RELATIONSHIP BETWEEN RAINFALL VARIABILITY ON MILLET (*Pennisetum americanum L.)* AND SORGHUM (*Sorghum bicolor (L) moench.*) YIELDS IN THE SUDAN SAVANNA ECOLOGICAL ZONE OF NIGERIA

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY

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DECLARATION

I hereby declare that this thesis `` **Relationship between Rainfall Variability on Millet (*Pennisetum americanun L.)* and Sorghum (*Sorghum bicolor(L) moench)* Yields in the Sudan Savanna Ecological Zone of Nigeria**`` is a record of my own research work under the supervision of Prof. E.O. Eguisi, Dr. B.A Sawa and Prof. O.F. Ati. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this has been submitted for the award of PhD. degree in any other University.

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Saleh, Haruna **Date**

CERTIFICATION

This thesis titled `` **Relationship between Rainfall Variability on Millet (*Pennisetun americanum L.*) and Sorghum (*Sorghum bicolor (L) moench.*) Yields in the Sudan Savanna Ecological Zone of Nigeria**`` by Saleh, Haruna meets the regulations governing the award of the degree of Doctor of Philosophy of Ahamadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Prof. E. O. Iguisi Chairman, Supervisors Committee	Signature	Date
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DEDICATION

This work is dedicated to my farther Mal Saleh A. Auwalu and my mother Aisha B. Kadi who by the will of Mighty Allah brought me into this world and my beloved two daughters, Zainab and Jamila.

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On a profound note, I would like to acknowledge Allahu Subuhanahu Wata`alah who brought me up to this time and gave me the opportunity that I am about to complete my PhD. programme. I would like to acknowledge all people who put their hands in the successful compilation of this thesis.

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ABSTRACT:

This study assesses theRelationship between Rainfall Variability on Millet (Pennisetum americanum L.) and Sorghum (Sorghum bicolor(L) moench.)Yields in the Sudan Savanna Ecological Zone of Nigeriausing daily rainfall data and the yields of the two crops (millet and sorghum) spanning from 1981 – 2010.It achieved a stated set of objectives which include: Identification of rainfall variables that influence yield, analyzing the trend of onset and cessation dates, length of growing season and annual rainfall for the study locations. Determination of the trend of millet and sorghum yields. Establish relationship between the yield of millet and sorghum in each study location with the observed rainfall variables. Develop a model for predicting yield of millet and sorghum on the basis of rainfall variables. Methods used for investigation include ogive of cumulative pentad rainfall, trend lines and linear trend line equations, product- moment correlation coefficient (r) bar chart and stepwise multiple regression analysis. Results obtained indicate significant variation in the onset and cessation dates, monthly rainfall amounts during the growing season, annual rainfall and length of the growing season within the study locations. There was an increasing trend in onset dates of the growing season, annual rainfall, length of the growing season, millet and sorghum yields, and decreasing in cessation dates of the growing season. Most of the rainfall parameters observed such as in May, June, July, August, September, October and annual rainfall and length of the growing season are significantly correlated at 0.05 levels of significance and few at 0.01 with the yield of the two crops (millet and sorghum).Results for stepwise multiple regression analysis gave four (4) yield forecast models, three (3) for millet at Kano ($y = 0.733\log_{10}AR + 2.483$), Katsina ($y = 0.503\log_{10}AR - 1.292$), Potiskum ($y = -0.185\log_{10}AR + 0.529$) and the last for sorghum at Potiskum ($y = -0.008\log_{10}M - 0.018$). The two (2) best fitted crops yield forecast models among these for the study area are $y = 0.503\log_{10}AR - 1.292$ for millet yield at Katsina and $y = -0.008\log_{10}M - 0.018$ for sorghum yield at Potiskum. Based on these findings, it is recommended that,farmers be guided to plant their field crops on the derived mean onset date of 22-May at Kano, 1-June at Katsina, 5-June in Maiduguri, 10-June at Potiskum, 3-June at Sokoto and 23-May at Gusau.Be made aware that the length of growing season in the Sudan Savanna is generally short, onset dates commences on June or May and cessation date ends in the month of September or October. Advised to obtain early maturing seed varieties for planting before the onset of rainy season. Apply the two crops yield models for planning and forecasting the yields of these crops (millet and sorghum) in the study area.

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Acronyms and Definition of Term

AR	Annual rainfall
BFM	Biogeographical feedback mechanisms
cT	Tropical continental
CV	Coefficient of variation
EL- NINO	Warming of the upper ocean lasting up to a year or more
ENSO	El-Nino southern oscillations
FAO	Food and agricultural organization
GDP	Gross domestic production
IPCC	Intergovernmental panel on climate change
ITD	Inter tropical discontinuity
La- Nina	The cooling phase of the upper ocean
LGS	Length of the growing season
MER	Month with effective rainfall
mTTropical maritime	
NESTA	National endowment for science, technology and the arts
NFRA	National food reserve agency
NIMET	Nigerian meteorological agency

NPC	National population commission
SO	Fluctuations of atmospheric and hydrospheric Circulation over Indo-Pacific Region
SSTA	Sea surface temperature anomaly
TEJ	Tropical easterly winds

REFERENCES

CHAPTER ONE

1. 0 INTRODUCTION

1.1Background to the Study

Global climate change has become a popular theme among climatologists. There is a very high degree of confidence among them that climate change will, on the average, result in a wetter world. Climate models consistently project an increase in global mean precipitation of between 3% and 15% as temperature increases from 1.5^0C to 3.5^0C (Schneider *et al* 1990; IPCC, 1996). The global average, however, hides significant differences in regional precipitation patterns, with some regions showing increase, some decrease and considerable inter-annual variability. Rainfall varies considerably even within a few kilometer distance and on different time scales. Rainfall variability is important parameter which influences crop production in Nigeria.

Variability is defined as the variation of the hydrological time series around the mean. Thus, relationship between rainfall and crop yields is established by statistical analysis of the long-term rainfall for a variety of time scales (i.e. daily, pentad, decade, weekly, monthly, annually, among others). A spatial comparison of rainfall variability using a most standard criterion is the coefficient of variability, which is defined as the ratio between the standard deviation and the mean (Longley, 1952). Conrad (1941) and Nicholls (1988) defined relative variability as the mean of the absolute deviations from the long-term mean.

Theoretically, there are three (3) different forms of rainfall variability: Spatio-temporal; inter-annual and intra-annual (NESTA, 2003). Spatio-temporal variability has to do with differences in total rainfall received between places structurally located within a given region over a period of time. Inter-annual rainfall variability is defined as the annual deviation from long-term average or differences in rainfall between years. Obasi(2003) refers to it as the distribution of rainfall within a year. According to Ayansina, (2008) rainfall variability is very high in the Northern Guinea Savannah of Nigeria (Yola, Minna, Illorin and Kaduna) with values of coefficient of variation between 26% and 49%, while in Southern Guinea Savannah, the coefficient of variation is very low especially in Enugu (9%) and Shaki (8%). The author added that rainfall anomalies such as decline in annual rainfall, change in the peak and retreat of rainfall and the false start are detrimental to crop germination and yields, resulting to a little or no harvest at the end of the season. Another study on the effect of climatic variability on Maize production in Nigeria by Sowunmi and Akintola (2010) revealed significant differences in average annual rainfall, temperature, Maize hectarage and output in seven identified ecological zones. The output of Maize per hectare exhibited high variability in the ecological zones.

Rainfall variability in Nigeria is caused by different mechanisms of rainfall- producing systems. Some of these include the Inter-Tropical Discontinuity (ITD) movement, Tropical Easterly Jet (TEJ), Tropical Atlantic Sea Surface Temperature Anomaly (SSTA), Biogeophysical Feedback mechanisms (BFM) and El-Nino Southern Oscillations (ENSO) (Olaniran, 2002).

Nigeria receives rainfall from the southwest wind which invades the country from the Gulf of Guinea coastline off the Atlantic Ocean. This moist airstream is overlain by the northeast trades which originates from above the Sahara and are thereby dry and dust-laden. The zone of contact of the two air masses at the surface is a zone of moisture discontinuity called Inter Tropical Discontinuity (ITD) zone. The ITD advances inland as far as 22-25^{0}N in August and at the margin of the Sahara considerably beyond Nigeria's northern border (Adejokun, 1964; Adedokun, 1978). It does not retreat equator ward beyond latitude 4^{0}N during the "Harmattan" dry season (Adefolalu, 1983).

The TEJ is part of the Indian summer monsoon system, and it extends from the Indian Ocean over Africa within the Northern Hemisphere in summer months, generally at a height of around 12-15km. The west-east axis of the TEJ is located between 4-10^{0}N. TEJ reinforces aridity over the extreme northern part of the country but causes a belt of above average rainfall in the central part.

According to Palmer (1986), warming of the Tropical Atlantic Ocean reduces the meridional gradient of sea surface temperature (SST) south of the ITD and this results in a weakening of the Hadleymeridional circulation (that is the pattern of the circulation of the atmosphere over the tropics). The weakened circulation reduces the intensity of the southwest monsoon flow into west and central Africa and consequently rainfall over southern Nigeria.

Farmer and Wigley (1985) have provided an excellent summary of the studies of

Otterman (1974), Charney (1975) and Radsool (1984) on biogeophysical feedback mechanisms (BFM). All these researchers agree that reduced rainfall, combined with human activities, such as overgrazing could reduce the vegetation cover and increase the reflectivity, or albedo as well as degradation of land surface. Undoubtedly BFM has served to reinforce drought condition over the northern part of Nigeria.

