model and Object Oriented Database Model. Vector database model were used during the creation of map layer while object oriented approach were used for writing Java programming languages. Logical Design Phase involves the representing the database model designed to reflect the recording of the data in the GIS. This process is also known as data Structuring (Kufoniyi, 1998). Relational data structure was adopted for this study (Fig. 3.1). Although, we have many other types of data structures like hierarchies; object-oriented, object-relational, among others, but relational data structure presents data in a simple uniform manner in form of tables or relations. Physical Design Phase involves choosing GIS subsystems to be used for the study (Fig. 3.1). The GIS hardware components that were used for this research include digitizer, scanner, printers, keyboard, among others. A computer system of Pentium IV Processor, 850 MHZ, 80 GB hard dick, was used for the analysis and cartographic works.   ILWIS 3.2 and Arc-view GIS software were used for spatial analysis, interpolation and cartographic presentations.

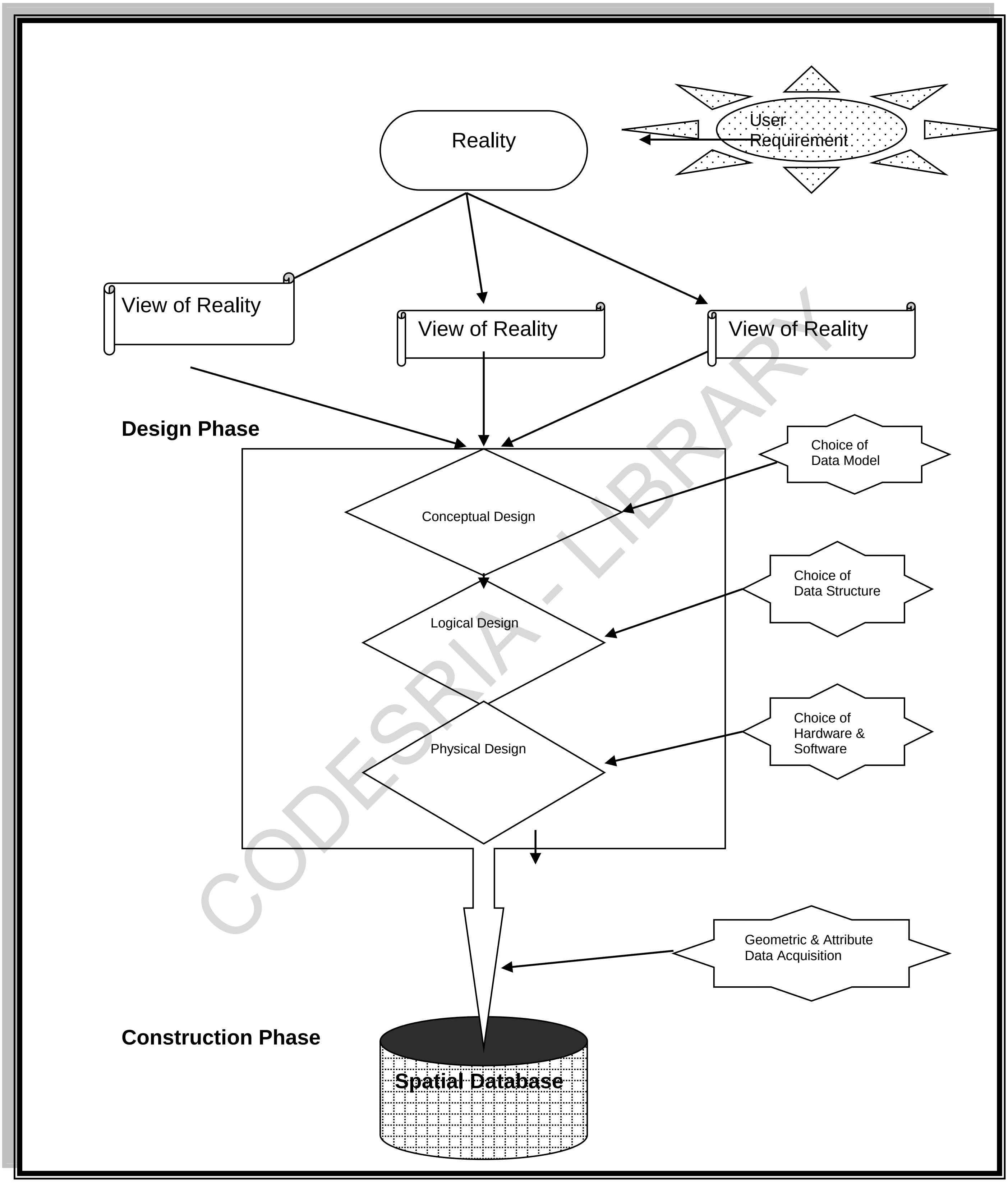


Figure 3.1. Database Design Phases (After KufonIyi, 1995).

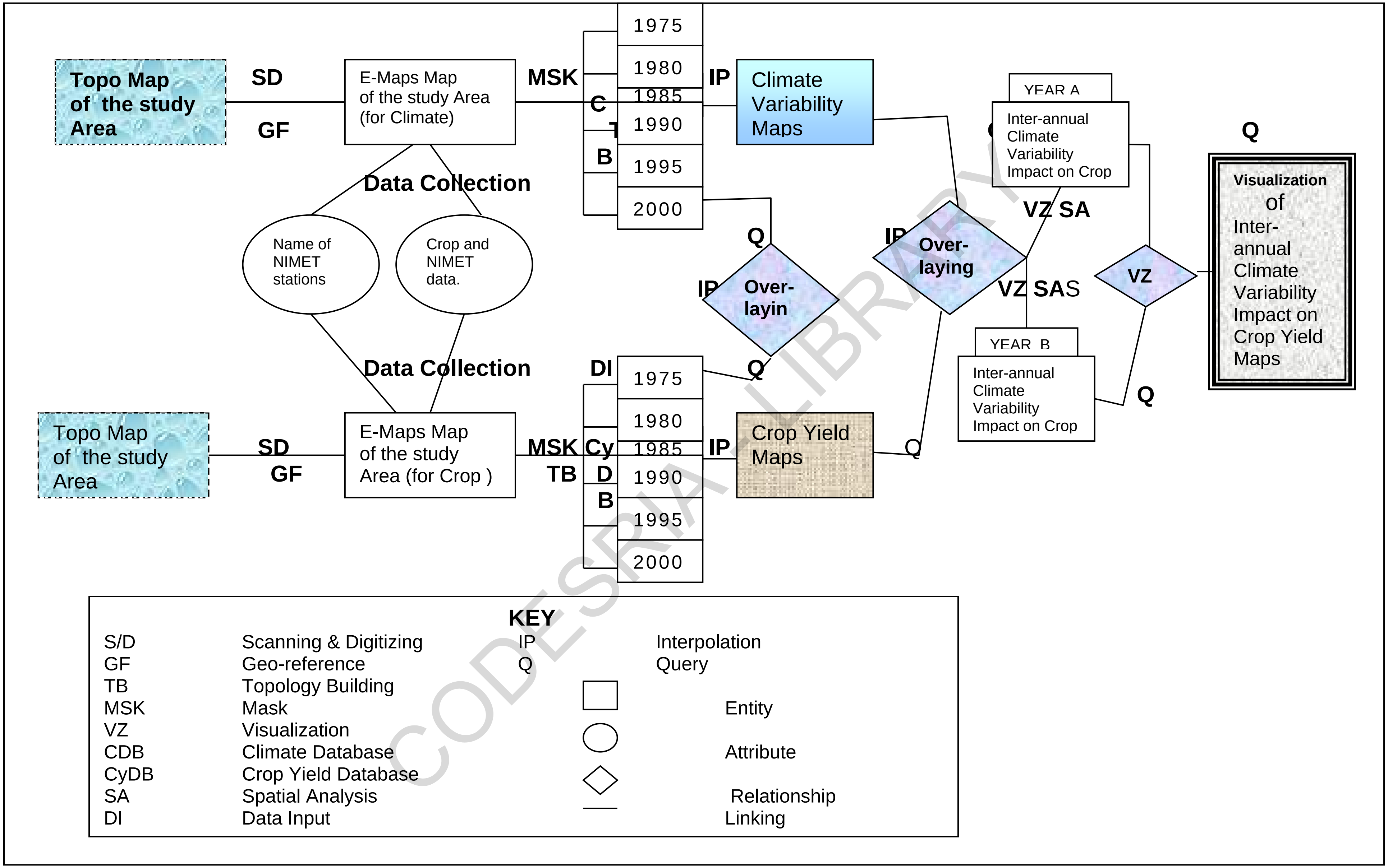


Figure 3.2: GIS Entity-relationship Model for Inter-annual Climate Variability Impact on Crop Yield. (GCMICVIC)

3.3.1.3 Mapping Techniques

To produce spatially explicit maps of rainfall and crop yield variability, Ordinary Kriging was used to interpolate the point observations from a network of rainfall base stations. The software used for all interpolations was ArcGIS, produced by Environmental Systems Research Institute (ESRI). Java script was developed to automate the running of the maps on the Internet. Though, several spatial interpolation methods have been tested for the production of maps in this study: Cokriging; Universal Kriging; Residual Kriging and ordinary Kriging. After many attempts and qualitative and quantitative verifications, the last of these- Ordinary Kriging- was chosen for the map productions. Ordinary Kriging estimates for a rainfall and crop yield distributed variable at any unmonitored location are computed as a weighted average of the known values from a surrounding set of sampled points. Kriging weights are derived from a statistical model of spatial correlation expressed as semivariograms that characterize the spatial dependency and structure in the data. A major strength of the method is that measured spatial dependence in the weather parameter of interest and this is used to produce digital maps.

Special attention was paid to rainfall regimes that have practical values (e.g the length of the growing season and inter-annual variation). GIS – Ordinary Kriging- tool enable the easy calculation and display of the area under specific rainfall and crop yields variation and the display of maps for rainfall/crop relationship for impacts assessment purposes.

3.3.1.4 Implementation in GIS

The GIS software platform used in this research includes Arcview GIS 3.2, ILWIS 3.1 plus PCI Geomatics 9.0. These are commercial products well known as powerful tools for environmental spatial modelling. Arcview GIS uses an object-relational data model for representing geographic information in a Database Management Systems (DBMS). Arcview of ESRI is used to organize, harmonize and combine both rainfall and crop yields datasets applied.

In order to make the digital maps produced run on internet, two approaches were tested which differ slightly in the way the spatial interpolation of rainfall and crop maps were implemented on internet. First, an approach using the in-built Internet algorithms in Arcview was tried. This approach worked well, but was very slow. The most time-consuming procedure in the computations was the calculation and sorting of the rainfall and crop datasets. In the second approach, rainfall data, crop yield data, rainfall stations and other related information were sorted once only. Each computation point was then assigned a vector with their nearest rainfall stations. The spatial interpolation was transferred to a JAVA-programme using this GIS table as input for database development. This approach was about 60% faster than the first one which applied the Arcview Internet algorithms.

3.3.2 Statistical Methods

The statistical methods that were employed for this study include coefficient of variation, multiple correlation, regression and z-distribution chart. Coefficient of variation (CV) was used to determine rainfall variability. Although, there are many measures of variability, the two most widely used are the relative variability and the coefficient of variation. The latter measure is the more efficient for this research work (Ayoade, 1988). Therefore, CV was used to examine rainfall variability and to assess the sensitivity or response (i.e. to assess impact) of crop yield to variability in rainfall. It is a measure of dispersion given by:

*Co-efficient of variation = (Standard deviation/mean) * 100.*

The mean and the standard deviations of the yields of crop for each station are first calculated, and then the co-efficient of variation is determined as a percentage of the mean. The coefficient of variation (CV) is mathematically expressed as:

$$CV = \delta / R'_f \ * \ 100\%$$

Where δ, the standard deviation is defined by

$$\delta = \{ \sum (R_f - R'_f)^2 \} / N$$

Where R_f is the annual rainfall for a given period, R'_f is the average annual rainfall and N is number of variable.

Rainfall of growing season months (April, May, June, July, August, September and October) were used for multiple correlation (MC) and regression analysis. Growing season monthly rainfall data were used because optimum crop yield is determined by the adequacy of rainfall at each phase in the growth and development of the crop plants from planting to harvesting. In regression analysis, the dependent variables were various crops, while the independent variables consisted of the monthly rainfall data of growing season. Regression equations are derived for every regression process carried out. These equations are used in predicting future scenario of the yield. In a simple term, future scenarios were generated using regression models:

$$y_d = \alpha+\beta\,(R_f)$$

Where y_d is the crop yield

R_f is the annual rainfall

α is the y_d -intercept which was obtained from the data through the equation $\alpha = y_d - \beta\,(R'_f)$

$$\beta = \{ \sum (y_d - y'_d)(R_f - R'_f) \} / \sum (R_f - R'_f)^2$$

R'_f is the Mean annual rainfall.

y'_d is the Mean annual Crop yield.