El-Nino is the term used to describe the extensive warming of the upper Ocean in the tropical eastern Pacific Ocean lasting up to a year or even more. The cooling phase of El Nino is called La-Nina. Changes in the El-Nino events are related to changes in the Pacific Walker circulation. These changes form a wider tropical fluctuation which is known as the "Southern Oscillation" (SO). This oscillation is the fluctuation in the intensity of inter-tropical general atmospheric and hydrospheric circulation over the Indo-Pacific region. The oscillation may be referred to either as southern oscillation (SO) or El Nino south oscillation (ENSO). ENSO has been shown to relate strongly to variations in Nigerian rainfall (Adebayo, 1999). Data reported by Owen and Ward (1989) and Adebayo (1999) also confirmed the relationship between extra-tropical SST over the north Atlantic , north Pacific and south Pacific and rainfall fluctuations in Nigeria.

In the last decade, inter-annual rainfall variations have caused great stress to farming activities, crop production and yields in the Nigerian Savanna (Adejuwon, 2004). Inter-annual rainfall variability in other parts of West Africa affects the various aspects of plant growth, and yields and consequently alters crop productivity (Awosika, *etal* 1994; FAO, 2001; Obasi, 2003; Adejuwon, 2004).

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. One undisputable cause of "famine" in the Guinea and Sudan Savannah of Nigeria is the failure of crops resulting from insufficient or untimely rainfall. Rainfall variability from year to year is the main factor responsible for fluctuation in agricultural yields and total agricultural production. Either a deficiency or a surplus of rain can cause crop failure and in turn affect crop yields as has been the case during the drought of 1968-1973 and 1979-1983 in northern Nigeria. The Semi-arid tropics are characterized by low and highly variable rainfall in space and time limiting potential crop yields in these areas (Graef and Haigis, 2001).

Millet and sorghum are regarded by dry land farmers as being more tolerant to drought than any other cereal crop. They have more mechanisms of drought tolerance than any other cereal crop. Based on these they are better adapted to Semi-arid conditions like that of the Sudan Savannah ecological zone of Nigeria. In wide agricultural terms, drought tolerance of crops implies their ability not just to survive but to produce acceptable yield when subjected to periodic moisture stress (Ashley, 1993). Jones, *et al* (1981) categorized mechanisms of drought tolerant crops into three: The drought escape; drought tolerance with high tissue water and drought tolerance with low tissue water potential.

Millet is widely grown in Sudan Savannah as "a hunger crop" because it is the earliest crop to be harvested when the food reserve is at its lowest level. Mill production has been stagnant between 1992 and 2000 in ECA. Africa and Asia account for about 94% of global millet output, which was estimated at about 28 million tonnes in 1997. The global

millet area under has, however, shown a slight drop from 38.1 million ha in 1981 to37.6 million ha in the mid-1990s (FAO, 2004). Millet and Sorghum depend almost entirely on rainfall as their moisture supply. The amount and distribution of rainfall are important factors in determining the ultimate productivity of these crops. It is estimated that Sorghum together with Millet accounts for over 60% of cereal production in Nigeria (Awoyemi, 1986).

Globally, the production of sorghum expanded from 40 million tonnes during early 1960s to 66 million tonnes in early 1980s. However, it rose to 64 million tonnes by 1996 is projected at 73 million tonnes in 2005. Acreage under sorghum declined marginally from about 45.6 million ha in early 1960s to 44.4 million ha in the mid-1990s. The global growth of area under sorghum has shown a general slight decline of about -0.2%/yr, before 2000. Expansion of acreage in Africa increased at about 3.6%/yr, although yield declined at about -1.%/yr (FOA, 2000)

1.2 Statement of the Research Problem

Previous studies on the impacts of rainfall variability on crop yields were focused on some specific crops at specific locations. Among these studies are Hess (2000), FAO (2001), Adejuwon (2004), Adejuwon and Adekunle (2006). Hess (2000) observed that over the period of 1961-1990, the northeast arid- zone of Nigeria experienced a decline in annual rainfall which led to decline in millet yields. FAO (2001) observed that, a long-term change in rainfall has occurred in the Semi-arid and Sub-humid zone of West Africa. The zonal variability of rainfall especially is observed to bring about only the

differences in the type of crops (Osagie, 2002; Adejowun and Adekunle, 2006). Irregularities in rainfall reliability and spread have contributed significantly to the poor yields and high variability in production from year to year (Mortimore, 1974; Kowal and Kassam, 1974).

In a study of the influence of climatic factors on maize yields Nigeria,Folorunso, *et al* (1998) observed that, rainfall, sunshine, time trend and temperature are jointly responsible for more than 55% of the total variations of Maize yields over the period under investigation. Rainfall during the growing season is positively and significantly correlated at 5% level with the Maize yields, while the total maximum and minimum temperature, sunshine hours and soil temperature during the growing season have positive but none significant relationship with the Maize yields at 5% confidence level (Folorunso, *et al* 1998). Fakorede (1985) further reported that under rain-fed agricultural system, the extent of variation of maize yields would depend on the date of planting. Akinola (1983) also concluded that agro-climatic factors were correlated with the yields of maize and cowpea in Ibadan.

In addition, Aliyu (2009) observed a downward trend in the duration (length) of the growing season in some locations in northern Nigeria from 1978-2007, with a significant variability in most of the stations north of latitude 9^0N in Nigeria. He did not however, relate the trend of length of growing season days,annual rainfall,and monthly rainfall amounts during growing season with current trend yields of some major crops grown in these stations. Sawa (2010) studied the relationship between precipitation effectiveness,

the occurrence and persistence of dry spells in northern Nigeria north of latitude 10^0N and reported that there is a general gradual increase in the probability of dry spells with progressive increase in latitudes. In addition, that onset and cessation dates, length of rainy season, hydrologic ratio and seasonality all show a defined general north – south variations in pattern. It well known that, the direct effect of high probability of occurring of dry spells on crop in any place is reduction in yields. He did not, however, investigate the join distributing effect of onset and cessation dates, annual rainfall, and monthly rainfall amounts during growing season and length of growing season on crop yields.

Odekunle (2004) defined "growing season" as a period of the year during which rainfall distribution and characteristics are suitable for crop germination, establishment and full development. It is the period between the onset and cessation of the rains. Walter (1967) stated that the length of the growing season could be taken as the period between the onset and the cessation date which may be determined by calculating the number of days in between the onset date and the cessation date. Adefolalu (1993) stated that the length of the growing season could be obtained by subtracting the onset pentad from the cessation pentad and multiplying by five. Among authors that have emphasized linkages of the growing season with reliable onset of rains are Dagg (1965), Bello (1996), Olaniran (1983 and 1984), Ati, et al (2000), Sawa and Adebayo (2011).

It is conceivable, therefore, that given enough information on the rainfall variability parameters; it is possible to deduce a simple relationship between millet, sorghum yields and rainfall variability parameters such as, length of growing season,annual rainfall,and

monthly rainfall amounts in months of the growing seasons, onset and cessation dates. Empirical information on the relationship between these two crops and these rainfall parameters is inadequate in the Sudan Savannah ecological zone of Nigeria. This is a research gap that needs to be bridged.

1.3 Research Questions

The research questions for this study include:

i. What is the contemporary trend ofonset and cessation dates, length of growing season(LGS),and monthlyrainfall amounts during the growing season and annual rainfall (AR) in the Sudan Savannah ecological zone of Nigeria?

ii. What is the trend of millet and sorghum yields in the study area?

iii. What is the relationship between, monthly rainfall amounts duringthe growing season, length of growing season,annual rainfall andyields of millet and sorghum in this region?

1.4 Aim andObjectives of theStudy

The aim of this study is to examine the variations in rainfall parameters and millet (*Pennisetum americanum L.)*andsorghum (*sorghum bicolor(L) moench)* yieldsin the Sudan Savanna ecological zone of Nigeria.

The study attempts to achieve the following objectives, to:

i. Identify the rainfall variables that influence yields

ii. Analyze the trendof onset and cessation dates, length of growing season (LGS) and annual rainfall(AR) of each location for the study period

iii. Determine the trend of millet and sorghum yield in each location.

iv. Establish the relationship between the yields of millet and sorghum withmonthly rainfall amounts during the growing season, AR and LGS in each location,

v. Develop a model for predicting the yield of millet and sorghum at each location on the basis of rainfall parameters.

1.5 Justificationofthe Study

The full potentials of climate as an agricultural resource in Nigeria have yet been fully investigated. Several crops are still grown traditionally in most areas in Nigeria without considering the suitability of climate. Most of the production potentials of climate are left unutilized. Exploitation of these potentials will no doubt improve agricultural productivity and food security to the ever increasing population of this climatic zone.

Various effects of rainfall variability on crops yields in Nigeria have been studied.For example Hess (2000) observed a decline in annual rainfall which led to the decline in millet yield in northern Nigeria over the period of 1972-73. But, the declined in annual rainfall might not be the only rainfall parameter which could lead to decline in millet yield. There might be other rainfall parameters which are critical to millet yield. Oladipo (1989) reported that,since 1972-73 Sudano-Saheliandroughts in Nigeria, rainfall in this

region has been irregular and unpredictable. Unfortunately, the influence of this irregularity in rainfall since the occurrence of these droughts in relation to crop yields is not fully investigated in this region. The anomalies in the Nigerian`s rainfall pattern have caused crop and animal losses.Adejuwon and Adekunle (2006) reported that, differences in the type of crops are the function of zonal variability of rainfall.

The extent of variation of maize yields and date of planting under rain-fed agricultural system attracted the interest of Fakorede (1985) who reported that corn yield of maize (*Zee Mays*) was decreased by 38 and 43kgha^{-1} for each day by which sowing was delayed after the first planting in March in 1980 and 1981 respectively.Odekunle (2004) also observedthat rainfall during the crop growing season determines crops germination, establishment and full development. He further defined growing season as period between onset and cessation of the rains. However, investigation on the annual growing season rainfall, monthly rainfall amounts during the growing season, length of growing season days, annual rainfall, onset and cessation dates using daily rainfall data, and relating them with crop yields isinadequate in the Sudan Savanna ecological zone of Nigeria. This is a missing link which is worth investigating. Although these are not the only rainfall variables that could influence crop yield, but they are the most critical factors. Further research may investigate the influence of other rainfall variables. A study of this nature is therefore necessary because a relative large proportion of the labor force in the study area engaged in farming.

The results of this research would no doubt guide farmers to identify the characteristics of

onset and cessation dates, length of growing season, annual rainfall and monthly rainfall amounts during the growing season in the area.Provide empirical information on the relation betweenannual rainfall, length of growing season and monthly rainfall amounts during the growing season with the yields of these crops. This will assist farmers, non-governmental organizations (NGOs), such as Food and Agricultural Organization (FAO), the Sasakawa African Fund for Extension Education (SAFE), policy makers and agricultural stakeholders in planning and monitoring the production of these crops.

1.6Scope of the study

This is an empirical study which attempts to determine the statistical relationship between the yields of Millet and Sorghum and rainfalls attributes in the study area. It covers a period of 30 years (1981-2010) in Kano, Katsina, Maiduguri, Potiskum, Sokoto and Gusau in the Sudan Savanna ecological Zone of Nigeria.

It focuses theonset of objectives which include the identification of rainfall variables that influence yield, analyzing the trend of onset and cessation dates, length of growing season and annual rainfall for each of the study locations. Others are determination of the trend of millet and sorghum yield and establishing the relationship between the yields of these two crops with the observed rainfall variables. Develop a model for predicting the yields of these crops at each location on the basis of rainfall variables.

1.7 Research Hypotheses

The study attempts to test the following hypotheses:

The rainfall parameters series of data are not normally distributed. There is no significant relationship between the yields of millet and sorghum and monthly rainfall amounts during the growing season, length of growing season (LGS) and annual rainfall (AR).

1.8Organization and Presentation of Study

This study isorganized and presented in six chapters. Chapter one is the introduction which outlines and discusses the background of the study, the statement of research problem, aim and objectives, justifications of the study, scope and research hypotheses of the study. Chapter two addresses issues of literature review. It attempts to outline and review some related works on crop-climate relationship such as fundamental approach to crop-climate relationship, empirical approach to crop-climate relationship and crop-climate relationship under the control environment. It also reviews the trend of monthly and annual rainfall, patterns of millet and sorghum production and crop yield forecasting models. Chapter three describes the research methodology and study area. It outlines and discusses issues such as types and sources of data, derivation of onset and cessation dates, and monthly rainfall during growing season, length of growing season and techniques of data analysis, location of the study area, relief and drainage, geology, climate, soils and vegetation, population, economic activities and environmental problems.

Chapter 4 dwells on presentation and discussion of results. It presents the result on non-parametric test of rainfall data collected from the six locations sampled in the study area.

It also presents the results of derivation of the onset and cessation dates, length of growing season (LGS), annual rainfall (AR) and monthly rainfall amounts during the growing season for each location. It also presents results of test of relationships between the millet and sorghum yields and rainfall parameters and forecast models for the yields of the two crops in each location.

Chapter five discusses the entire results of the study. It discusses the trends of onset and cessation dates; annual rainfall (AR), length of growing season (LGS), trend ofmillet and sorghum yields within each location for the study period. It discusses relationships between the milletand sorghumyields and monthly rainfall amounts during growing, LGS andAR. It also discusses model for predicting the yields of the two crops in each location based on rainfall parameters. Chapter sixpresents summary, conclusion andrecommendations based on theresearchfinding

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Crop- Climate Relationship studies

Hanna (1971) studied the climatic influence on yields of Sugar cane in Uganda and found that yield is mostly influenced by physiological factors (particularly age at harvest) rather than by climatic conditions. He noted that of all the climatic elements, temperature and soil determined the yield of tea in Uganda. Widgley and Qipu (1983) applied a new technique in statistical crop-climate analysis in Western Australia. In their study, they linked spatial patterns of crop yield and spatial patterns of climate, where yield and climate data from networks of crop reporting districts and meteorological stations were available. They decomposed their data into orthogonal components using principal analysis. Each yield component was then expressed in a function of the climate components using multiple regressions. These regression equations were then combined to give inter-annual variations in the spatial patterns of yield to inter-annual variations of selected climate variables. Thecontribution climate was shown to be highly significant with winter precipitation being the most important variable. This was in conformity with Musteka and Wasch (1962) who reported that the amplitudes of the dominant corn yield anomaly patterns are significantly correlated with the monthly amplitudes of several temperature and precipitation patterns during the growing season.

In another related finding, Hobbas*et al* (1988) observed that, crop yields are determined by environmental factors at different management levels. They proposed the concepts of potential and attainable yield as major determinants of yield variant. For the potential

yield, crop growth is determined solely by climatic factors (growth-defining factors) such as solar radiation or temperature. When soil resources such as water or nutrients are in suboptimal supply, the growth limiting factors decrease potential production, resulting in attainable yield. Finally the growth reducing factors, such as diseases and weeds determine the actual yield. The gap between the potential and attainable yield has a practical basis. It is agronomical possible to increase the viability of growth limiting factors by management, while the growth defining factors are usually outside the control of farmers. Based on these, climate can be considered as a random process and control of weeds and diseases is part of the crop management that has been improved greatly in the last few decades. Hobbas*et al* (1988) further observed that time series of crop yields consist of two (2) components. One is tendency of yield to increase as result of technological improvement, such as application of high-yielding varieties, increased use of chemical fertilizers and herbicides among others. The other is the variation in yield caused by a temporal variation in climate, known as the meteorological yield.

In another study, Yu and Liu (2001) in their study of the climatic factors causing variation in rice yield in the Yangtze Delta of China, used multiple regression analysis to determine the relationship between variations in yields and climatic factors. The number of hours of sunshine, the temperature and precipitation was each defined for different intervals during the growing season and different regression variables. The number of hours of sunshine during the tilling stage and the heading to milk stage particularly affected the yield. In both periods, radiation was low. In the first period, the vegetative organs of the rice were formed while in the second period solar radiation was important

for grain filling. The average temperature during the tilling period to jointing stage reached its maximum, which affected rice yield was negative. Precipitation was generally low during the jointing and booting stages, which had a positive correlation with yield while high precipitation had a negative effect during the milk stage. The results indicate that the climatic factors should be expressed as 20 to 30-day average in the Yangtze Delta; a shorter or longer period, e.g 10 to 40-day is less appropriate.

Based on the work of Kassam and Andrews (1975) in Nigeria, the growth cycle of sorghum mayconveniently be described in terms of development phasesas follows:

i. Pre-sowing stage
ii. Vegetative phase i.e., from sowing to head initiation
iii. Flowering or panicle initiation and development phase i.e., formpanicle initiation to anthesis
iv. Grain filling (or physiological maturity) i.e., fromheading to the end of grain filling

The nature and extent ofrelationships between sorghum yield and climate at each stage of growth were analyzed using multiple correlationand regressions techniques

Beside these, Jiquant*et al* (2004) in an attempt to determine the relationships between the fluctuation of maize yield and drought , water logging and cool summer in Maize growing area of Songliao plain, crop-yield analysis and regression analysis was employed. It was shown that from 1949 to 1990, the negative value years of the fluctuation of Maize yield due to meteorological hazards accounted for 55% of seasons,

of which 14% was caused by drought, 30% by water logging, 4% by cool and drought, 9% by cool summer and water logging, 13% by drought and water logging and 30% by drought, water logging and cool summer.

In Nigeria according to Olaniran (1981) the study on crop- climate relationships is classified into three approaches:

i. The fundamentals of crop-climate relationships

ii. An empirical approach in which crop-climate relationships were studied for a number of places within a given area for a long period where records of both climate agriculture are available and deducing agro-climatological relationships from analysis data.

iii. The study of crop-climate relationships under controlled environments which involves varying climatic conditions in the climate control chambers, and then searching for relationships between plant and climate.

2.1.1 Fundamental of Crop-Climate relationships

There are few studies on the fundamental approach on crop-climate relationships in Nigeria due to limitations of data (Ogutoyinbo, 1972). Some of these studies include Kowal and Andrews (1973) who investigated the pattern of water requirements for two varieties of Sorghum (short kaura and American hybrid) at Samaru in Zaria Local Government Area, Nigeria. Their result indicated that the American hybrid had a shorter growing season and gave higher grain yield but of low quality because it matured during a period of high rainfall and humidity. Kowal and Kassem (1973) computed grossand net

photosynthesis for both the forest and Savannah zones of Nigeria, and reported that mean at photosynthesis throughout the year in the Savannah zone is 20-40% greater than in the forest and 19-34% greater than in the forest during the growing season. They also computed the rates of dry matter production and yield of different cereal crops for the two zones and observed the rates of dry matter production are nearly twice as high in the Savannah zone as in the forest zone, and yield for all crops are over 70% greater in the Savannah zone.

2.1.2 Empirical Approach to Crop-Climate relationships

This is an approach in which crop-climate relationships are studied based on the availability of climatic and agricultural data over a series of time. There are many empirical studies on crop-climate relationships in Nigeria. The notable ones include the study by Kowal and Adeoye (1973) who illustrated the use of empirical approach in determining the geographical limits of crop production in Nigeria. They matched water requirements of Millet in terms of water availability and length of the rainy season separately with latitude and delineated the northern boundary for the successful cultivation of the crop without irrigation on latitude 14.7^0N. Kowal and Kassam (1973b) also used this approach and solved a series of regression equations between total annual rainfall and latitude on the one hand and water use by groundnut crop and latitude and found out that water requirements of a 20-day crop of groundnut would be met south of latitude 11.8^0N.

Egharev*aet al* (1980) and Fakorede (1985), investigated the effects of rainfall and date of planting on millet and maize yields in Nigeria, respectively. These researchers reported that when planted at less than 50mm of rainfall or too late into rainy season, there would be less moisture in the soil and decreased heat unit respectively and adversely affected the yields of these crops. Akintola (1983), analyzed the effects of climate on production of food crops in Ibadan, Nigeria and observed that agro-climatic factors correlate with the yields of maize, rice and cowpea.