In order to estimate the relative contribution of each growing season month in determining the variability of crop yield, backward elimination procedure were used. This is the second phase of regression analysis. The method begins with the regression of each crop yield on all seven months (growing season months). The method automatically remove the least powerful explanatory variable (months with least effect on crop) at each subsequent cycle of regression. This eventually creates models with decreasing R, decreasing number of variables, decreasing degree of freedom and improving "goodness of fit" (Mather 1976). The optimum model is the one with the highest R at $\alpha \leq 0.05$. Cumulative effect of monthly rainfall on each crop studied was also analyzed using regression model. The mean rainfall of the whole station in the study area was regressed with the mean yield of each crop. Thus, the regression analysis, using backward elimination procedure is not only useful in identifying the more powerful predictors; more importantly it helps to discover models with acceptable data (Adejuwon, 2005). The procedure produced acceptable optimum model for some crops; while for other crops none of the models produced was acceptable, because α remained outside the limit of significance.

To show the impacts on chart, z-distribution chart was adopted for this study. The crop yield array was converted to a z-distribution format varying in magnitude from – 3 to +3. Hence, if the variations in crop yield from one year to the other are caused by the variation in rainfall, then the impacts represent negative and positive anomalies of crop yield which was computed for each year. From this format, significant positive and significant negative impacts, separated by the normal yield level could be discriminated. Whenever the anomaly is significant, it is counted as an impact. This Z- Distribution anomaly (which was used to draw z-distribution chart) is mathematically expressed as:

Index variation **(Z)** = $\dfrac{[s-m]}{SD}$

$s = \sum y_1, y_2, y_3, \ldots y_n,$ Where y = yield of maize

$m = \sum fy / n$ This shows the mean of maize yield

$SD = \sqrt{\sum\{y-m\}^2 / \sum fy}$ This shows the standard deviation of the yield

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RAINFALL VARIABILITY AND ITS IMPACTS ON CROP YIELD

4.1.1 Rainfall Variability

Figure 4.1 shows rainfall variability per decade in Guinea Savanna, part of Nigeria, from 1970 to 2000. As depicted in Figure 4.1a, rainfall gradually reduces from Southern Guinea Savanna to Northern Guinea Savanna during the period of 1970 -1979. Figure 4.1b however shows that mean rainfall has reduced during 1980-1989. The highest mean rainfall occurred in stations around Jos, Kaduna and Enugu in 1980-1989. Figure 4.1c shows that mean rainfall are normally distributed during 1990-1999. Highest mean rainfall occurred in Southern Guinea Savanna and. The mean rainfall is very high in Lokoja, and Enugu with values ranging from 2174 to 2987mm. The results obtained from this study imply that rainfall variability is very high in most parts of Northern Guinea Savanna (e.g Yola, Minna, and Kaduna) except Jos which has a unique pattern. Generally, the decadal mean rainfall values vary from 550mm to 2987mm. The highest mean rainfall was during the third decade (1990-1999) with six interpolation silhouettes while the least was observed during the second decade (1980-1989) with four interpolation silhouettes. The results have also shown that in the first time slide (1970-1979), Makurdi and Yola emerge with the same mean rainfall values ranging from 550mm to 956mm which is the least value during this time slice. It is

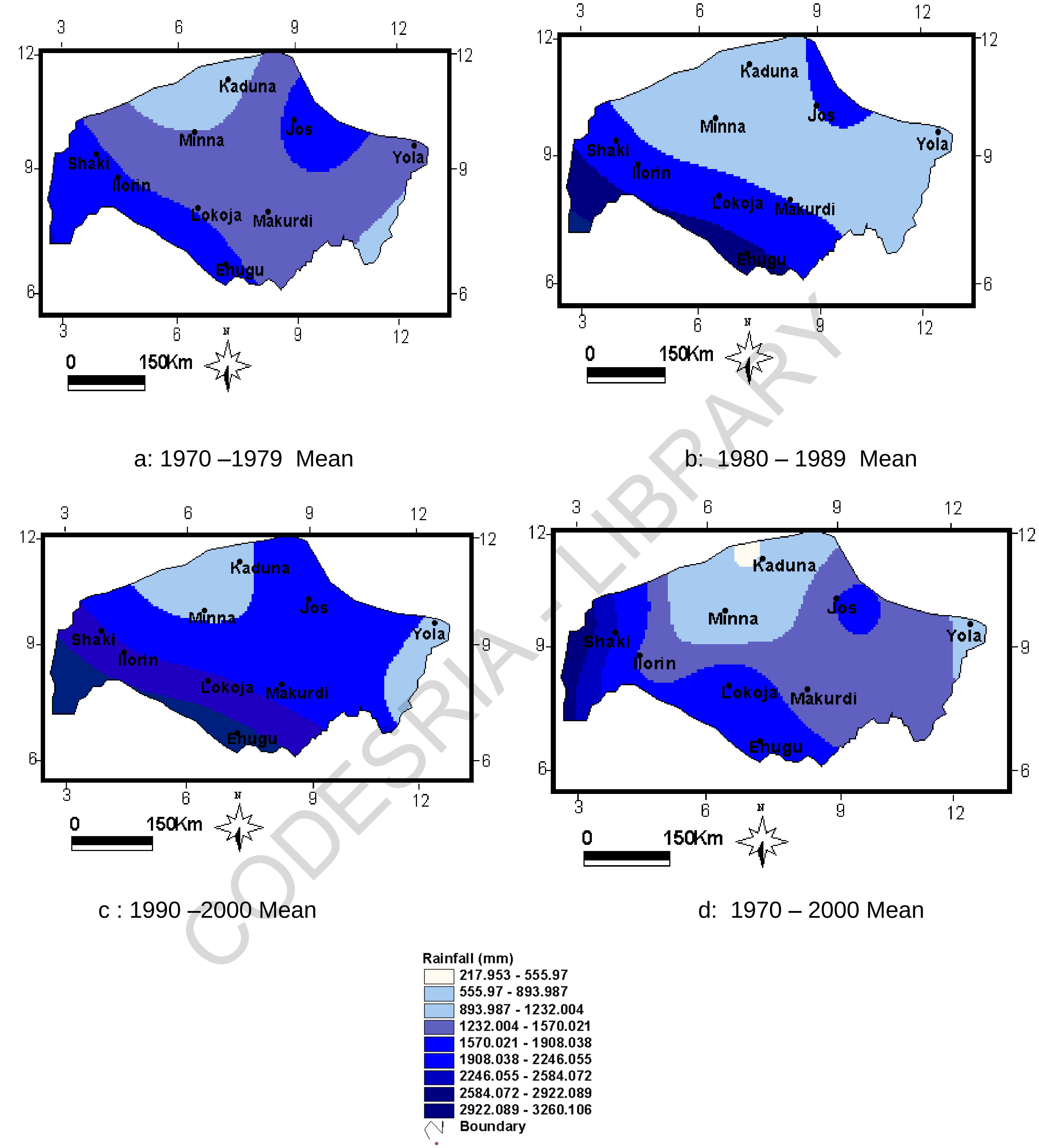


Figure 4.1: Rainfall Variability Per Decade in Guinea Savanna part of Nigeria (1972 to 2000)

observed that Jos, Kaduna and Minna appear in the values ranging from 1362mm to 1768mm but the peak interpolation silhouette value was recorded for Lokoja, Ilorin and Shaki (1768mm to 2174mm). The observation thus showed that during the second time slice, IIorin, Yola and Makurdi have the same value (550mm to 956mm) while Lokoja and Minna fall into the same group (1362mm to 1768mm). This is evident in Figure 4.1b. The mean rainfall in Figure 4.1d (i.e 1970-2000) shows a different pattern with six interpolation silhouettes. These results confirmed that rainfall variability is higher in many stations in Northern Guinea Savanna than that of Southern. This confirmed that rainfall varies both spatially and temporally. This study therefore confirmed previous observations of Chiew (2002), Anuforom (2004); Adejuwon and Odekunle (2006); Odekunle and Adejuwon (2007) that rainfall exhibits significant variation in time and space in Nigeria. This result also confirmed the observation of Nicholson et al. (2000) that in West Africa, there has been a pattern of continued variability in rainfall since the late 1960s.

Generally, in Southern Guinea Savanna, the coefficient of variation is very low especially in Enugu (9%) and Shaki (8%) (Table 4.1). However, the stations in the Northern Guinea Savanna have a relatively high coefficient of variation. For instance, Minna has 49%, Kaduna (43%) and Yola has 44%. This implies that the lower the annual rainfall total, the higher the value of coefficient of variation and thus variability in rainfall. From the results, it is very clear that rainfall varies both in time and space. The impacts of its variability are very significant on crop yield especially in the Guinea Savanna part of Nigeria. This may be as a result of evaporation potential that is very high throughout the year in the region. This study also corroborates the observation of Ojo and Oni, (2001) that the rainfall variability generally increases with decreasing total rainfall. It should be noted that rainfall varies inversely with the mean rainfall and also rain becomes less reliable as one moves towards the Northern Guinea Savanna part of Nigeria.

Although, both Southern and Northern Guinea Savanna are similar in that they experience alternate wet and dry seasons of varying intensity at times of high and low radiation respectively (Gbuyiro and Aisikuebo, 2003), it is not very satisfactory from an agricultural point of view to lump them all together. Apart from local differences due to differences in altitude (e.g high altitude of Jos), it was observed that there are remarkable variations in the number of rainfall per annum (p.a) in the duration of these seasons and in the amount of annual and seasonal rainfall. These results thus support the view of Gbuyiro and Aisiokuebo (2003) that variability of rainfall is an important factor in Guinea Savanna part of Nigeria where rainfall tends to be more seasonal in its incidence within the year. The results also corroborate the result of Nicholson et al (2000) that global climate change has manifested in West Africa, especially in the Savanna region, as high variability in rainfall in recent decades. These results also confirmed the view of Anuforom (2004) that between 1981-1987, the rainfall was below 700mm p.a while from 1988, it was above 700mm with 1998 having the highest 1800mm p.a.

.

Table 4.1: Coefficient of Variation of Rainfall of the Selected Stations (%)

STATIONS	**COEFFICIENT OF VARIATION (%)**
ENUGU	9
ILORIN	42
JOS	21
KADUNA	43
LOKOJA	17
MAKURDI	42
MINNA	49
SHAKI	8
YOLA	44

4.2 MAIZE YIELD VARIATIONS: SENSITIVITY TO RAINFALL VARIABILITY

4.2.1 Variation in Maize Yield

Figure 4.2 shows variation in maize yields per decade in Guinea Savanna part of Nigeria, in responses to rainfall variability. The figure is divided into four time slices (i.e. Figure 4.2a, b, c and d) which stand for the periods of 1970-1979, 1980-1989, 1990-2000 and 1970-2000 respectively. There is remarkable variation in maize yield per decade in all the stations. Generally, the figures show that maize yields behave in a similar manner i.e., increased in rainfall results in increased yield (see Figures 4.2a, b, c and d). For instance, it was observed that in all the stations, there is continuous increase in maize yield as noted during the first decade (i.e 1970 to 1979) while there are notable reductions in yield during the second decade (1980 to 1989). These results show that in general, maize yields are on the increase during the third decade, i.e 1990 to 2000. The results thus showed that rainfall variability actually influences maize yield during the second decade (1980-1989) and this leads to reduction in the maize yield in all the stations except in Lokoja where the interpolation dots are many during the time slice. Probably this is because Lokoja is located in wetter area with many rivers and lakes for irrigation. The yield is significantly low during the period 1980-1989 in Makurdi, Minna, Kaduna, Jos and Yola. The increase in yield recorded in 1990-2000 decade in all stations may be attributed to the increase in rainfall during the planting and growing seasons.