In addition, Yayock and Owonubi (1986) reported the influence of weather on groundnut production in Nigeria and stressed that rainfall is a critical factor. Also Muhmud, *et al* (1997) studied the effect of rainfall on the production of Green Gram (*Vignradiata L)* in the Zaria area. Adebayo and Adebayo (1997) reported that, four critical climatic factors: hydrological ratio, onset dates of rains, number of dry spells (in pentads) during the growing season and rainfall in June influence rice yields in Adamawa State. Abdulhamid and Adebayo (2006) observed that total rainfall, relative humidity and seasonality index together accounted for about 76% of the variation of sorghum yield at Wailo (Bauchi State). Also Adebayo *et al* (2006) in their study of the influence of climatic factors on the growth of sugar cane at Numan observed total rainfall, relative humidity; minimum temperature and evaporation are critical to sugar cane growth and yield at various stages of development.

2.1.3 Crop-Climate Study under Controlled Environment

This type of study involves varying climatic conditions in the climate control chambers, and investigates for relationship between plant and climate. Based on this approach, Okigbo (1966) studied the effect of light on bitter leaf growth and development and found that there is a significant relationship between photoperiodism, light and leaf area development. Babalola (1972) varied the soil moisture regime inside a green house with relative humidity averaging 80 per cent and air temperature of 26^0 to study the effect of different soil moisture status on the root and aerial development of young plants of cocoa, kola and coffee

.

2.2 TrendsofMonthly and Annual Growing Season Rainfall

Trend is defined as a general direction which a situation is changing or developing (Hornby, 1948).In a study of rainfall trends in Kafanchan, Kaduna State, Nigeria, Abaje*et al*.,(2010) observed the sub-period 1974-1983 and 1999-2008 for the months of June and October respectively were significantly drier. The linear trend lines further revealed that there was a decline in the annual rainfall as a result of substantial decline in July, September, and October rainfall which are critical months for agricultural production in the area. The linear trend lines for the period of study also demonstrated a general tendency towards a decrease in rainfall in the area. The study further compared sub-period means with long-term mean and observed the monthly rainfall was decreasing at the rate of 0.41% per year in July, 0.08% per year in August, 0.26% per year in September, and 1.56% per year in October.

Anyadike (1992), studied the regional variations of seasonal rainfall over Nigeria and observed the presence or absence of trends in the rainfall for a period of 72 years (1916 – 1987) using the Mann – Kendall statistic, mathematically expressed as:

$$\tau = \{4(\sum_{i=1}^{N-1} n_i / N(N-1)\} - 1 \quad \text{..... 2.1}$$

Where N is the number of years in the data set; n is the number of values greater than the $(i)^{th}$ value in the series subsequent to its position in the time series. The expected value of τ in a random series is zero, and its variance (δ^2) is provided by

$$\delta^2 = (4N + 10) / 9N (N - 1) \text{.....2.2}$$

He suggested that the ratio of τ to its standard deviation ($\delta\tau$) is an indication of trend in the data. For the absence of trend in the series, the ratio lies within the limit of plus or minus 1.96 at 0.05 significance levels. He found out that the rainfall series in Nigeria exhibited some form of trends.

Pronounced long-trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia. Widespread increases in heavy precipitation events have increased. These changes are associated with increased water vapour in the atmosphere arising from the warming of the world`s oceans, especially at lower latitudes (Trenberth*et al.,* 2007)

In another study, Obot*et al* (2010)) reported that, while other locations in Nigeria had no significant trend yet in annual rainfall, Maiduguri showed an increase at a rate of 9.88mm/year. Twenty percent of Nigeria experiences a Semi- arid climate which

ischaracterized by increasing aridity since the 1960s, and in these areas, annual rainfall totals have been declining. There is a perception that the duration of growing season has been shorting (LeHou`erou, 1996). In these areas, the trend of the growing season follows the abrupt end of rains which occurs in mid-September in the North and early October in the South (Kowal and Knabe, 1972).

2.3 Patternof Millet and Sorghum Production

The West African semi-arid tropics are defined as those areas where rainfall exceeds potential evapotranspiration for two to seven months annually. This area encompasses the northern portions of Nigeria. Cereals occupy nearly 70 percent of total cultivated areas in this region and engage 50 to 80 percent of total farm-level resources (Matron, 1990). Millet and sorghum account for 80 percent of cereal production. During the last 25 years, growth in millet and sorghum production has been slow and the total output has been about one percent lower than the population per year. Average yield per unit area of millet and sorghum has declined during this period, and the small production increases have primarily resulted from expansion of cropped area. Many factors have contributed to the increased productivity, including demographic pressure and climatic change (Matron, 1990).

Matron (1990) reported that, the potential for major increases in sorghum and millet supplies exist only in the Sudano-Guinean zone and to a lesser extent in the Sudanian zone. The Nigerian Savannah ecology is the major cereal production area in Nigeria. It

accounts for about 665,600 square kilometers (about 67 million hectares), which also represent about 70% of the geographical area of Nigeria (Idem and Showemimo, 2004).

2.4 Crop Yield Forecasting Models

Among the meteorological variables, rainfall parameters, temperature, sunshine hours, relative humidity, wind velocity and soil moisture are some of the most important factors which affect crop yield significantly. Most of the developed forecasting models for crop yields were based on weather variables (Amrender*et al*, 2005). Few of thesemodels include study by Agrawal*et al*(1980), Adebayo and Adebayo (1997), Adejuwon (2005), Abdullahi*et al*(2006),Sawa(2010), Sawa and Ibrahim (2011) among others. An exception to these is that of Prasad and Dudhane (1989) who developed a forecast model for rice yield in the Gangetic Bengal using rainfall and agricultural technology including trend variables in the model as a measure of technological change.

Agrawal *et al* (1980) developed a model for forecast of rice yield using climatic variables and found out that rainfall and temperature are critical factors to rice yield.

Adebayo and Adebayo (1997) developed double log multiple regression model to predict rice yield in Adamawa State, Nigeria. The general form of his model is expressed as*:*

$$Y = a + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_4 \log x_4 + - - - b_n \log x_n \text{----------} 2.1$$

Whereby:

Y= predicted yield in kg/ha ($\log_{10}$)

x_1= hydrological ratio

x_2= onset of the rain

x_3= number of pentad dry spells between May and September

x_4= total rainfall in June

a, b_1,b_2,b_3, b_4- - - - - b_n are the coefficients of double log multiple regression.

Adejuwon (2005) in the study of food crop production and present effects of climatic variables in Nigeria adopted aforecast model for the yields of cowpeas, groundnut, millet, maize and sorghum in Potiskum and Maiduguri using bivariate correlation andstepwise multiple regression analysis techniques. The form of his model is mathematically expresses as:

$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$ ---------- $+b_nx_n$ -------- 2.2

Whereby:

Y = Crop yield

a, b_1, b_2, b_3, b_4,b_5---------- b_n are the coefficients of stepwise multiple

Regression

x_1,x_2,x_3, x_4, x_5---------- x_n are rainfall parameters (predictors variables)

He used this equation to develop four yields forecast models of cowpea, groundnut, millet and sorghum in the Nigerian Arid Zone. He reported that the predicted models generated for the yield of cowpeas, groundnut, millet and sorghum were statistically significant with $\alpha \leq 0.05$. Among more powerful determinants of crop yield were rainfalls at the onset and at the cessation of months of the growing season. Bivariate correlation, multiple correlation and regression analysis were also conducted to assess the relationship between crop and climate in Nigeria using SPSS Software of a computer (Einstein and Abernerthy, 2000).

Abdullahi*et al*(2006) in their study on econometric analysis of the relationship between drought and millet production in the Arid Zone of Nigeria: A case study of Borno and Yobe States, used a supply response model. They used this model to isolate the systematic effect of rainfall on millet production using ordinary lease squares (OLS) estimate. Linear and double log functions were lead equations for the production and yield, with coefficient of determination (R^2_s) of 0.86 and 0.77 respectively. They observed that rainfall and trend variables were significant ($p \leq 0.01$) for both production and yield function.Recently,Sawa and Ibrahim (2011) adopted aforecast model for the yield of millet and sorghum in Sami-Arid region of northern Nigeria using the occurrence of dry spells of 5, 7, 10 and equal or greater than 15 consecutive days during the growing season. Bivariate correlation analysis, stepwise (forward selection) and double log multiple regression were then used to develop models for the prediction of the yield of two crops. In this study, however, monthly rainfall amounts in monthsof the growing season from the onset dates of rains to the cessation dates of rains, onset and cessation dates` rainfall, annual and length of growing season rainfall, and the length of growing season days are employed to develop yield forecasting models for the two crops

CHAPTER THREE

3.0 RESEARCHMETHODOLOGY AND STUDY AREA

3.1 Types of Data Needed

In this type of empirical study, two types of data are required: The first are daily rainfall records, and the second are the crop yield/values for millet and sorghum (metric tons/ha) or Kg/ha

The analysis covers the growing season – 1st May to 31st October, for this is the period when all the stations in this climatic zone receive about 95% of their total annual rainfall (Anyadike, 1993). However, analysis trend of millet and sorghum yields; and relating them with the rainfall effectiveness indices earlier stated in each of the locations in the study area was based on the availability of yields data of these crops. The basis of this is because no location in the area has crop yield data that matches rainfall records to the end of the study. The yields data obtained for these crops in each of the six (6) locations range between 11 –29 years

The list of these stations and their geo-coordinates are given in Table 3.1. The spatial distribution of these stations are shown in Fig.3.7

3.2 Sources of Data

The rainfall data for each of the six (6) locations were sourced from the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos. Most of the annual yields of millet and

sorghum for each of the six locations were sourced from the respective State Agricultural Development Programmes (ADPs).The rest were sourced from National Food Reserve Agency (NFRA). The period for millet and sorghum yield data, however, varied among these locations. This was due to irregularities in available yield records of these crops. The available yield data sourced among these locations ranged from 11 to 29 years. Table 3.1 illustrates the period of available rainfall (mm), millet and sorghum (tons/ha) data used for each location in the study area.

Table: 3.1 Records of rainfall and crop yield data used

Location	**Rainfall**	**Millet Yield used**	**Sorghum Yield used**
Gusau	30 years (1981-2010)	11 years (1999-2009)	11 years (1999-2009)
Kano	30 years (1981-2010)	29 years (1982-2010)	29 years (1982-2010)
Katsina	30 years (1981-2010)	11 years (1991-2001)	11 years (1991-2001)
Maiduguri	30 years (1981-2010)	17 years (1993-2009	17 years (1993-2009)
Potiskum	30 years (1981-2010)	11 years (1999-2009)	11 years (1999-2009)
Sokoto	30 years (1981-2010)	16 years (1993-2008)	16 years (1993-2008)

Source: NIMET, States` ADPs , NFRA

3.3 The Selected Meteorological Stations

This study covers the Sudan Savannah ecological zone of Nigeria. Six (6) states meteorological stations chosen were: Kano, Katsina, Maiduguri, Potiskum, Sokoto and Gusau. These locations were chosen on the basis of the availability of meteorological data within this climatic zone and production of millet and sorghum. These meteorological stations are synoptic stations that have long period of daily rainfall records. They are consistent in location since their establishment; have no significant missing rainfall records and are geographically well distributed within the area. The list of selected meteorological stations and their Geo-coordinates are presented in Table 3.2

Table 3.2: The list of selected Meteorological stations and their Geo-coordinates

S/No	***Station Name***	***Station No.***	***Latitude***	***Longitude***	***Altitude***	***Yr.of Estab.***
1	Gusau	1206.14	$12^0$10`N	06^0 42`E	461m	1942
2	Katsina	1307.04	$13^0$10`N	07^0 41`E	514m	1924
3	Kano	1208.03	12^0 03`N	08^0 32`E	461m	1906
4	Maiduguri	1113.50	11^0 51`N	13^0 05`E	351m	1915
5	Potiskum	1111.40	11^0 22`N	11^0 02`E	412m	1936
6	Sokoto	1305.00	13^0 10`N	05^0 11`E	348m	1916

Source: Nigerian Meteorological Services Department Oshodi, Lagos

3.4TechniqueofData Collection

This study centered on secondary data. Daily rainfall and millet and sorghum yields records were collected in the Sudan Savanna Ecological Zone of Nigeria. Daily rainfall records were collected through visit to Nigerian Meteorological Agency (NIMET) at Oshodi Lagos. Records of crop yields for the two crops were also collected through visit to the State Agricultural Development Programs (ADPs) located in each of the selected stations. Some were collected through visit to the National Food Reserve Agency at Abuja, Nigeria

3.5 Techniques of Data analysis

3.5.1 Normalityof thederived Rainfall Parameters

Thederived rainfall parameters for the six locations aretested for their normality distribution. They aretested using standardized coefficients of Skewness (Z_1) and kurtosis (Z_2) statistics as defined by Brazel and Balling (1986).Skewness measures the extent to which the bulk of the values in the distribution are concentrated to one side or the other of the mean. If the bulk of the values arebelow the mean, the distribution is called positively Skewed distribution. If there are more values greater than the mean, the distribution is called negatively Skewed distribution. Kurtosis measures the extent to which values are concentrated in one side of a frequency distribution. It describes the Preakness of a distribution. Z_1 is mathematically expressed as:

$$Z_1 = \left[\left(\sum_{i=1}^{N}(xi-\bar{x})^{3/N}\right) \Big/ \left(\sum_{i=1}^{N}(x_i-\bar{x})^{2/N}\right)^{3/2}\right] \Big/ (6/N)^{1/2} \quad \text{- - - - - - - - - - - - - - } 3.1$$

And the standardized coefficient of Kurtosis ($Z_{2)}$ was determined as:

$$Z_2 = \left[\left(\sum_{i=1}^{N}(xi - x)^{4/N}\right) \Big/ \left(\sum_{i=1}^{N}(x_i - x)^{2/N}\right)^2\right] - 3 \Big/ (24/N)^{1/2} \quad \text{- - - - - - - - - - - - - - - - - 3.2}$$

Where x_i isthe rainfall effectiveness parameter, $\bar{x}$ is the long-term mean and N is the study period (30 years). Significant level of 95% is chosen to be the normalizing limit of the error margin. These statistics are used to test the null hypothesis that the individual temporary samples came from a population with a normal (Gaussian) distribution. If the absolute values of Z_1 and Z_2 are greater than 1.95, a significant deviation from the normal curved is indicated at 95% confidence level (Brazel andBalling, 1986). If the data are not found to be normally distributed, they would be transformed to normal.

3.5.2Data Transformation

There are various methods that could be used in transformation of data. These include Log_{10} transformation, Lambad transformation of Box and Cox (1964), Square and Cube Root transformations (Stidd, 1970) and SMEMAX transformation methods among others. In this study, the rainfall effectiveness parameters considered are transformed to Log_{10}if tested not normally distributed.

3.5.3 Agro-climatic Analyses

Methods employed in the derivation of onset and cessation dates, rainfall of onset and cessation dates, annual rainfall (AR), length of growing season (LGS) and monthly rainfall totals in months of the growing seasonare discussed here.

3.5.4 Determination of Onset Date of Growing Season

Onset refers to the time a place receives an accumulated amount of rainfall sufficient for growing crops. Traditional farmers have several methods of determining the onset date of growing season rainfall. This involves the use of traditional weather lore, behavior of heavenly bodies like stars, change in wind direction, arrival of seasonal migratory birds and ``Ramadan`` month (Ati, 1995). These methods lack scientific backing as they are based on poor knowledge of decision making of traditional farmers. The ones which have scientific backing and often used by various researchers are the semi-empirical and scientific techniques. The semi-empirical techniques are based on accumulated rainfall totals, while the scientific techniques are based on rainfall and evapotranspiration relationships. Both these techniques have been employed in determining the onset date of the growing season rainfall in various locations in Nigeria.

The use of accumulated rainfall total is based on the assumption that after a particular amount of rainfall is received, the probability of a long dry spell sufficient to lead to crop failure is small. The rainfall and evapotranspiration relationships assume that rainfall equal to or more than half the potential evapotranspiration and maintained throughout the season would be enough to sustain crop growth. Evapotranspiration is the combined process by which water is transferred from the soil (evaporation) and plants (transpiration) to the atmosphere (Mbagwu, 1986).

Series of studies have been devoted by various researchers on semi-empirical and scientific techniques of determining the onset date of growing season rainfall in Nigeria.

Koppen and Geiger (1936), cited by Hulme (1987), defined the onset date of growing season rainfall as the month having more than 60mm of rain. Darnault (1947), also cited by Hulme (1987), used a much lower threshold. He took the first month having more than 30mm of rainfall as the start of the growing season rainfall.

The model based on accumulated monthly totals was discussed by Walter (1967), Olaniran (1988), Sivakumar (1988) among others. Walter (1967) defined the onset of the growing season rainfall in terms of the time of receiving an accumulated amount of rainfall. In its original form, Walter (1967) computed the start of the rains as:

Days in month with effective rainfall (MER) multiplied by

(50.8-Accumulated total rainfall of previous months) divided

by total rainfall for MER

Using Katsina as an example, the rainfall distribution for 2008 (April-October) given in mm was:

A	M	J	JL	A	S	O
16.6	10.2	171.4	449.9	254.9	178.5	8.1

Using Walter (1967) criteria, the optimum planting date in Katsina is calculated as:

i. MER is June with 30 days and rainfall of 171.4mm

ii. Accumulated rainfall of previous months (Jan-May) is 16.6mm+10.2mm=26.8mm

Therefore, from this the onset date of growing season for Katsina in 2008 would be: 30(50.8-26.8)/171.4=4.20

This gives 4.20 for 2008, so the required onset date is 4th June following Walter`s empirical formula.

This formula has shortcoming as it does not account for dry spells which are common in semi-arid areas of Northern Nigeria. This shortcoming was discussed by Olaniran (1988). He suggested that the model can only be accepted if it is not followed by a month with less than 51mm of rainfall. Based on this, Olaniran (1988), developed a modified version of Walter`s relationship to calculate the start of the growing season rainfall. The Olaniran`s version of Walter`s derivation is given by:

Days in MER multiplied by (50.8-Rainfall of succeeding
Month to MER divided by rainfall of the second month after
MER

Using Kano as an example, the rainfall distribution for the rainy months (April-September) of 1971 given in mm was:

A	M	J	JL	A	S
13.00	68.85	24.23	174.68	223.89	204.26

Using Olaniran (1984), the onset date for Kano in 1971 is determined as:

i. Rainfall of the succeeding month (June) is 24.23mm
ii. Rainfall of the second month after MER (July) is 174.68mm

Substituting these in the modified formula of Olaniran (1984) will give:
31(50.8-24.23) /174.68=4.7, this gives 4.7 for Kano in 1971. Therefore, the onset date of planting season for Kano following Olaniran (1984) is 5th July.

Sivakumar (1988), working on 58 locations in the Sahelian and Sudanian zones of

Nigeria and Republic of Burkinafaso, comparably defined the onset of the growing season rainfall as the date after 1st May when rainfall accumulated over three consecutive days was at least 20mm and when no dry spell within the next 30 days exceeded 7 days.