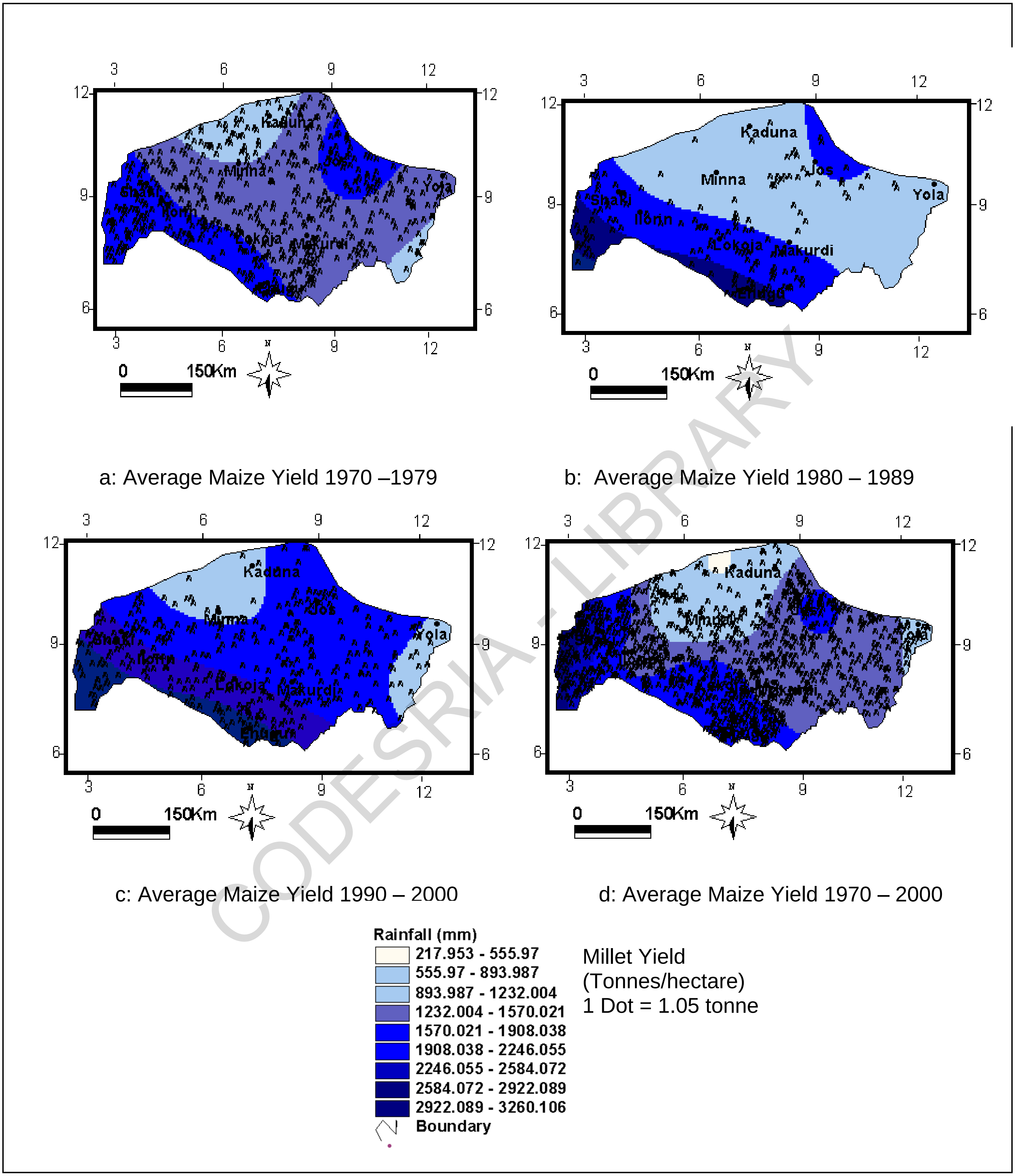


Figure 4.2: Maize Yield Variations: Sensitivity to Rainfall Variability in Guinea Savanna of Nigeria (1970-2000)

The results obtained in this study showed that reduction in maize yield observed from 1980 to1989 may be as a result of very low rainfall during growing seasons. This result authenticates the view of Obasi (2003a,b) that rainfall variability affects the various aspects of plant growth and yield. The results indicate that maize yield is highly dependent on rainfall availability.

4.2.2 Determinants of Inter-annual Variation on Maize Yield

Table 4.2 shows the result of correlation of maize yield with growing season rainfall for Guinea Savanna part of Nigeria. The results of multiple correlations of maize yields with monthly rainfall of growing seasons are not really strong. For example, in Makurdi, the result of correlation of rainfall of April and May with maize yield are significant with R = 0.50 ($\alpha = 0.01$) and 0.49 ($\alpha = 0.01$) respectively. June rainfall is highly significant in Ilorin with R = 0.52 ($\alpha = 0.01$). Generally, the results signify that correlation values for the stations are very low in the months of July, August, September and October with R < 0.30 ($\alpha = 0.05$ or 0.01). These results actually connote that rainfall of July, August, September and October contributed less than 30% to the yield of maize in all the stations.

Table: 4.2: Result of Correlation of Maize with Growing Season Rainfall for Guinea Savanna part of Nigeria

Stations	Correlation of Maize Yield with Growing Season Rainfall							
	TOTAL	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
ENUGU	-0.070	-0.137	0.126	0.039	-.0149	-0.151	0.331	-0.074
ILORIN	0.286	0.105	0.129	0.517**	0.191	0.077	-0.210	0.069
JOS	0.243	0.293	0.044	0.091	0.022	0.045	0.098	0.161
KADUNA	0.068	0.116	0.219	0.301	0.019	-o.194	-0.246	0.301
LOKOJA	0.043	-0.093	-0.010	0.103	0.011	-0.145	0.241	0.078
MAKURDI	0.213	0.486**	0.490**	-0.342	0.266	0.001	0.131	0.222
MINNA	0.023	0.070	0.050	0.102	-0.217	-0.228	0.226	0.107
SHAKI	0.365	0.044	0.226	0.284	0.184	0.187	0.181	0.287
YOLA	-0.034	0.060	0.176	0.073	0.146	-0.305	0.054	-0.0174

**Correlation is significant at $\alpha \leq 0.01$
*Correlation is significant at $\alpha \leq 0.05$
Dependent variable y is maize yield while explanatory variable x is rainfall

The results illustrate that in Minna, Shaki, and Enugu for example, the correlation values for these months are very low (R < 30, $\alpha = 0.05$ and 0.01). In order to assess the cumulative effects of the total rainfall of growing season on maize yield, total rainfall of growing season was correlated with the yield of maize. The output of the cumulative correlation was recorded under the column named "Total". It is observed that cumulative effects of the rainfall of growing season months are not significant in almost all the stations except in Shaki where R = 0.37 ($\alpha \leq 0.05$). This essentially reveals that variation in rainfall of Shaki has contributed really to the variation in maize yield of the station. Correlation results in other stations, however, are very low with R < 0.30 meaning that they are not significant. This essentially means that other farm operations probably contribute to the yield more than rainfall of the growing seasons in the stations.

In addition, regression models confirmed the result from the correlation and are presented in Tables 4.3 and 4.4. Table 4.3 represents influence of total rainfall of growing season on maize yield while Table 4.4 shows Influence of Monthly rainfall on Maize yield in Guinea Savanna part of Nigeria. It is observed that only Shaki has correlation value that is significant and regression model is presented in Table 4.3 (Cumulative of growing season months). But, those in Table 4.4 represent the regression model generated using backward regression procedure.

Table 4.3. Influence of Total Rainfall of Growing Season on Maize Yield in Guinea Savanna part of Nigeria

Station	Model	r
Shaki	$Yield_{maize} = 1.996 – 0.008 TFGS$	0.37

Prediction model having $\alpha \leq 0.05$

TFGS = Total Rainfall of Growing Season

Table 4.4. Influence of Monthly rainfall on Maize Yield in Guinea Savanna part of Nigeria

STATION	**MODEL**	**R^2**
Makurdi	$Yield_{maize} = 0.0035 Apr + 0.0023 May + 0.016 July – 0.0023$	0.76
Yola	$Yield_{maize} = 1.083 – 0.0017 Aug$	0.38
Ilorin	$Yield_{maize} = 0.476 + 0.003 Jun + 0.0013 Sep$	0.59
Kaduna	$Yield_{maize} = 1.10 – 0.0034 Aug – 0.0041 Sept$	0.32
Minna	None of the months is most “powerful determinant” of yield	
Lokoja	None of the months is most “powerful determinant” of yield	
Shaki	None of the months is most “powerful determinant” of yield	
Enugu	$Yield_{maize} = 0.481 + 0.0014 Apr$	0.33
Jos	None of the months is most “powerful determinant” of yield	

Prediction model having $\alpha \leq 0.05$

The results in Table 4.4 validate that only April, May and July rainfall had great influences on the yield of maize in Makurdi with $R^2 = 0.76$. This result points out that about 76% of variability in maize yield is determined by rainfall of April, May and July. Based on the backward elimination procedure, the results revealed that April, May and July are more powerful predictors of maize yield in Makurdi than any other months. The main predictor of maize yield in Yola is August rainfall while it is June and September for Ilorin ($R^2 = 0.59$), and August and September for Kaduna. Also, the only predictor of maize yield in Enugu is April rainfall. However, none of the months has significant correlation with maize yield in Minna, Lokoja, Shaki and Jos. This actually, means that for maize, the proportion of the variability in maize yield determined by rainfall variability is very low and that other farming activities significantly determine the yield of maize in Minna, Lokoja, Shaki and Jos.

4.2.3 Annual Impacts of Rainfall Variability on Maize Yield

Figure 4.3 shows maize yield anomalies as a response to rainfall variability and Table 4.3 shows z-distribution values for the entire region of Guinea Savanna part of Nigeria. Figure 4.3 was derived from the z-distribution values obtained from Table 4.3. The results showed that there is an enormous positive impact of rainfall variability on maize yield in the entire region during 1973/1974 with z-value of about 1.9 while the great negative impact was observed for the period of 1982/1983. The results indicated that variations in maize yield are strongly influenced by fluctuations in annual rainfall both in terms of overall seasonal rainfall characteristics and extreme variability events.

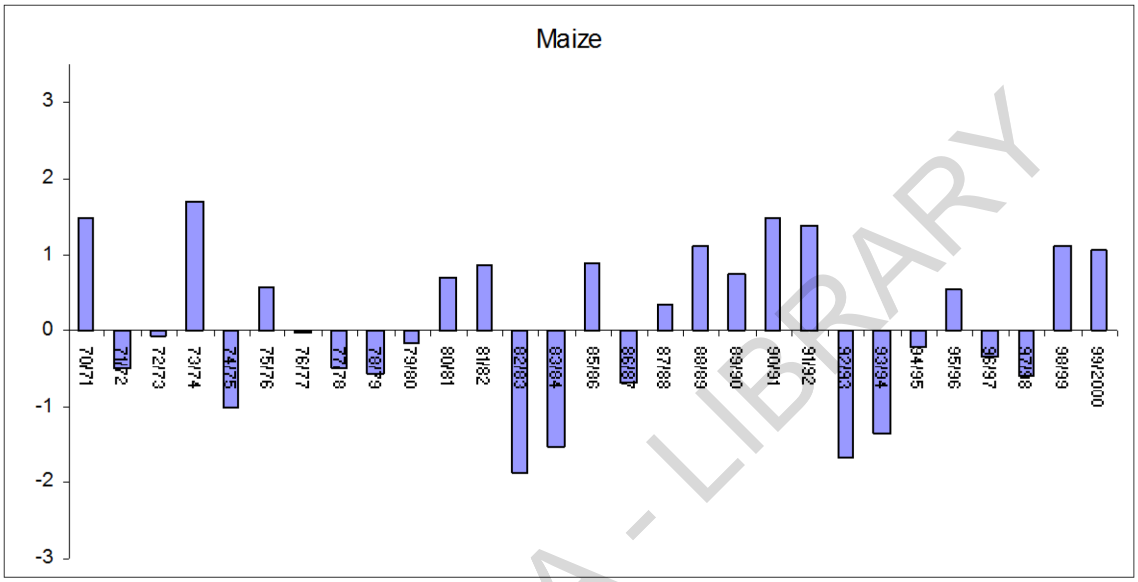


Figure 4.3: Maize Yield Anomalies; Responses to Rainfall Variability for Guinea Savanna part of Nigeria

Table 4.5: Z-distribution Anomalies for Maize

Maize	
70/71	1.486706
71/72	-0.48671
72/73	-0.06007
73/74	1.693531
74/75	-1.01231
75/76	0.578342
76/77	-0.0268
77/78	-0.47633
78/79	-0.55587
79/80	-0.17203
80/81	0.688996
81/82	0.86881
82/83	-1.87231
83/84	-1.51175
85/86	0.889558
86/87	-0.68727
87/88	0.346659
88/89	1.114324
89/90	0.75124
90/91	1.487783
91/92	1.384044
92/93	-1.65895
93/94	-1.35811
94/95	-0.21353
95/96	0.536847
96/97	-0.34839
97/98	-0.59044
98/99	1.12124
99/2000	1.052081

The results indicate that annual rainfall variability has considerable effects on the yield of maize. A number of atmospheric scientists have hypothesized that rainfall variability may alter the yield of crops. The results of this study confirmed the view of Adejuwon and Odekunle (2006) that variability and the severity of the little dry season have great effects on crop yield in Southwestern part of Nigeria. The results obtained in this study showed that the less variably the rainfall, the more reliable the maize yield. This is because the index of variability is a measure of the degree of likelihood of the mean annual rainfall being repeated each year and this influences maize yield. The results appear to corroborate the view of Fakorede and Akinyemiju (2003) that low variation in rainfall implies that the mean rainfall at a given year is reliable while higher variation implies wide fluctuation above the mean values which eventually leads to fluctuation in maize yield.

Usually, there are two major ways by which rainfall variability influences maize. These two important points must be emphasized at the outset of this result discussion. The first point is that rainfall is interrelated in its influence on maize. The effect of a given rainfall variable is modified by the other. That is, daily, seasonal and annual variations in the values of rainfall are greatly important in determining the efficiency of maize development. The second point is that in considering the rainfall requirement for any crop to grow, the microclimate immediately around the crop is vital. Water condition within the soil where germination takes place and very close to the ground where the crop growth is of higher significance to determine either crop yield will be high quality or otherwise (Stern and Coe, 1982). It is very clear that rainfall of growing months also determines whether maize seed will germinate or not. This is because there is a reversible moisture-sensitive block to germination that prevents germination in drying soils (Finch-Savage et al, 2001, Fakorede et al, 2001, and IITA, 2004) and therefore seeds tend to germinate following rainfall patterns or irrigation. In the absence of subsequent rain, only a brief opportunity for the completion of germination and seedling growth may be presented before the surface soil layers dry again, but the seeds/seedlings usually adapt to this. Rainfall variability also determines seed priming in any location. 'Seed priming' in the soil means that germination can be rapid when water becomes available and then the initial rapid downward growth of both the root and hypocotyls described here, will contribute to maintaining contact with soil moisture as the surface layers dry (Finch-Savage et al, 2001).

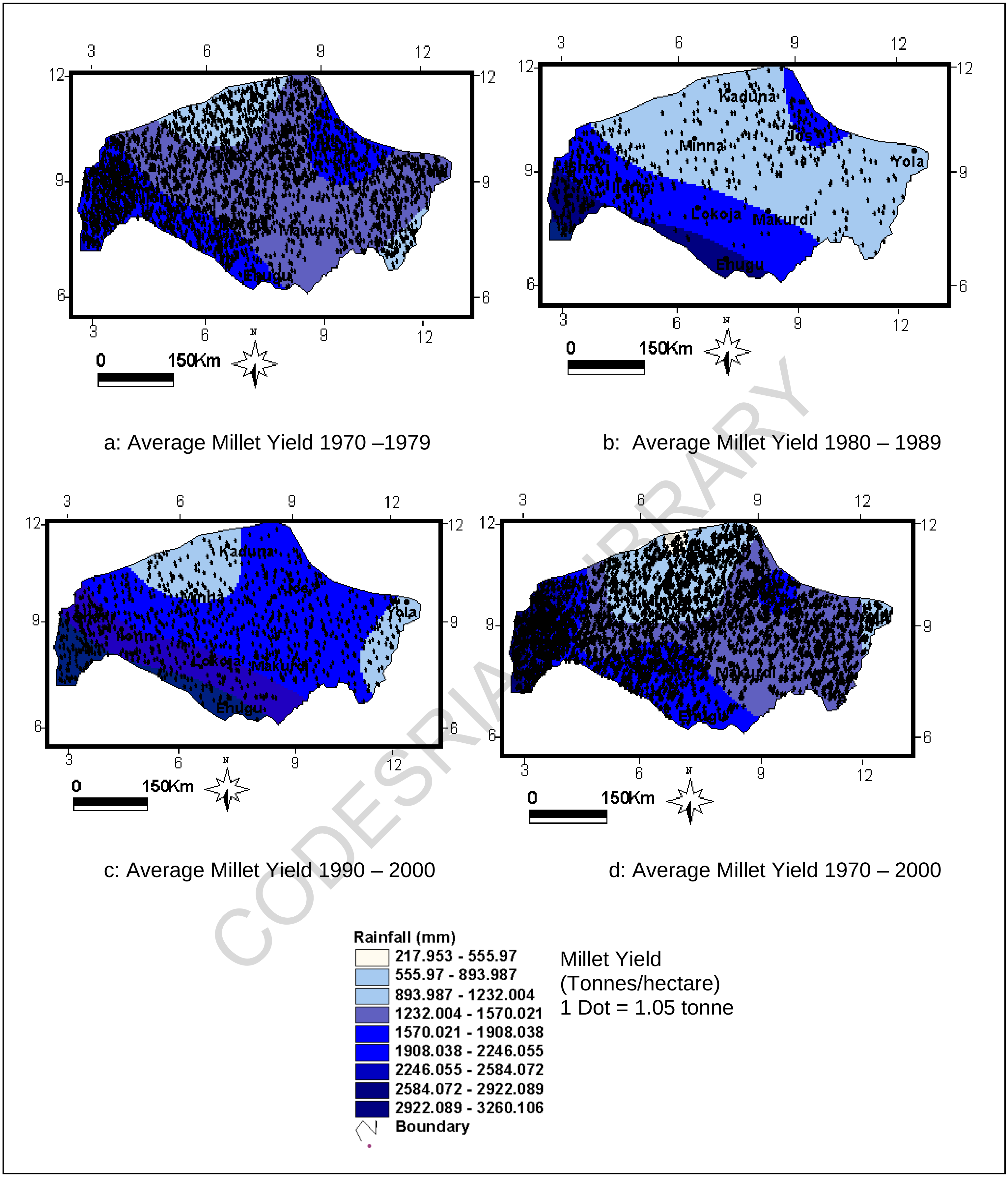
Furthermore, rainfall variability in fact determines the hydraulic conductivity of soil and later influences the yield of a crop. The hydraulic conductivity of soil in the surface layer quickly falls to a very low value as drying continues and this will tend to reduce the rate of water loss from deeper layers (IITA, 1992). The seedling root will therefore grow into increasingly wet soil and may not subsequently become severely water stressed. This same scenario is to be expected for seeds in the surface layers of soil under natural conditions. The initial period of downward seedling growth following germination is therefore critical to successful seedling establishment. Rainfall potential has large predictable effects on seedling growth and this will interact under variable conditions. For example, maize seedling growth rate increases as sub-optimal rainfall increases (Fakorede et al, 2001). Consequently, the rate of growth will decrease as the soil around the seedling starts to dry. Thus soil moisture rapidly becomes a limiting factor during post-germination seedling growth for maize (Fakorede et al, 2001). It is therefore reasonable to consider that the results collected in the present work symbolize that rainfall variability is significant to maize yield.

It is imperative to note that the instability in the yield of maize has major consequences on population in the study area. Many people and most undernourished households in Guinea Savanna part of Nigeria depend on cereal (most especially, maize) as a contributing, if not principal, source of food and nutrition (Central Bank of Nigeria, 2005). In fact, these farm households value maize because it produces large quantities of dietary energy and has stable yields under conditions in which other crops may fail (FAO, 2001). The fact remains the same that maize (Zea mays) is the most important cereal crop in Nigeria and one of the three most important cereal crops in the world (Fakorede, 2001). Maize is high yielding, easy to process, readily digesting, and costs less than other cereals. It is also a versatile crop that grows across a range of agro ecological zones. Every part of the maize plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and non-food products (Fakorede, 2001). However, the people of Guinea Savanna part of Nigeria consume maize as a starchy base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. But it is eminent that during the past decades, maize yield, associated with rainfall variability, varies differently in the year with high rainfall more than the year with low rainfall. Thus, from all the analyses, tables, charts and maps, it is clear that variations in the rainfall tend to have a remarkable impact on maize yield. This shows that the impacts of rainfall variability over the period 1970-2000 on the maize yield are very remarkable in Nigeria, for this has astounding impacts on entire population. This result is in line with the results of the authors like Fakorede et al (2004); Hulme et al, (2002); Okpara (2003); Gbuyiro and Aisiokuebo (2003) and Adejuwon(2005).

4.3 MILLET YIELD VARIATIONS: SENSITIVITY TO RAINFALL VARIABILITY

4.3.1 Variation in Millet Yield

Figure 4.4 shows variation in millet yield and its sensitivity to rainfall variability in the study area for the period of 1970 to 2000. Figures 4.4a, b and c show average millet yield per decade 1970-1979, 1980-1989, and 1990-2000 respectively. The observation shows that rainfall has great influence on millet yield most especially in the Northern part of the study area. For example, during the first decade, (Figure 4.4a), it was observed that increase in rainfall during this period increased the millet yield in both Northern and Southern part of the study area. The results depicted in Figure 4.4b, however, indicate a considerable decrease in millet yield during the second decade, which is as a result of reduction in rainfall.



a: Average Millet Yield 1970 –1979

b: Average Millet Yield 1980 – 1989

c: Average Millet Yield 1990 – 2000

d: Average Millet Yield 1970 – 2000

Figure 4.4: Millet Yield Variations: Sensitivity to Rainfall Variability in Guinea Savanna part of Nigeria (1970-2000)

Also, the results obtained generally showed that millet yields are very low in Enugu and Shaki which may be due to the fact that these stations do not really meet the water requirements for millet to thrive well. This result is in agreement with the result obtained earlier in some studies (e.g Anuforom, 2004).

4.3.2 Determinants of Inter-annual Variation in Millet Yield

Table 4.6 shows the result of correlation of millet with rainfall of the growing season (April to October). For example, in Makurdi, the result of correlation of rainfall of April and May with millet yield is significant with R = 0.40 ($\alpha = 0.05$) and 0.48 ($\alpha = 0.01$) respectively. June rainfall is highly significant in Kaduna and Ilorin with R = 0.32 and 0.39 ($\alpha = 0.05$) respectively. The results obtained form this study therefore showed that in Shaki, August and September rainfall are very significant for millet yield and this is evident in the correlation results of both months which are R = 0.36 and 0.37 respectively ($\alpha = 0.05$).

The results obtained for Enugu showed that April rainfall is significant (R = 0.38, at $\alpha = 0.05$) while September rainfall is significant for Jos (R = 0.35, at $\alpha = 0.05$). In order to assess the cumulative effects of the growing season rainfall variability on millet yield, total rainfall of growing season was correlated with the yield of millet. The results showed that cumulative effects of the rainfall of growing season months are significant in Ilorin, Shaki, Enugu and Jos with R = 0.32, 0.36, 0.39 and 0.49 respectively. The correlation value for Jos is significant

Table: 4.6: Result of Coefficient of Variation and Correlation of Millet with Growing Season Rainfall

Stations	Correlation of Millet yield with Growing Season Rainfall							
	TOTAL	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
ENUGU	0.388*	0.382*	-0.034	0.178	0.032	0.081	0.296	0.274
ILORIN	0.318*	0.149	0.284	0.391*	0.244	0.012	-0.024	0.092
JOS	0.491**	0.216	-0.281	0.234	0.202	0.295	0.345*	0.064
KADUNA	0.083	0.110	0.236	0.317*	0.029	-0.198	-0.244	0.257
LOKOJA	0.050	-0.089	-0.004	0.101	0.015	-0.135	0.236	0.079
MAKURDI	0.205	0.400*	0.482**	-0.344	0.272	-0.012	0.132	0.219
MINNA	0.021	0.072	0.048	0.103	-0.218	0.219	0.227	0.111
SHAKI	0.356*	0.022	0.013	0.188	0.124	0.356*	0.367*	0.044
YOLA	-0.092	0.128	0.113	0.031	0.245	0.377*	0.031	-0.280

**Correlation is significant at $\alpha \leq 0.01$

*Correlation is significant at $\alpha \leq 0.05$

Dependent variable y is millet yield while explanatory variable x is rainfall at $\alpha = 0.01$, but Ilorin, Shaki and Enugu are significant at $\alpha = 0.05$. This actually means that variation in rainfall of Jos has contributed greatly to the variation in millet yield in the station.

The correlation outputs in other stations, however, are very low with R < 0.30 which are not significant. This basically implies that farming operations may account for the variation in yield more than rainfall of the growing seasons in these stations. The observation in Ilorin, Shaki, Enugu and Jos authenticates that rainfall of growing season contributed significantly to the yield of millet which brings about the variation in yield.

Table 4.7 represents the influence of total rainfall of growing season on millet yield in Guinea Savanna part of Nigeria. The models obtained connote the regression model developed and this was obtained to observe the cumulative impacts of total rainfall of growing season on millet. On the other hand, Table 4.8 shows influence of monthly rainfall of growing months on millet yield in the region. The correlations between millet yield and growing monthly total at Makurdi, Yola, Kaduna, Minna, and Lokoja are not significant (Table 4.7). However, at Ilorin, Shaki, Enugu and Jos, there are significant relationships between millet yield and growing season monthly totals. For example, growing season monthly total determines about 40% of the yield of millet in Jos (Table 4.7)

The results in Table 4.8 revealed that millet yield in the study area is not strongly affected by rainfall variability especially in Yola, Kaduna and Shaki.

Table 4.7. Influence of Total Rainfall of Growing Season on Millet yield in Guinea Savanna part of Nigeria

Station	**Model**	**r**
Ilorin	$Yield_{millet} = 0.197 + 0.007\ TFGS$	0.32
Shaki	$Yield_{millet} = 1.723 – 0.007\ TFGS$	0.36
Enugu	$Yield_{millet} = 0.521 – 0.003\ TFGS$	0.39
Jos	$Yield_{millet} = 0.189 + 0.005\ TFGS$	0.40

Prediction model having $\alpha \leq 0.05$

TFGS = Total Rainfall of Growing Season

Table 4.8. Influence of Monthly rainfall on Millet yield in Guinea Savanna part of Nigeria

STATION	MODEL	R^2
Makurdi	$Yield_{millet} = 0.007 + 0.0029\ Apr + 0.0027\ May + 0.019\ July$	0.75
Yola	$Yield_{millet} = 1.318 – 0.0018\ Aug$	0.31
Ilorin	$Yield_{millet} = 0.0026\ May + 0.0040\ June – 0.147$	0.54
Kaduna	$Yield_{millet} = 0.888 + 0.006\ June$	0.32
Minna	None of the months is most “powerful determinants” of yield	
Lokoja	None of the months is most “powerful determinants” of yield	
Shaki	$Yield_{millet} = 1.275 – 0.0021\ Sept$	0.37
Enugu	$Yield_{millet} = 0.643 + 0.0013\ Apr + 0.0005\ Sept$	0.48
Jos	$Yield_{millet} = 0.490 + 0.0014\ June + 0.0010\ Sept$	0.53

Prediction model having $\alpha \leq 0.05$

For instance, only one out of seven months of growing season determined the millet yield in Yola (August), Kaduna (June) and Shaki (September). For other stations, the rainfall of about two to three months is highly significant and account for over 30% of the millet yield. In Makurdi for example, coefficients of multiple correlation are significant with respect to three months; April, May and July with $R^2 = 0.75$ at $\alpha = 0.05$ (Table 4.8). R^2 value indicates that millet is highly sensitive to April, May and July rainfall in Makurdi. Correlations are not in actual fact significant in the case of millet in Yola ($R^2 = 0.31$ at $\alpha = 0.05$) and Kaduna ($R^2 = 0.32$ at $\alpha = 0.05$). This result may be attributed to the fact that a substantial proportion of millet is produced at "fadama" sites and irrigation is also practiced especially where an impermeable, clayey sub-surface horizon is present. These practices are probably responsible for the lower sensitivity of millet (Adejuwon, 2005).