Davey *et al*, (1976) defined the start of growing season rainfall as the first ten-day period with 20mm or more of rain. This definition may give false starts. To care of false starts, Stern, et al (1981,1982), defined the starts of rain of growing season as 20mm in one or more consecutive days with no dry spell of 10 days or more within the next 30 days. Stern et al. (1981), Jolliffe and Sarria-Dodd (1994), defined the onset date of growing season rainfall as:

i. A period of 5 days (pentad) with at least 25mm of rainfall;
ii. the start day and at least two other days in this period are wet, i.e equal to or more than 0.1mm rainfall;
iii. No dry spell of 7 days or more occurs in the following 30 days

Ilesanmi (1972) defined the onset date of growing season based on a certain percentage of the annual total rainfalls, the contribution of daily and pentad rainfalls to the annual total. He used accumulated rainfall to derive the onset in the following manner:

i. Derivation of the percentage of the mean annual rainfall that occurs at each 5 days intervals for every station:
ii. Accumulation of the computed percentage at 5 days intervals;
iii. Plotting the accumulated percentage at 5 days intervals through the year;
iv. Identification of the time of the onset of the rainy season as the firs point of

maximum curvature on the slope of cumulative percentage graphs of 5 days rainfall. From these calculations, the point of maximum curvature on the graph for each station was found to coincide with 7 and 8 cumulative Percentage. This means that the onset of rainfall at every station begins with an accumulated 7 to 8 percent of the annual rainfall.

Adefolalu (1993) applied the ogive method and determined the start of the growing season for some places in northern Nigeria. Here the months of the year are divided into pentads giving 72 pentads using the pentad calendar. Pentad rainfall was calculated for each pentad and cumulated. An ogive was then constructed from this. The points on the pentad axis corresponding to the first and the last points of maximum inflexion on the ogive gave the onset and cessation pentads respectively. While the last date in the onset pentad gives the exact date of onset of the rains. The first date in the cessation pentad gives the exact date of the cessation of the rainy season. The determined onset and cessation dates were then converted to Julian days. Julian days are obtained by numbering sequentially the days of the twelve months of the year from 1st January to 31st December to give figures that can be used statistically.

Kowal (1972) used the relationship between rainfall and evapotranspiration and calculate the onset date of the growing season. He defined the onset as the decade in which rainfall is greater than 25mm and where subsequent decade of rainfalls are greater than 0.5 potential evapotranspiration. This definition is based on the assumption that the recharge of the surface by 25mm of water will allow cultivation of land and that an amount of

rainfall in the following decades of at least 0.5 potential evapotranspiration will sustain growth. Another related rainfall/evapotranspiration model for Nigeria is the one proposed by Benoit (1977). He defined the onset date of the growing season rainfall as when accumulated daily rainfall exceeded 0.5 accumulated potential evapotranspiration for the remainder of the season, provided that no dry spell longer than five days occurs immediately after this date. This is based on the assumption that planting can start when rainfall is adequate to provide water equivalent to or greater than 0.5ETP. The second assumption is that a dry spell of more than five days immediately after planting will dry out the top soil and produce a failure to germination.

3.5.5 Determination of Cessation Date of Growing Season

Cessation means termination of the effective rainy season. Walter (1967) defined the cessation date of the rains as the last date on which a threshold is reached. The determination of cessation date of growing season according to Walter (1967) is done in the same way as the onset date except that here, the working is done backward from December. Based on Walter (1967), he said it is the number of days in the first month from December with cumulative monthly rainfall is greater than 51mm multiplied by (51-Rainfall total of the previous month) divided by total rainfall of the first month with cumulative rainfall greater than 51mm.

Kowal and Knabe (1972) defined cessation date of a growing season as any day from 1st of September after which there are 21 days or more days consecutive of rainfall less than 50% of the crop water requirement. In this method days after 1st September must have

more than 50% of water requirement for crop growth. He further said water requirement for proper crop growth must first be determined. Hulme (1987) also defined cessation date of a growing season rainfall as when the end of the rainy season is being preceded by at least ten days of drought following each other consequently.

Omotosho (1990) expressed cessation date of a growing season rainfall as any day from 1st September after which there are 15 or more days of consecutive rainfall less than 50% of the crop water requirement. Odekunle*et al* (2004) stated that cessation date of the rainy season is when rainfall distribution may no longer sustain plant growth. It implies that cessation date is the stage when plants no longer grow well due to shortage of rainwater, and no need other means of water supply to sustain them. The cessation date of growing season rainfall according to Madeoye (1985) is defined as the last date on which a threshold is exceeded. Zargina (1987) used the minimum daily rainfall threshold of 25mm to determine the cessation date of growing season rainfall. In the procedure, the soil is assumed to be at field capacity of 100mm on the last day of rain that is greater than 0.5PET provided that the date is not proceeded by a dry spell (less than 1mm average daily rainfall) or more than five days (Benoit, 1977; Stern *et al*, 1982). It is assumed that the depletion of available soil moisture below 40% of its field capacity will cause rapid reduction in water availability to crops.

3.5.6 Determination of Length of Growing Season (LGS)

`Growing season`` is defined as the period of the year during which rainfall distribution characteristics are suitable for crop germination, and full development (Odekunle, 2004).

It is the period of the year categorized as rainy or wet season. The length of the growing season varies spatially and temporally.

Literature reveals that the length of the growing season rainfall can be determined in a variety of ways. Some people, notably Thornthwaite (1948), Thornthwaite and Mather (1955), Cocheme and Fraquin (1967) and Benoit (1977), have employed a rainfall–evapotranspiration relation model to determine the onset and cessation of the growing season. Others like Bee *etal.,* (1977) and Omotosho (1990, 1992) based their prediction method on upper wind data. Recently, Omotosho*et al.*, (2000) made another attempt, using daily mean values of surface pressure, temperature, and relative humidity. More recently, Omotosho (2002) used the Theta-E technique, which is dependent on the equivalent potential temperature. However, most workers (Dagg, 1965; Walter, 1968; Ilesanmi, 1972; Igeleke, 1973; Kowal and Adrews, 1973; Olaniran, 1983, 1984; Adejuwon*et al*., 1992; Adefolalu, 1993; Bello, 1995; Nnoli, 1996; Ati et *al*., 2002; Sawa and Adebayo, 2011) have employed rainfall alone to determine the onset and cessation of the growing season.

Daily rainfalls are more widely used mainly because they are more readily available (Olaniran, 1983). The author also believes that the use ofdaily rainfall data is a more direct approach rather than the use of some other related factors. Although Thornthwaite and Mather (1955) employed rainfall and temperature (both of which are readily available data) to estimate their climatic water budget for agriculture, the model has not found wide use in West Africa for three main reasons. Firstly, it has been found that temperature is not a good indicator of the available energy for evaporation or potential

evapotranspiration, since it lags behind solar radiation (Ojo, 1977). Secondly, the model does not take into consideration the effect of advection (Ojo, 1977). Thirdly, in the tropics, temperatures are relatively uniform and seasonal variations are small, thereby allowing a wide range of suitable crops in relation to temperature conditions (Nieuwolt, 1982).

Also in tropics, `the growing lasts, thermally, the whole year` (Reihl, 1954). There is never the danger of ground frosts damaging crop plants and leading to crop failure. For example, the coefficient of variation (CV, SD/mean) of maximum temperature average less than 5% across climatic zones in Nigeria. On the other hand, the CV of monthly rainfall can be as high as 600% in certain locations and during certain months of the year. Thus, temperatures are not a critical factor in tropical agriculture. Therefore, rainfall is the principal controlling element in tropical agriculture (Nieuwolt, 1982; Stern and Coe, 1982).

In the use of rainfall data alone, there are two main approaches found in literature: an absolute definition, based on a certain threshold value; and a relative definition, based on a certain proportion relative to the total rainfall (Adejuwon, 1988). The most widely accepted is the relative definition method (Ilesanmi, 1972) who reported that rains in Nigeria start early in the south and progressively later northward. In addition, that the two major rainfall peaks occur in the south while only one primary peak is experienced in the northern Nigeria.

The length of growing season can also be determined by subtracting for each year, the date at which the rains start from the date that it ends (Madeoye, 1985; Zargina, 1987). Also Oladipo and Kyari (1993) in their study of growing season rainfall of Northern Nigeria indicated that the onset, cessation and duration of growing season show latitudinal progress but with some disruptions due to orographic effect in the central area (Jos). So based on these reviews, it could be observed that rainfall probability, especially daily rainfall probability, which is the most direct method of rainfall reliability estimate, has been relatively neglected in the determination of onset, cessation dates, the length of the growing season and monthly rainfall amounts in months of growing season.

A particular study which was based on relative definition and adopted to this study is the study by Adefolalu (1993), who stated that the length of growing season could be obtained by subtracting the onset pentad from the cessation pentad. He determined the onset and cessation dates of the growing season by dividing each year into pentads making 72 pentads, and using the pentad calendar, Pentad rainfall was then calculated for each pentad and cumulated. Pentads rainfall was plotted against the number of pentad giving an ogive for each year in the study area. The points on the pentad axis corresponding to the first and last points of the maximum inflexion on the rainfall ogive correspond to the onset and cessation pentads respectively (Fig.4.1). The last date in the onset pentad gives the exact onset date and the first date in the cessation pentad gives the cessation date of the rainy season. The derived onset and cessation dates were then converted to Julian days using Julian day time-table.

This method is adopted in the derivation of onset and cessation dates of rains and length of growing season in the study area. The typical of this method for 1981 for each of the six respective locations is presented from (Fig.3.1 to 3.6).The method utilizes daily rainfall data which makes it more accurate and precise method for determining the onset, cessation date and the length of growing season than other methods.