4.3.3 Annual Impacts of Rainfall Variability on Millet Yield

Figure 4.5 shows the millet yield anomalies as response to rainfall variability for the whole study area. The chart was derived from z-distribution result (Table 4.9). It was obvious that during 1970/1971 (Z-Value = 1.45), 1974/1975 (Z-Value = 1.60), 1988/1989 (Z-Value = 1.32), 1997/1998 (Z-Value = 3.13),1998/1999 (Z-Value = 1.18) and 1999/2000 (Z-Value = 1.08), the z-distribution values are positive which literally means that rainfall has positive impacts on the millet yield during these periods in the whole area.

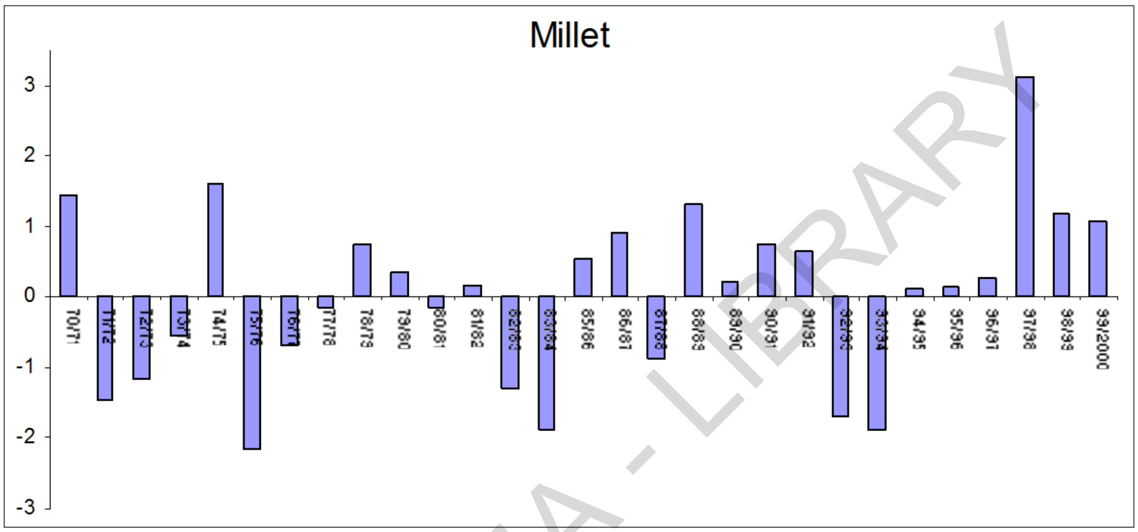


Figure 4.5: Millet Yield Anomalies; Responses to Rainfall Variability for Guinea Savanna part of Nigeria

Table 4.9: Z-distribution Anomalies for Millet

Millet	
70/71	1.454006
71/72	-1.45401
72/73	-1.15259
73/74	-0.54439
74/75	1.603174
75/76	-2.13757
76/77	-0.67895
77/78	-0.14609
78/79	0.763526
79/80	0.359849
80/81	-0.14071
81/82	0.171466
82/83	-1.30218
83/84	-1.87383
85/86	0.532085
86/87	0.924997
87/88	-0.87809
88/89	1.323291
89/90	0.22529
90/91	0.758144
91/92	0.645114
92/93	-1.68545
93/94	-1.87383
94/95	0.106878
95/96	0.144555
96/97	0.284496
97/98	3.131764
98/99	1.18335
99/2000	1.075703

The results showed negative impacts in 1982/1983 (Z-Value = -1.30), 1987/1988 (Z-Value = -0.87), 1992/1993 (Z-Value = -1.69) and 1993/1994 (Z-Value = -1.87). The results imply that variation in rainfall during these periods affected the millet yield adversely. Previous studies established that millet is an important food crop in the Guinea Savanna part of Nigeria; its yield instability is a detriment. For example, Obasi, (2001a) established that for maximum production and adequate yield, a medium maturity millet crop requires between 500 and 800 mm of water depending on climate. But frequent drought and inter-annual rainfall variability have a pronounced effect on millet yield. Despite its high yield potential, millet production and yield are however faced with numerous constraints. One of the major constraints is frequence of drought during the growing season and this considerably reduces millet yield as it was also confirmed by Adejuwon and Odekunle (2006). The result of other studies also validates (e.g Obasi 2001a) that in 1983 and 1993, millet recorded highest negative yield anomalies. Drought at the beginning of the growing season affects crop establishment and reduces plant population while drought during the flowering period of the millet leads to a complete millet yield failure.

To reduce the negative effects of rainfall variability and improve food security, efforts are being made at International Institute for Tropical Agriculture (IITA) to develop or identify drought-tolerant millet varieties that can adapt to the ecological situation of the Guinea Savanna part of Nigeria (Fakorede et al, 2004). Nonetheless, major widespread droughts are rare, whereas local droughts are very common (Adejuwon, 2005). From the results, it is very clear that millet appears relatively tolerant to water deficits during the vegetative and ripening periods. Assessment from previous studies revealed that greatest decrease in yields is caused by water deficits during the flowering period which includes tasselling, silking and pollination, due mainly to a reduction in grain number per cob which substantiates the results of this study.

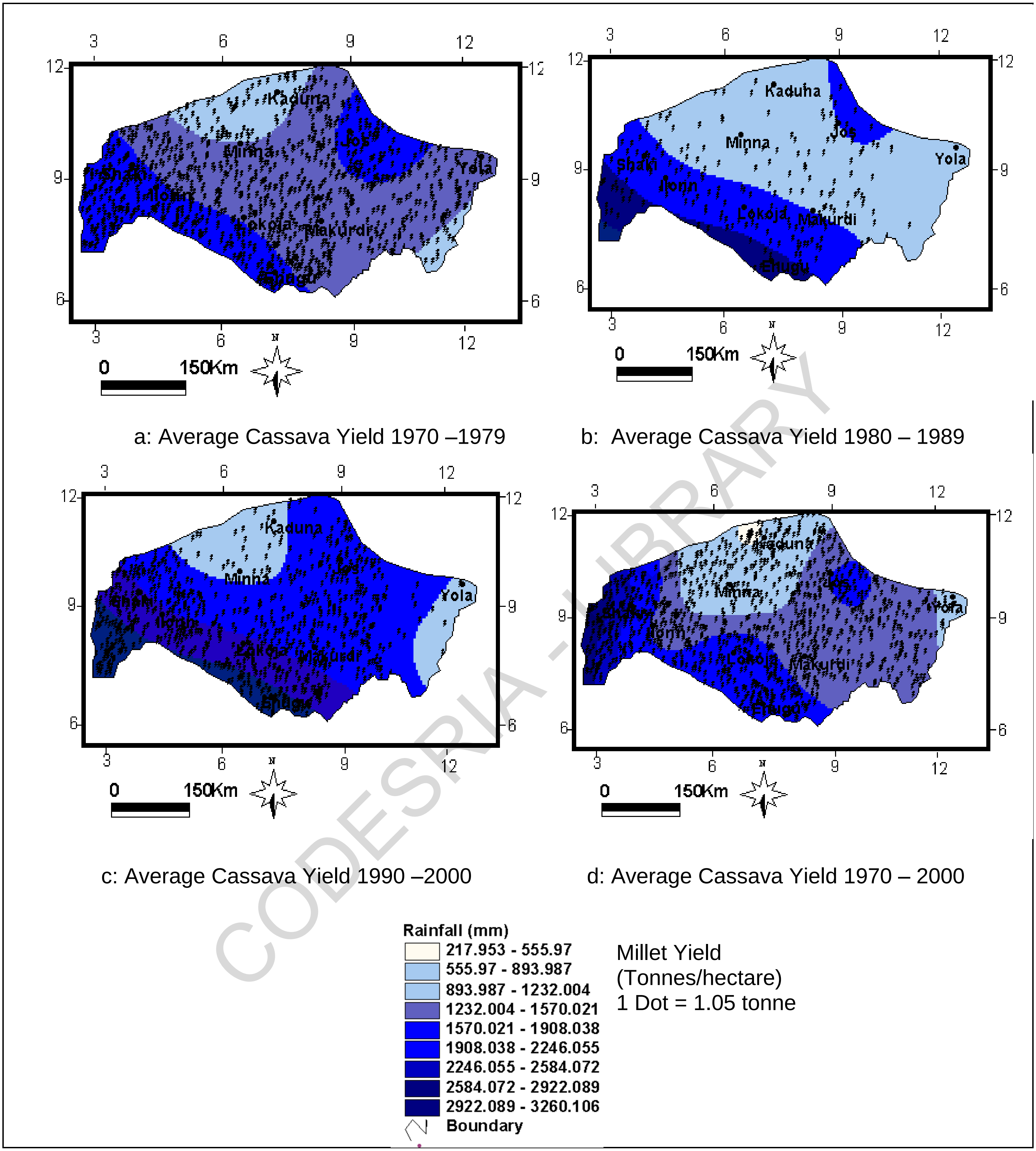
This study also confirms that too much of rainfall has great effect on the yield of millet. For example, Emechebe E, (1998) established that millet flourishes on well-drained soils and water logging should be avoided particularly during the flowering and yield formation periods. Water logging during flowering period can reduce yields by 50 percent or more. He further pointed out that too much of rainfall adversely affects the yield of pearl millet. However, regardless of the effects of rainfall variability, millet constitutes about 87 to 98 percent of the cereal grains consumed in the Guinea Savanna part of Nigeria. For instance, Emechebe, E., (1998) affirmed that Nigeria uses 73 percent of the millet produced for human consumption, Pearl millet is now been recommended as basic food for children, the elderly and the convalescents because of its high energy and protein contents. It plays an important role in the reduction of malnutrition and increases food security in semi-arid areas of the country (Emechebe E, 1998). Looking at global pattern, FAO (2001) established the fact that although millet represents less than two percent of the world cereal utilization, it is important in the countries of the semi-arid tropics among which is Guinea Savanna part of Nigeria. FAO (2001) estimated that 80% of the world's millet (out of which 33% comes from Asia and 47% from Africa) is used as food while the remainder is being divided between feed (7%) and other uses such as seed, beer and so on.

4.4 CASSAVA YIELD VARIATIONS: SENSITIVITY TO RAINFALL VARIABILITY

4.4.1 Variation in Cassava Yield

Figures 4.6a, b, c and d show cassava yield variations as sensitivity to rainfall variability in Guinea Savanna part of Nigeria from 1970 to 2000. The figures are presented in form of time slices (decades) in relation with the rainfall variability per decade. Figures 4.6a-c show average cassava yield for three decades 1970-1979, 1980-1989 and 1990-2000 respectively while Figure 4.6d represents average cassava yield for the periods between 1970 and 2000.

The result obtained in Figure 4.6a shows that increase in cassava yield was recorded during the first time slice (1970-1979) and all stations also recorded major increase in the yield of cassava although the yield was high in southern compared with that of northern part. However, cassava yield was very bad during the second decade (1980-1989) especially in the northern part of the study area (Figure 4.6b). The result shows also that in Minna, Makurdi, Yola and Kaduna, the cassava yield were poor during the period of 1980 to 1989 (Figure 4.6b), but third decade (1990-2000) appears better compared with that of the second decade (1980-1989). Figure 4.6c depicts increase in cassava yield during 1990-2000 particularly in Shaki, Ilorin, Lokoja and Enugu.



a: Average Cassava Yield 1970 –1979

b: Average Cassava Yield 1980 – 1989

c: Average Cassava Yield 1990 –2000

d: Average Cassava Yield 1970 – 2000

Figure 4.6: Cassava Yield Variations: Sensitivity to Rainfall Variability in Guinea Savanna part of Nigeria (1972 to 2000)

It was very clear in the maps that yields were in increase during the period of increase in rainfall (This is obvious in figure 4.6d). In general, the various results corroborate some of the earlier studies by scholars that rainfall is an important climatic element that determines whether cassava yield will be good or poor (Anuforom, 2004).

4.4.2 Determinants of Inter-annual Variation in Cassava yield

Table 4.6 depicts the result of correlation of cassava with monthly rainfall of growing season. Rainfall total for the growing season months (April to October) was correlated with the cassava yield. The results obtained showed that in most cases, there are no significant relationships between rainfall total and cassava yields in most of the stations. Except in Makurdi where April and May rainfall are significant with R = 0.40 ($\alpha = 0.05$) and 0.48 ($\alpha = 0.01$) respectively. Other relationships observed are statistically not significant. Correlation values are significant in June for Ilorin, April for Enugu and September for Jos. This actually means that cassava yields depend on rainfall in these months. This result is in agreement with the result obtained earlier by one author, Anuforom (2004). The period of low yields are the years when rainfall variation was not in favour of cassava yield.

In order to assess the cumulative effects of the growing season rainfall variability on cassava yield, total monthly rainfall of the growing season were correlated with the yield of cassava.