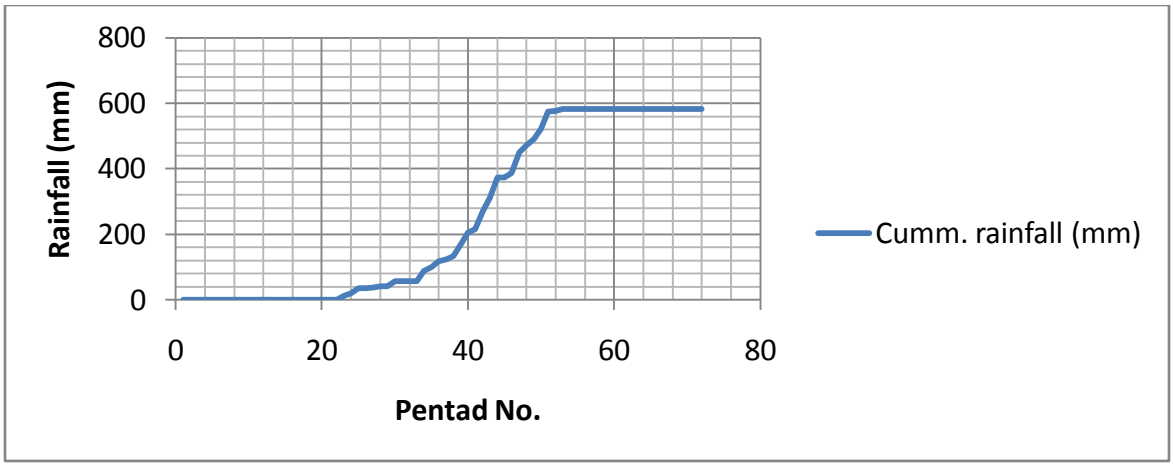

Fig.3.1: Ogive of cumulative pentad rainfall at Kano (1981) for determination of Onset, cessation dates and length of growing season

In fig. 3.1 at Kano, the onset pentad falls on pentad 29 and the onset date of rainfall corresponds to 21-May, 1981. The cessation pentad falls onpentad 53 and the cessation date of rainfall corresponds to 25-September, 1981.

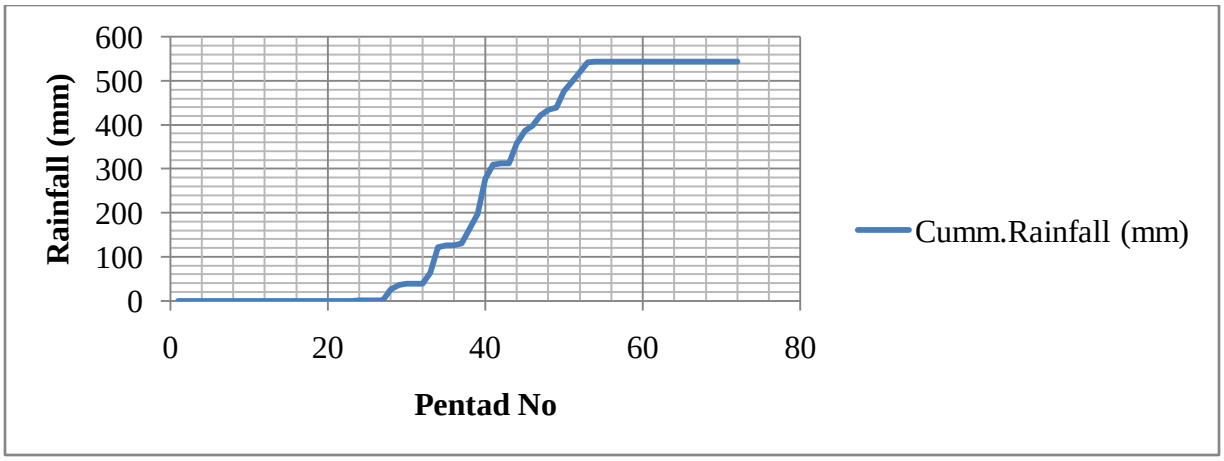

Fig.3.2 Ogive of cumulative pentad rainfall at Katsina (1981) for determination of onset, cessation dates and length of growing season

In fig. 3.2 at Katsina, the onset pentad falls on pentad 20 and the onset date of rainfall corresponds to 31-May, 1981. The cessation pentad falls onpentad 53 and the cessation date of rainfall corresponds to 25-September, 1981.

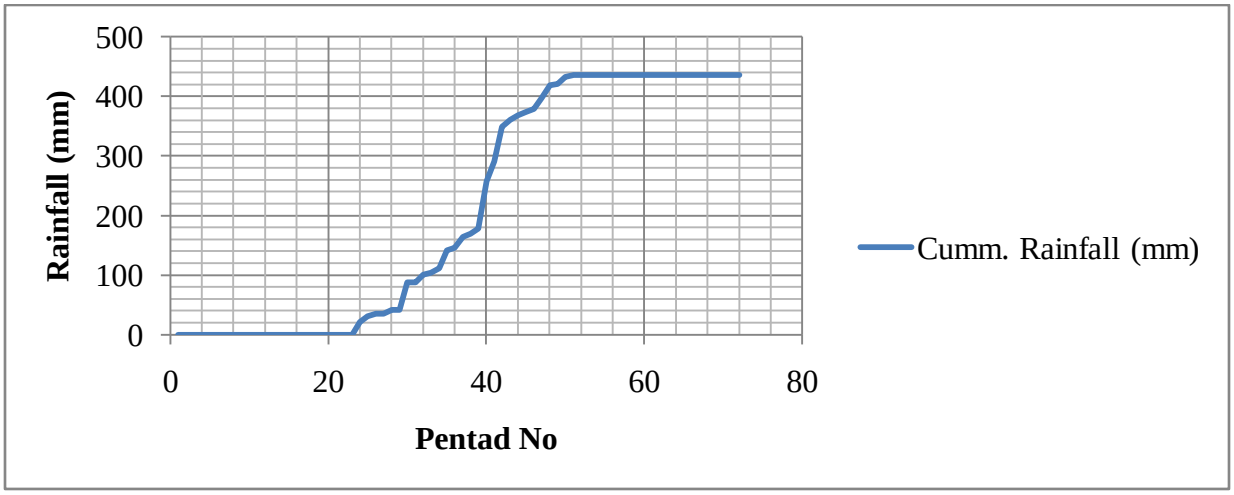

Fig.4.3 Ogive of cumulative pentad rainfall at Maiduguri (1981) for determination of onset, cessation dates and length of growing season

In fig. 3.3 at Maiduguri, the onset pentad falls on pentad 26 and the onset date of rainfall corresponds to 10-May, 1981. The cessation pentad falls onpentad 49 and the cessation date of rainfall corresponds to 5-September, 1981.

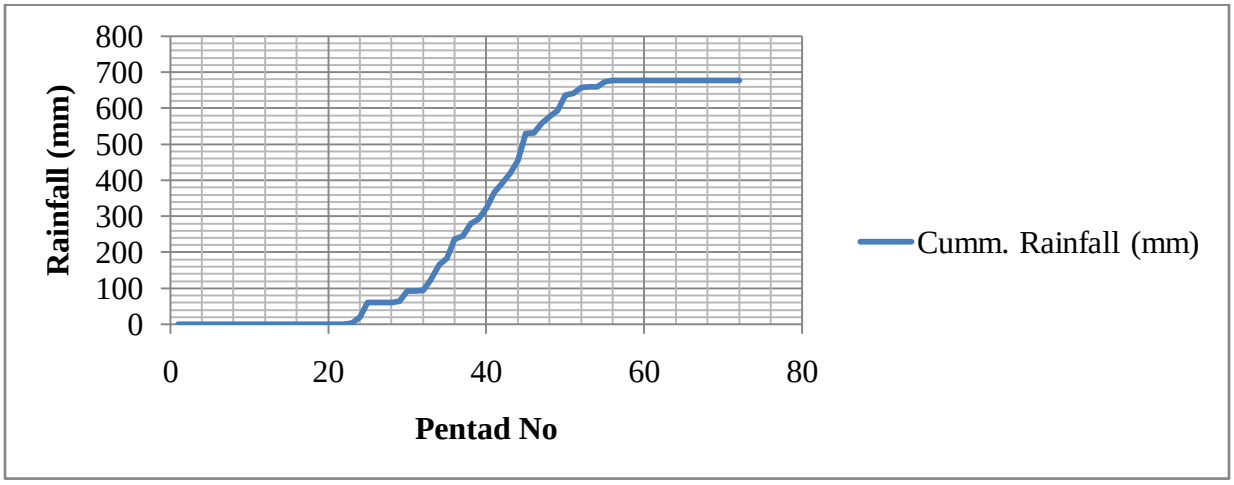

Fig.3.4 Ogive of cumulative pentad rainfall at Potiskum (1981) for determination of onset, cessation dates and length of growing season

In fig. 3.4 at Potiskum, the onset pentad falls on pentad 25 and the onset date of rainfall corresponds to 5-May, 1981. The cessation pentad falls onpentad 56 and the cessation date of rainfall corresponds to 6-Oct, 1981.