Table: 4.10: Result of Coefficient of Variation and Correlation of Cassava with Growing Season Rainfall

Stations	Correlation of Cassava yield with Growing Season Rainfall							
	TOTAL	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
ENUGU	0.380*	0.382*	0.034	0.178	0.032	0.091	0.295	0.274
ILORIN	0.318*	0.149	0.284	0.399**	0.244	0.082	0.024	0.092
JOS	0.303*	0.071	0.117	0.005	0.088	0.259	0.407*	0.172
KADUNA	0.049	0.234	0.140	0.248	0.045	-0.307	-0.144	0.212
LOKOJA	0.025	0.050	0.024	0.140	0.012	0.256	0.239	0.135
MAKURDI	0.205	0.400*	0.482**	-o.344	0.242	-0.012	0.132	0.219
MINNA	0.021	0.072	0.048	0.103	0.218	-0.219	0.227	0.111
SHAKI	0.379*	0.056	0.136	0.032	0.111	0.211	0.345	0.270
YOLA	0.034	0.060	0.167	0.073	0.146	0.305	0.093	-0.174

**Correlation is significant at $\alpha \leq 0.01$
*Correlation is significant at $\alpha \leq 0.05$
Dependent variable y is cassava yield while explanatory variable x is rainfall

The result of the cumulative correlation was evident under the column named “Total”. It is observed that total rainfall of growing season is not significant in Makurdi, Yola, Minna and Lokoja. But, it is observed that the coefficient of correlation is significant with respect to total monthly rainfall of growing season for some stations, like Ilorin, Shaki, Enugu and Jos with R = 0.32, 0.38, 0.38 and 0.30 (Correlation is significant at $\alpha \leq 0.05$) respectively (Table 4.10). The result in Ilorin, Shaki, Enugu and Jos authenticate that rainfall of the growing season determines yield of cassava.

Table 4.11 shows the influence of total rainfall of the growing season on cassava yield in Guinea Savanna part of Nigeria. Essentially this stands for the regression model developed to observe the cumulative impacts of total rainfall of growing season on cassava. However, Table 4.12 shows the influence of the monthly rainfall on cassava yield in Guinea Savanna part of Nigeria. The correlations between cassava yield and growing season monthly totals at Makurdi, Yola, Kaduna, Minna, and Lokoja are not also significant (Table 4.11). On the other hand, at Ilorin, Shaki, Enugu and Jos, there are significant positive relationships between cassava yield and growing season monthly totals. For example, the growing season monthly total accounts for about 40% of the yield of cassava in both Shaki and Enugu (Table 4.11).

The results from the backward elimination procedure showed that cassava yields in the study area are generally not significantly affected by rainfall variability in Yola, Kaduna and Shaki (Table 4.12) during these periods.

Table 4.11: Influence of Total Rainfall of Growing Season on Cassava Yield in Guinea Savanna part of Nigeria

STATION	MODEL	r
Ilorin	$Yield_{cassava} = 1.183 + 0.042TFGS$	0.32
Enugu	$Yield_{cassava} = 4.69 + 0.025\ TFGS$	0.38
Shaki	$Yield_{cassava} = 23.143 - 0.094\ TFGS$	0.38
Jos	$Yield_{cassava} = 5.813 + 0.019\ TFGS$	0.31

Prediction model having $\alpha \leq 0.05$

TFGS = Total Rainfall of Growing Season

However, Only one month out of the seven months of the growing season months determines cassava yield in Yola (August), Kaduna (August) and Jos (September). For other stations, the rainfall of about two to three months is highly significant and accounts for over 30% of the cassava yield. In Makurdi for example, coefficient of multiple determination is significant with respect to three months: April, May and July with $R^2 = 0.75$ at $\alpha \leq 0.05$ (Table 7.12).

The results showed that in Makurdi, cassava yield is highly sensitive to April, May and July rainfall. The coefficient of multiple determinant appears relatively weak in the case of cassava in Yola ($R^2 = 0.31$ at $\alpha \leq 0.05$) and Kaduna ($R^2 = 0.31$ at $\alpha \leq 0.05$). This is explained by the fact that April is the month of the onset of rainy season and that cassava needs adequate rainfall in May and July for sufficient germination. Low April rainfall implies a delayed onset of rainy season, which becomes too short for cassava in Makurdi. In general, the results obtained showed that low or inadequate rainfall in April, May, July, August and September is evident that the season is truncated before it could provide adequate moisture for cassava during the critical phases of development (Adejuwon, 2005).

4.4.3 Annual Impacts of Rainfall Variability on Cassava Yield

Figure 4.7 and Table 4.13 show cassava yield anomalies as response to rainfall variability for the whole study area. Figure 4.7 was derived from z-distribution result (Table 4.13). It is obvious that z values are positive for 1970/1971 (z = 1.10), 1988/1989 (z = 1.09), 1989/1990 (z = 3.21), and

Table 4.12: Influence of Monthly rainfall on Cassava yield in Guinea Savanna Part of Nigeria

STATION	MODEL	R^2
Makurdi	$Yield_{cassava}$ = 0.0459 + 0.0176 Apr + 0.0159 May + 0.0118 July	0.75
Yola	$Yield_{cassava}$ = 9.225 – 0.0138 Aug	0.31
Ilorin	$Yield_{cassava}$ = 0.01606 May + 0.0242 June – 0.881	0.54
Kaduna	$Yield_{cassava}$ = 9.245 - 0.0035 Aug	0.31
Minna	None of the months is most "powerful determinants" of yield	
Lokoja	None of the months is most "powerful determinants" of yield	
Shaki	$Yield_{cassava}$ = 29.441 – 0.0298May – 0.0404 Sep – 0.0393 Oct	0.58
Enugu	$Yield_{cassava}$ = 5.784 + 0.0115 Apr + 0.0053 Sept	0.48
Jos	$Yield_{cassava}$ = 7.276 + 0.0056 Sept	0.41

Prediction model having $\alpha \leq 0.05$

1999/2000 (z = 0.39). This in reality means that rainfall has positive impacts on the cassava yield. Negative impacts were noted for most of the years, especially, 1981/1982, 1982/1983, 1991/1992 and1998/1999. The results obtained confirmed the earlier findings of Adejuwon (2005) that rainfall does have impact on the crop yield during the growing season and that negative impacts was recorded during 1982/1983.

This result established that the reduction in rainfall observed during 1980 to 1989 had a great impact on cassava yield. The farmers could also recall bad harvests during this decade, which resulted from early termination of the rainfall during the growing seasons. The result confirmed the previous view of Adejuwon (2005) that within 1990 to 2000 alone, the average cassava yield for this savanna region is about 20 million tones making it one of the African largest producers. The average yield in the year 2000 was 10.2 tonnes per hectare, but this varied from 1.8 tonnes per hectare in 1980 to 5.3 tonnes per hectare in 1989 which demonstrated the effects of rainfall. Studies have shown that cassava is planted throughout the rainy season in the study area like other parts of Nigeria. The early plantings have enough moisture for growth and the tubers partly mature into the dry season.

Thus the cassava planted late often experience water stress during vegetative and tuber development stages. This in reality means that cassava tubers mature within the rainy season and that any shortage in rainfall severally affects the yield.

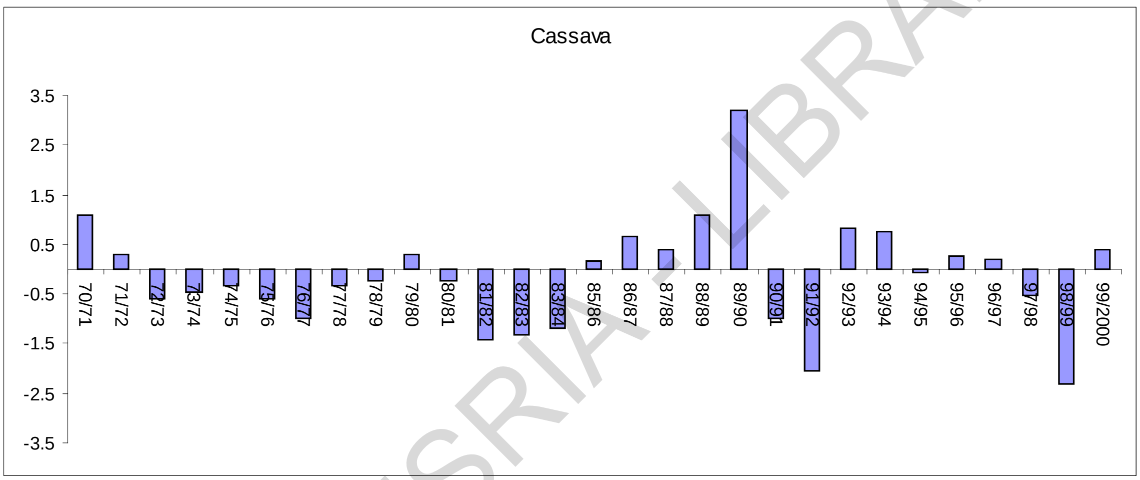


Figure 4.7: Cassava Yield Anomalies; Responses to Rainfall Variability for Guinea Savanna part of Nigeria

Table 4.13: Z-distribution Anomalies for Cassava

Cassava	
70/71	1.105418
71/72	0.305418
72/73	-0.58502
73/74	-0.44867
74/75	-0.31766
75/76	-0.59731
76/77	-0.97436
77/78	-0.32485
78/79	-0.24229
79/80	0.302636
80/81	-0.21887
81/82	-1.42154
82/83	-1.31585
83/84	-1.20153
85/86	0.165128
86/87	0.663217
87/88	0.380549
88/89	1.094987
89/90	3.21349
90/91	-0.97807
91/92	-2.03778
92/93	0.821595
93/94	0.762232
94/95	-0.06374
95/96	0.265766
96/97	0.194809
97/98	-0.53725
98/99	-2.3163
99/2000	0.391448

The result of this study is in line with the observation of Agbaje and Akinlosotu (2004) who stated that although the application of NPK fertilizer and other farm operations are very essential but the effect of rainfall or availability of adequate water is much more. It has also been observed that early and mid-season water stress significantly reduce top and root biomass than late or terminal stress that occurred during tuber maturity in cassava (Agbaje and Akinlosotu, 2004).

Observation also shows that the time of planting influences the yield of cassava. For example, one may say that planting cassava at the onset of rain during the first decade (1970-1979) gave higher yield than late season planting during the second decade (1980-1989). This implies that the vegetative stage and tuber initiation of late planted cassava suffered severe stress due to termination of rainfall during the decade with inadequate rainfall in Guinea Savanna part of Nigeria because dry season is characterized by low soil moisture and high soil temperature. Water stress during root and tuber formation reduces the cassava yield drastically but, after seven months of planting, rainfall appears not to have significant or no influence on yield (Agbaje and Akinlosotu, 2004). This indicated that water stress at vegetative and growth stages rather than at post maturity stage causes lower yield in cassava. With the high cost of irrigation, introduction of drought resistant varieties for late season cultivation will be a viable option for improving the yield of cassava significantly among peasant farmers in Guinea Savanna part of Nigeria. This is in line with the observation of Agbaje and Akinlosotu (2004) that stated that the response of cassava to fertilizer will improve late season cultivation where a controlled irrigation system is used but the application of fertilizer to early-planted cassava will remain uneconomical and wasteful in season of excessive rainfall.

However, some studies have shown (e.g IITA, 2004) that in Guinea Savanna part of Nigeria, cassava provides a basic daily source of dietary energy, so roots are processed into a wide variety of granules, pastes, flours, etc., or consumed freshly boiled or raw. It was also discovered that its leaves are also consumed as green vegetables, which provide protein and vitamins A and B.

Cassava has the ability to grow on marginal rainfall condition where cereals and other crops do not grow well. It can tolerate drought and can grow in low-nutrient soils. This is because cassava roots can be stored in the ground for up to 24 months, and some varieties for up to 36 months. In Nigeria, cassava has taken on an economic role. It is used as a binding agent, in the production of paper and textiles, as monosodium glutamate and an important flavoring agent in cooking. In Nigeria, cassava is beginning to be used in partial substitution for wheat flour, but the effects of rainfall still need maximum attention. Despite the importance of cassava, this study affirms that it is very sensitive to rainfall variability and that enormous variations in rainfall do have negative impacts on the yield of cassava.

4.5 YAM YIELD VARIATIONS: SENSITIVITY TO RAINFALL VARIABILITY

4.5.1 Variations in Yam Yield

Figure 4.8 shows yam yield variation as sensitivity to rainfall variability in Guinea Savanna part of Nigeria for the period of 1970 to 2000. The result shows that yam yield increased during the first decade, that is, 1970 to 1979. This is essentially true as a result of the adequate rainfall experienced during this period. This is evident on the map of rainfall variability. All the stations experienced quality yam yield during this period.

The results obtained also showed that yam yield was very poor during the second decade (Figure 4.8b). The results are presented in dots maps. The dots in Figure 4.8a is more than that of Figure 4.8b which implies that cassava yield was very low during the period of 1980-1989. For instance, Shaki, Ilorin, Yola, and Lokoja have scanty dots (Figure 4.8b), which implies that the yield was actually poor during the second decade whereas high yield was recorded during the first decade and third decades.

4.5.2 Determinants of Inter-annual Variations in Yam Yield

Table 4.14 shows the results of correlation of yam with monthly rainfall of the growing season. Rainfall total for the growing season months (April to October) was correlated with the yam yield. It is noted that correlation values are not significant for monthly total in almost all the stations except Enugu (R = 0.38, $\alpha = 0.05$). The correlation between yam yield and monthly rainfall of the growing season are not significant in most of the stations, except in Makurdi where April and May rainfall are significant with R = 0.43 and 0.44 respectively. Correlation values are significant in April for Enugu, June for Ilorin and August for Minna. The results obtained from correlation confirmed that yam yield in the study area is generally not significantly affected by rainfall variations (Table 4.14).

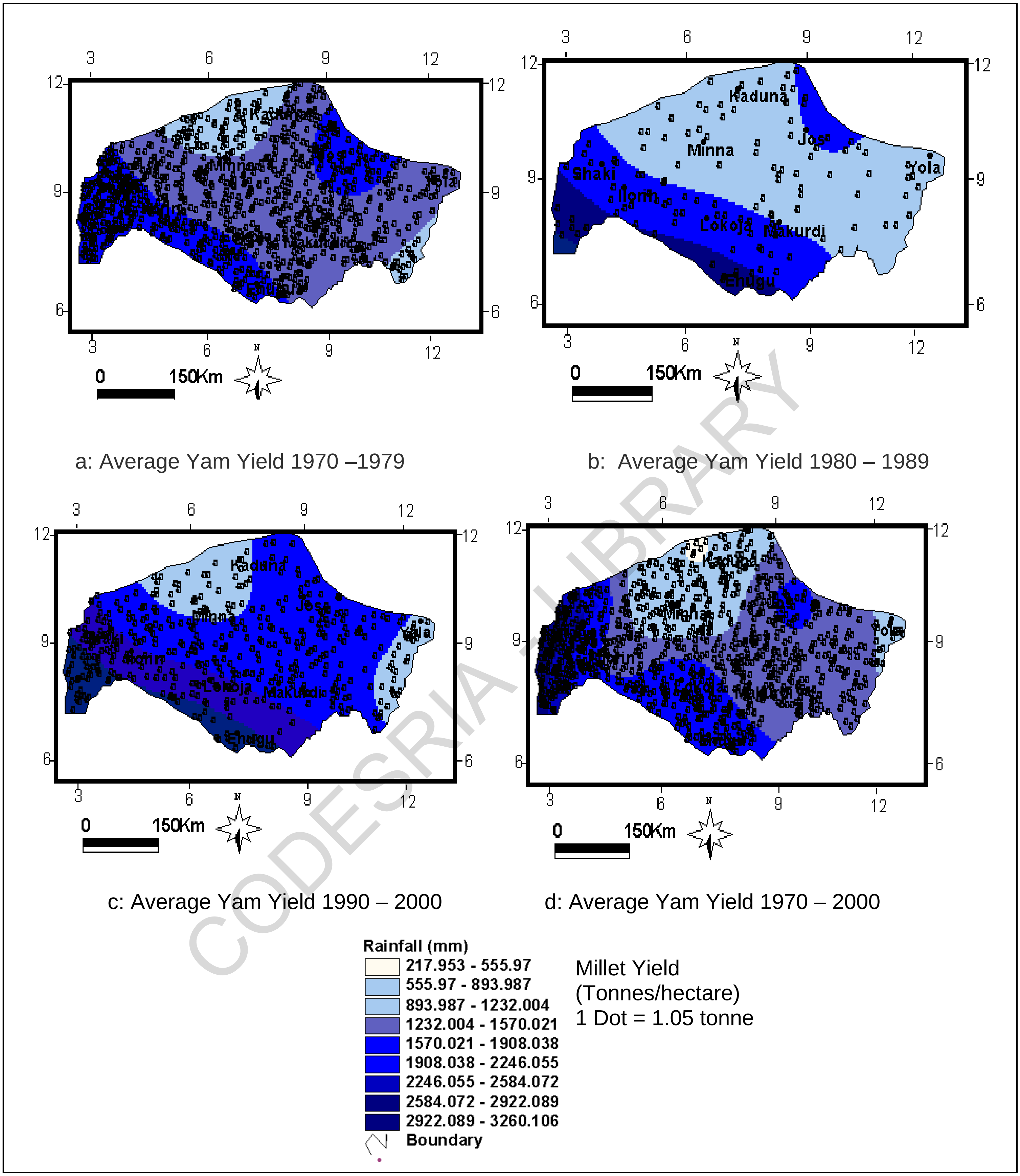


Figure 4.8: Yam Yield Variations: Sensitivity to Rainfall Variability in Guinea Savanna part of Nigeria (1970-2000)

Table: 4.14: Result of Coefficient of Variation and Correlation of Yam with Growing Season Rainfall

Stations	Correlation of Yam yield with Growing Season Rainfall							
	TOTAL	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
ENUGU	0.380*	0.382*	0.034	0.179	0.032	0.091	0.295	0.273
ILORIN	0.286	0.105	0.129	0.516*	0.190	0.077	-0.210	0.070
JOS	0.030	0.093	0.172	0.227	-0.140	-0.346	-0.071	0.206
KADUNA	0.134	0.136	0.236	0.313	0.080	0.193	0.227	0.286
LOKOJA	0.043	0.093	-0.010	0.103	0.011	0.145	0.241	0.078
MAKURDI	0.170	0.426*	0.436**	-0.344	0.253	-0.101	0.180	0.244
MINNA	0.046	0.192	0.076	0.102	0.097	0.367*	0,063	0.061
SHAKI	0.151	0.024	-0.134	0.003	0.077	-0.172	-0.235	0.150
YOLA	0.014	0.186	0.122	0.008	0.162	-0253	0.088	-0.221

**Correlation is significant at $\alpha \leq 0.01$

*Correlation is significant at $\alpha \leq 0.05$

Dependent variable y is yam yield while explanatory variable x is rainfall

The results obtained from some of the stations showed that correlation values are very low in the months of July, August, September and October with R < 0.30 ($\alpha = 0.05$ or 0.01). The results actually suggest that rainfall of July, August, September and October did not contribute more than 30% to the yield of yam in all the stations. In Minna, Shaki, and Enugu for example, the correlation values for these months appeared very low (R <0. 30, at $\alpha = 0.05$ and 0.01). In order to assess the cumulative effects of the growing season rainfall variability on yam yield, total rainfall of the growing season was correlated with the yield. It is observed that the cumulative effects of the rainfall of growing season months are not significant in almost all the stations except in Enugu where R = 0.38 (at $\alpha \leq 0.05$). This actually means that variation in rainfall of Enugu has contributed greatly to the variation in yam yield in the station. The correlation results in other stations, however, are very low with R < 0.30 (Table 4.14). This essentially means that other factors contribute to the yield more than rainfall of the growing seasons in these stations.

Furthermore, the regression models obtained confirmed the results from the correlation and are presented in Tables 4.15 and 4.16. Table 4.15 represents the influence of total rainfall of the growing season on yam yield and Table 4.16 shows the influence of monthly rainfall of the growing season on yam yield in Guinea Savanna part of Nigeria. It is observed that only Shaki has correlation value that is significant for the rainfall total of the growing season and regression model is presented in Table 4.15 (cumulative of growing season months).

Table 4.15: Influence of Total Rainfall of Growing Season on Yam Yield in Guinea Savanna part of Nigeria

STATION	MODEL	R
Shaki	$Yield_{yam} = 4.17 + 0.022\ TFGS$	0.38

Prediction model having $\alpha \leq 0.05$

TFGS = Total Rainfall of Growing Season

Table 4.16: Influence of Monthly rainfall on Yam Yield in Guinea Savanna part of Nigeria

STATION	MODEL	R^2
Makurdi	$Yield_{yam} = 0.868 + 0.0260\ Apr + 0.0198\ May + 0.0158\ July$	0.73
Yola	None of the months is most "powerful determinant" of yield	
Ilorin	$Yield_{yam} = 4.283 + 0.0327\ Jun + 0.01153\ Sep$	0.59
Kaduna	$Yield_{yam} = 7.944 + 0.0056\ Jun$	0.31
Minna	$Yield_{yam} = 3.585 + 0.0114\ Jun$	0.37
Lokoja	None of the months is most "powerful determinant" of yield	
Shaki	None of the months is most "powerful determinants" of yield	
Enugu	$Yield_{yam} = 5.784 + 0.0102\ Apr + 0.0047\ Sept$	0.48
Jos	$Yield_{yam} = 9.117 + 0.0088\ Jun – 0.0073\ Aug$	0.47

Prediction model having $\alpha \leq 0.05$

The result shows that April, May and July rainfall have great influence on the yield of yam in Makurdi with $R^2 = 0.73$ (Table 4.16). This actually means that about 73% of variability in yam yield is determined by rainfall of April, May and July. The results thus imply that April, May and July are significant predictors of yam yield in Makurdi than any other months. The main predictor of yam yield in Kaduna is June but June and September rainfall are predictors for Ilorin ($R^2 = 0.59$). Also, the only predictor of yam yield in Minna is June rainfall but, none of the month has significant relationship with yam yield in Yola, Lokoja, and Shaki. This result thus indicates that the proportion of the variability in yam yield that is determined by rainfall variability is very low and that other farming operations considerably determine the yield in the stations.

4.5.3 Annual Impacts of Rainfall Variability on Yam Yield

Figure 4.9 shows yam yield anomalies as response to rainfall variability for the whole study area while Table 4.17 is the result of z-distribution values for the whole regions. Figure 4.9 was derived from z-distribution result obtained from Table 4.17. It was obvious that during 1970/1971 (Z-Value = 1.20), 1971/1972 (Z-Value = 1.30), 1989/1990 (Z-Value = 1.44) and 1990/1991 (Z-value = 1.82), the z-distribution values are positive which means that rainfall has positive impacts on the yam yield during these periods in the whole areas. The results obtained revealed that negative impacts were prominent during 1981/1982 (Z-Value = -1.51) 1982/1983 (Z -Value = -1.35), 1983/1984 (Z-Value = -1.52) 1992/1993 (Z-Value = -2.18).and 1993/1994 (Z-Value =-2.26). This implies that variation in rainfall during these years affected the yam yield adversely. It should be noted

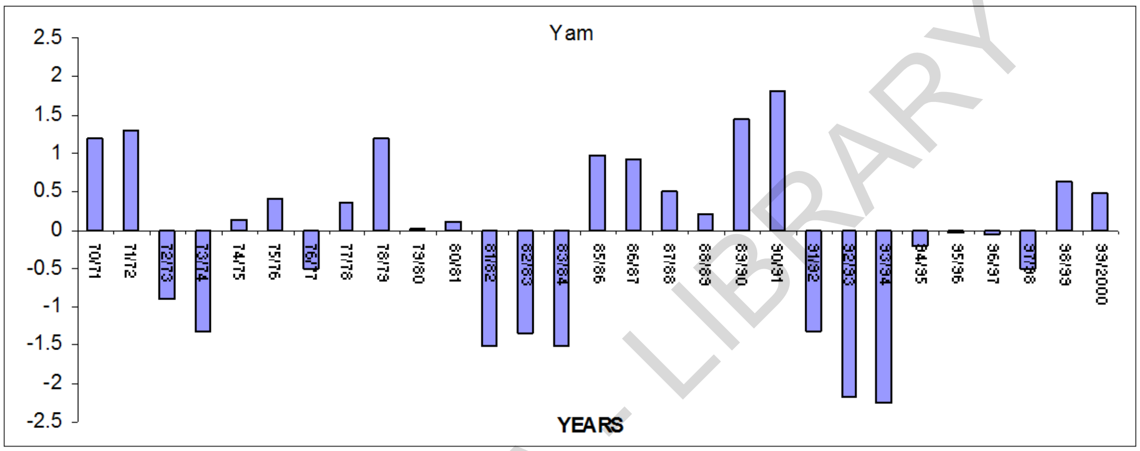


Figure 4.9: Yam Yield Anomalies; Responses to Rainfall Variability for Guinea Savanna part of Nigeria

Table 4.17: Z-distribution Anomalies for Yam

Yam	
70/71	1.200872
71/72	1.300872
72/73	-0.89017
73/74	-1.32856
74/75	0.139472
75/76	0.401352
76/77	-0.51062
77/78	0.366743
78/79	1.192186
79/80	0.009108
80/81	0.112937
81/82	-1.51268
82/83	-1.35174
83/84	-1.51754
85/86	0.975298
86/87	0.913
87/88	0.494799
88/89	0.210422
89/90	1.44426
90/91	1.816892
91/92	-1.32452
92/93	-2.18227
93/94	-2.25553
94/95	-0.22047
95/96	-0.04742
96/97	-0.05723
97/98	-0.49908
98/99	0.626316
99/2000	0.487877

that the impacts are in two dimensions i.e. positive and negative impacts. With positive impact, it means that the rainfall during these periods (e.g. 1990/1991 with z-value of 1.81) has supportive impact on yam yield thereby facilitating increased yield. But negative impacts imply that the variations of rainfall lead to a decreased yield of yam.

Studies have shown that during plant season, yams are usually planted when the soil is dry and wait for the rains to put out its leaves. Anuforom (2004) established that yam rainfall requirements are modest during early growth. Soil water content during germination and the early growth is critical. Once the yam seed coat ruptures and the radicle (root) and plumule (shoot) emerge, it cannot return to seed dormancy. Thus, if the germinating yam seed does not receive ample rainfall, it will die or the yield will be very low.

The fact to note here is that too much water will also displace air containing needed oxygen in the soil and the yam tuber will suffocate. Yam water requirements increase with increased growth and leaf area. Causal organisms associated with yam diseases also have specific environmental needs, some of which are related to rainfall (IITA, 1992). High humidity, flooding, and drought may promote the development of specific infectious agents and the spread of their associated diseases (IITA, 2004). Really, the tubers have a large sink capacity and continue to grow and store food reserves throughout the year as long as rainfall conditions remain favourable. After harvest, another advantage of yam, compared with other tuber crops, is its relative long storage life (4-6 months). Nevertheless, heavy and frequent rainfall sometimes is a great disadvantage to yam yield by increasing the leaching of nutrients or carrying away top soil and applied fertilizers in surface run-off.

However, despite all the constraints resulted from rainfall variability, studies have shown that more than 85% of the Nigeria's yams are currently grown in Guinea Savanna part of the country annually (IITA, 2004). Yams (Dioscorea spp.) are annual or perennial climbing crop with edible underground tubers. There are over six hundred (600) yam species grown throughout the world, but in the study area, three (3) main species are dominant: white yam, yellow yam, and water yam. Yam is a preferred staple food crop in some parts of the country, and also has a prominent socio-cultural role. The real fact about yam is that its tubers can be processed into various types of food, including pounded yam, boiled Yam, roasted or grilled yam, fried yam slices, yam balls, mashed yams, yam chips, and yam flakes. Fresh yam tubers are also peeled, chipped, dried, and milled into flour that is used to prepare dough called “amala”.

4.6 Crop Sensitivity to average rainfall between 1970 and 2000 in Guinea Savanna part of Nigeria

Table 4.18 shows the result of correlation of mean rainfall of all stations between 1970 and 2000 with the total yield of each crop. This analysis was carried out to test the impact of the total rainfall of the study area within 1970 to 2000 on the total yield of the entire crops selected for this study. Coefficients of correlation are significant with respect to each crop. Millet has R value of 0.678, R = 0.619 for maize, R = 0.679 for cassava and yam has R value of 0.618. R values indicate that millet and cassava (R = 0.678 and 0.679) are the most sensitive to rainfall variability in the study area, followed by maize and yam (R = 0.619 and 0.618 respectively).

Table 4.18: Influence of mean total rainfall on mean total yield of all crops in Guinea Savanna part of Nigeria

Crop	R
Millet	0.678
Maize	0.619
Cassava	0.679
Yam	0.618

Prediction model having $\alpha \leq 0.05$

Generally, this implies that for millet, the proportion of variation in yield determined by rainfall variability for the whole study area is 68% while 61% for maize, 68% for cassava and the proportion for yam is 62% (Table 4.18). The sensitivity of crop yield to rainfall appears to be subject to the ecological zone (Leibig, 1847) and that changes in yield will result when rainfall approach variation. For example, if rainfall were adequate for optimum crop yield over a period of say 30 years, thus rainfall variability will have little or no impact on crop yield and this makes it difficult to develop measures of impact based on linear models.

Thus, the results show that the cumulative impacts of rainfall variability on each crop yield are apparent in Guinea Savanna part of Nigeria and this gives better results than monthly rainfall. This study confirms the fact that Guinea Savanna of Nigeria suffers from seasonal rainfall variability. This situation however makes the whole country particularly vulnerable to this rainfall variability.

Several scholars (For example, Liebig 1847, Adejuwon 2005, Anuforom 2004, Hare 1985 IPCC, 2004a, b) have already discovered such effect of rainfall variability on crop yield. For example, the sensitivity of crop yield to rainfall variability appears to be subject to the "ecological law of the minimum" propounded by Liebig (1847). According to Liebig (1847), changes in yield will result when rainfall and moisture supply approach the critical minimum. Adejuwon (2005) established that whenever rainfall supply is adequate, change in crop yield will cease to depend on it, i.e. it would no longer be the limiting factor. For example, if rainfall were adequate for optimum crop yield over a period of 30 years, rainfall variability would have no impact on crop yield.

The results obtained in this study supports IPCG, (2004a) findings, which demonstrate that long period of wet and dry years, will give rise to frequent changes in agro-climatic characteristics and increased variability of crops. Although the control of pest and diseases is the work of the plant pathologists, climate (most especially rainfall) is an important factor in such control which plant pathologist must consider its significance. Various pests, such as maize weevil would probably expand their distribution areas in the events of rainfall variability. Also, an increase in the frequency of extreme rainfall events such as prolong drought could create condition that could be conducive to disease or pests outbreaks. This is in accordance with the findings of Fakorede and Akinyemiju (2003) that some level of drought during the vegetative phase of maize might not affect early season grain yield adversely especially if the latter part of the season is normal but prolong drought during the season may affect the yield.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY OF FINDINGS

This study aims at examining and mapping the rainfall variability and its impacts on crop yields in the Guinea Savanna part of Nigeria with the aid of GIS Kriging Interpolation technique. Data on annual crop yields were obtained from the National Bureau of Statistics, Abuja, while rainfall data were collected from the archives of the Nigerian Meteorological Services, Oshodi Lagos for a period of 1970-2000 for nine stations within the region. Ordinary Kriging was used to interpolate the point observations from a network of rainfall and crop base stations and this method allows the sharpest interpolation of rainfall and crop data. Coefficient of Variation (CV) was used to determine rainfall and crop variability while Multiple Correlation was used to determine the strength of the relationship between rainfall and crop yield at each crop station. Regression techniques were used to explore the possibility of identifying the powerful determinant of crop yield and as a result, backward elimination procedure was adopted. This study discovered that cumulative rainfall anomalies are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season. As a result, there is a remarkable fluctuation in yield per decade in all the nine stations. An imperative observation in all the stations is that a continuous increase in crop yield is noted during the first decade (i.e. 1970 to 1979) while there are notable reductions in yield during the second decade (1980 to 1989).

5.2 CONCLUSION

The impacts of rainfall variability on the yield of selected crops in Guinea Ecological Zone of Nigeria have been analyzed and mapped using Geographical Information Systems. Generally, some of the main findings in this study are related to its methodology. Results from the study revealed that GIS techniques proved efficient in assessing rainfall variability. It is easy to calculate and map the mean monthly or seasonal rainfall for specified periods and the deviations from the mean value. It is hard to imagine contemporary rainfall monitoring without GIS applications. GIS tools give very exact and detailed images of analyzed data more effectively than traditional. GIS tools also enable the uncomplicated calculation and display of the areas under specified rainfall conditions and the display of maps for rainfall assessment purposes.

Though, several spatial interpolation methods have been tested for the production of maps in this study like Co-Kriging; Universal Kriging; Residual Kriging and Ordinary Kriging. After many attempts of qualitative and quantitative verifications, the last of these - Ordinary Kriging- was chosen for the map productions. Thus, Ordinary Kriging interpolation method is found useful and others are less efficient interpolation methods for this research work. Ordinary Kriging is the method that allows the sharpest interpolation rainfall data and is the most representative.

Also, the results obtained from coefficient of variation revealed that rainfall variability is very high in most of Northern Guinea Savanna parts (e.g Yola, Minna, and Kaduna) with values of coefficient of variation between 26 and 49 percent while in Southern Guinea Savanna parts, the coefficient of variation is very low especially in Enugu (9%) and Shaki (8%). Therefore, it was found out that rainfall varies both in time and space. It was observed that cumulative variation in rainfall truly influences crop yield during the second decade (1980-1989) leading to momentous reduction in the crop yield. The increase in yield recorded in 1990-2000 decade in all stations may perhaps be attributed to the increase in rainfall during the planting and growing seasons within the periods. But 1980-1989 experienced a very low rainfall during planting and growing seasons that had been due to greater number of drought episodes (Obasi 2003a and b). Probably, this may be due to the fact that agricultural productions are rain-fed and that about 95 percent of all cropland of this zone depends on rainfall as the sole source of water for crop yield. In these rain-dependent agro-ecosystems, the interaction of rainfall and other climatic elements determine the availability of water for crop yield. This study discovers that rainfall anomalies such as decline in annual rainfall, change in the peak, retreat of rainfall and false start of rainfall are detrimental to crop germination and yield, resulting in little or no harvest at the end of the season.

When correlation method was adopted, it was observed that the total and monthly growing season rainfall was not significantly correlated with crop yield for most of the stations. Better results were achieved by adopting cumulative impact of rainfall of the study area on each crop. The results of this study revealed that the correlation values between crop yield and monthly total of growing season are not significant for some crops in most of the study stations. For example, correlation results are not significant in Minna (for maize, millet and cassava) and Lokoja (all crops are not significant). However, the proportion of variability in millet determined by cumulative rainfall of the study area is 68%, while 62% for maize, 68% for cassava and the proportion for yam is 62%. The results established the fact that the impacts of cumulative rainfall variability on crop yield are apparent in Guinea Savanna part of Nigeria. This study confirms the fact that Guinea Savanna part of Nigeria suffers from seasonal rainfall variability and the situation however makes the whole country particularly vulnerable to this rainfall variability. There is no doubt that changes in farm operational schedules could also lead to changes in crop yield. Nevertheless, rainfall is the only input that varies from year to year, so the predicted variability in crop is due to the variability in rainfall (Stern and Coe, 1982). As a result, this study ascribes changes in crop yield mainly to the cumulative rainfall of the study area because it has the same annual time resolution as crop productivity.

The findings of this study are useful to determine approximately when farmers could plant maize, millet, cassava and yam with the present variation in rainfall. This will enable farmers to have a reasonable certainty of crop survival. For instance, the correlation results of backward elimination procedure revealed that April and May rainfall are the most powerful determinant of maize and millet yield in Makurdi, Ilorin, Shaki and Enugu. This implies that in Southern Guinea

Savanna parts, farmers could plant their maize and millet crops as from April, which is also evident from the findings of Fakorede and Akinyemi (2003), and cassava and yam could be planted from September. But in Northern Guinea Savanna parts, farmers could plant maize and millet as from May/June and cassava could be planted as from June/July. Planting of these crops earlier than this date is not advisable unless where irrigation facilities and drought-tolerant varieties of crops are available.

With the foregoing in mind, the key question now is "what can be done to achieve an increase in crop yield despite variation in rainfall pattern?"

5.3 RECOMMENDATIONS

Based on the findings above and the practicable conclusion of this study, the following recommendations are suggested in order to put the research work in proper implementation.

- Encouraging agro-climatological research to improve crop yields. Such research needs to address a means of improving crop yield in the present and in the future when the rainfall conditions may be less favourable for agricultural purposes;
- Implementing agricultural reform to enhance infrastructure investment in Nigeria;
- Investing in future water supply expansion and efficiency enhancement through modern day irrigation systems; and
- Improving farming techniques.

If agricultural research investments can be sustained, the continued application of conventional breeding and the recent developments in non-conventional breeding offer considerable potential for improving crop yield growth in rainfed environments such as the Guinea Savanna zone of Nigeria. Crop yield growth in farmers' fields will come both from incremental increases in the yield potential in rainfed and irrigated areas and from improved stress resistance in diverse environments, including improved drought tolerance. The rate of growth in yields will be enhanced by extending research both downstream to farmers and upstream to the use of tools derived from biotechnology to assist conventional breeding. Participatory plant breeding plays a key role for successful yield genetic through improvement in rainfed environments.

Emerging evidence shows that the right kinds of investments can boost agricultural productivities far more effectively than previously thought in many less favored lands. Increased public investment in many less-favoured areas may have the potential to generate competitive, if not greater, than comparable investments in many high-potential areas, and could have a greater impact on the poverty problems of the less-favoured areas in which they are targeted (UNEP 2001a). There is a need for certain development strategies for policy reform to enhance agro-infrastructure investment in the area. Key strategies include:

- ✓ the improvement of technology and farming systems;
- ✓ ensuring equitable and secure access to financial resources;
- ✓ ensuring effective risk management;

- ✓ investment in rural infrastructure;
- ✓ providing a policy environment that doesn't discriminate against crops areas;
- ✓ improving the coordination among farmers, NGOs, and public institutions (Petters and Ekpoh, 1994); and
- ✓ Increasing effective rainfall use through improved water management.

Water harvesting can increase effective rainfall use by concentrating and collecting rainwater from a larger catchment areas onto a smaller cultivated area. This would be used during terrible rainfall season. The runoff can either be diverted directly and spread on the fields or collected in some ways to be used at a later time. Water harvesting techniques include external catchments systems, micro-catchments, and rooftop runoff collection, the latter of which is used almost exclusively for nonagricultural purposes (Johansson, 2000). External catchment water harvesting involves the collection of water from a large area, a substantial distance from where crops are being grown. Types of external catchment systems include runoff farming, which involves collecting runoff from the hillsides onto flat areas, and floodwater harvesting within a streambed, using barriers to divert stream flow onto an adjacent area, thus increasing infiltration of water into the soil.

The use of improved farming techniques has been suggested to help more effective use of rainfall and soil conservation. Conservation tillage measures such as minimum till and no till have been tested in some other countries and this should be encouraged in Guinea Savanna part of Nigeria.

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