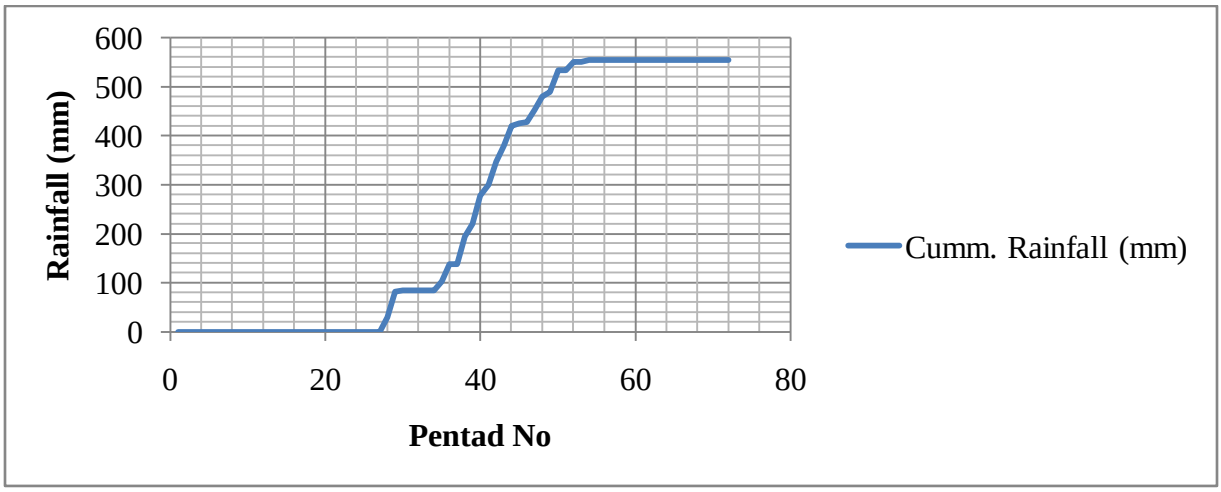

Fig.3.5 Ogive of cumulative pentad rainfall at Sokoto (1981) for determination of onset, cessation dates and length of growing season

In fig. 3.5 at Sokoto, the onset pentad falls on pentad 29 and the onset date of rainfall

corresponds to 25-May, 1981. The cessation pentad falls onpentad 54 and the cessation date of rainfall corresponds to 26-Oct, 1981.

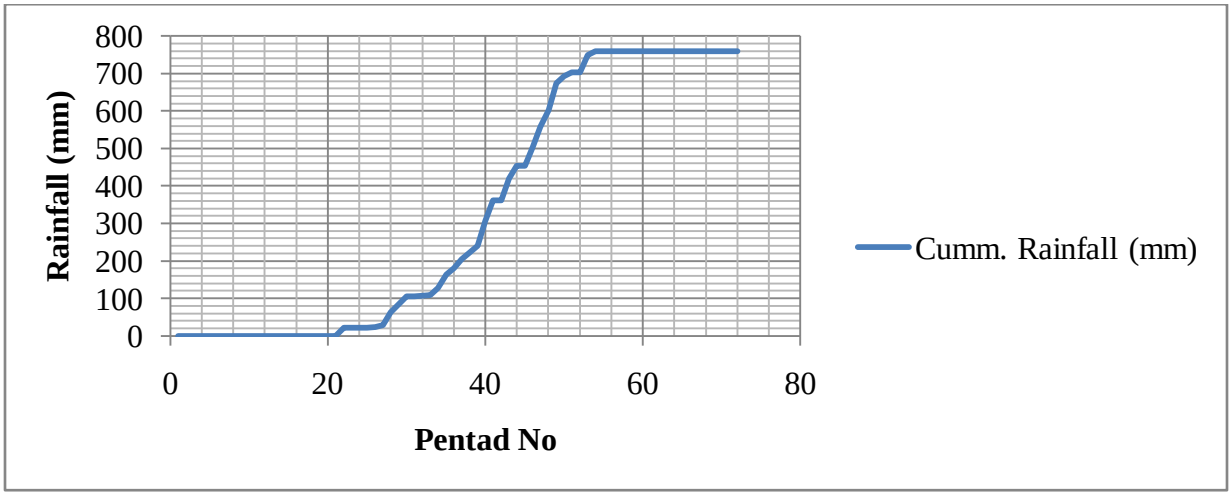

Fig.3.6 Ogive of cumulative pentad rainfall at Gusaau (1981) for determination of onset, cessation dates and length of growing season

In fig. 3.6 at Gusau, the onset pentad falls on pentad 30 and the onset date of rainfall corresponds to 31-May, 1981. The cessation pentad falls onpentad 54 and the cessation date of rainfall corresponds to 26- Sept, 1981.

The other onset and cessation dates and length of growing season for the study period in each location were obtained in similar manner using pentad calendar (Appendix A) and Julian day calendar (Appendix B)

3.5.7 Derivation of Monthly rainfall amounts during thegrowing Season

Daily rainfall data are cumulated from onset pentad to cessation pentad to give monthly rainfall totals in months of the growing season.

3.5.7 Derivation ofAnnual rainfall (AR)

Daily rainfall data are cumulated from January to December to give annual rainfall total for each station in the study period

3.5.8 Relationship between Crop Yield and Rainfall parameters

The Product moment correlation coefficient (r) is the ratio of the joint variation of two variables to the total variation (David, 1977). The technique assumes that both variables have come from normally distributed populations. TheProduct Moment Correlation Coefficient(r) was usedto test the relationship between crop yieldsand monthly rainfall in months during growing season, LGS and AR. The product moment correlation coefficient (r) between two variables is mathematically expressed as:

$r=\sum xy/N-\bar{x}\,\bar{y}/s_x s_y$ - - - - - - - - - - - - - - - - - 3.3

Where R is the product moment correlation coefficient,*x*is the rainfall effectiveness parameter of each location, y refers to total crop yields of each crop for each location; $\bar{x}$ is the mean rainfall effectiveness parameterfor each location, $\bar{y}$ is the mean total yield of each crop for each location and N is the study period. S_x is the standard deviation of rainfall total for each location; S_y is the standard deviation of total crop yields for each location. S_x and $s_y$are calculated by the following equations:

$$S_x = \sqrt{\left(\sum x^2 / N\right) - \bar{x}^2} \quad \text{- - - - - - - - - - - - - - 3.4}$$

$$S_y = \sqrt{\left(\sum y^2 / N\right) - \bar{y}^2} \quad \text{- - - - - - - - - - - - - - - 3.5}$$

3.6Models for predicting Crop Yield

The identified crops yieldTon/hectare(millet and sorghum) and rainfall effectiveness parameters are harmonized to common base ($\log_{10}$) using MINITAB Software of the computer. Later,rainfall amounts during growing season, annual rainfall and length of growing seasonwere correlated with the yields of the two crops in each location. These parameters are then subjected to stepwise multiple regression analysis using SPSS Software of the computer to develop yield forecasting models for the two crops station wise. The best fitted yield forecast models of the two crops were chosen among the six locations for the study area.

Various types of forecast models for crop yields have been discussed in the literature review, among which include forecast models for the yields of cowpea, groundnut, millet and sorghum using bivariate correlation and stepwise multiple regression analysis (Adejuwon, 2005), double log multiple regression model used by Adebayo and Adebayo (1997), as well as Sawa and Adebayo (2011). Thesetechniques are essential for prediction. In this study, the method of (Adebayo and Adebayo, 1997) was adopted to develop yield forecast models for millet and sorghum yields usingthe rainfall parameters identified in the study. The general form of the modelis mathematically expressed as:

$$Y= a+b_1\log x_1+b_2\log x_2+b_3\log x_3+b_4\log x_4 + b_5\log x_5 + b_6\log x_6 + b_7\log x_7 + b_8\log x_8 + \cdots + bn\log x_n \quad (3.6)$$

Whereby:

Y= Yield ton/yr

X_1= May rainfall

X_2= Jun. rainfall

X_3= Jul. rainfall

X_4= Aug. rainfall

X_5= Sep. rainfall

X_6= Oct. rainfal

X_7= AR (Annual rainfall

X_8= LGS (length of growing season)

The statistical tools of equations 3.1 to 3.6 were determined using statistics packet for social science(SPSS) software of the computer.

To check the appropriateness of the developed model, examination of the residuals was carried out. Residual is the difference between the observed and predicted value. The goodness of fit of the models was verified by coefficient of determination (R^2). The accuracy of this forecast model was checked by the forecast error (%) which was computed by the equation:

$$FE = \frac{\text{Observed Yield} - \text{Forecast Yield}}{\text{Observed}} \times 100 \quad \text{- 3.7}$$

For goodness of fit, the percentage errors should not vary significantly onefrom another. FE should not be greater than 25% otherwise the model is not appropriate for forecasting the yield of crops (Sawa, 2010)

3.7 Location of the Study Area

The study area is the Sudan Savannah ecological zone of Nigeria. It approximately lies between Latitudes 10^0 and 12^0 N and Longitudes 4^0 and 15^0 E (Fig.3.7). It stretches from the Sokoto plains in the west through the northern section of the High Plains of northern Nigeria in the east to the Chad Basin. It thus includes the States of Kaduna, Katsina, Kano, Jigawa,Zamfara, Sokoto, Kebbi,and Borno.

3.8 Relief and Drainage

The relief of the study area generally consists of irregularly gently rolling undulating plains often referred to as ``High plains of Northern Nigeria`` lying between 450m to 745m above sea level (Udo, 1970). It is characterized by outcrop of granitic hills and volcanic plateau such as that of Borno and Kotorkoshi in Zamfara States. In the northeast, the plains descend into the inland drainage basin of Lake Chad. In the northwest, the plains descend into Sokoto-Rima River basin. There are two types of drainage system in the study area: The first is Niger-Benue River system, and the second is the inland drainage of the Lake Chad. The Niger-Benue Rivers drain into the study area from North-west and North-east respectively; meet at Lokoja and flow southwards into the Atlantic Ocean. Sokoto- Rima Rivers which have their sources from the central Plateau of northern Nigeria flow into the Niger in the West. The Yedzarem, Hadejia-Jama`are, the Lunge, Chari and Yobe Rivers all drain into the Lake Chad in the northeast.

3.9 Geology

The geology of the study area according to Kowal and Knabe (1972) can be classified into two formations:

i. The Precambrian basement complex covering more than half of the area which occurs in the central, southwestern and eastern parts. It composed of metamorphic and igneous rocks like migmatites, gneisses and granites.

ii. The second formations are the tertiary deposits of Chad and Sokoto basins. These basins form vast monotonous plains tilting towards Lake Chad in the East and Sokoto Rima in the west. It is composed of wide spread of low landforms and vegetation. The dunes give way to extensive area of heavy cracking clay called vertisols in the eastern part of Chad basin.

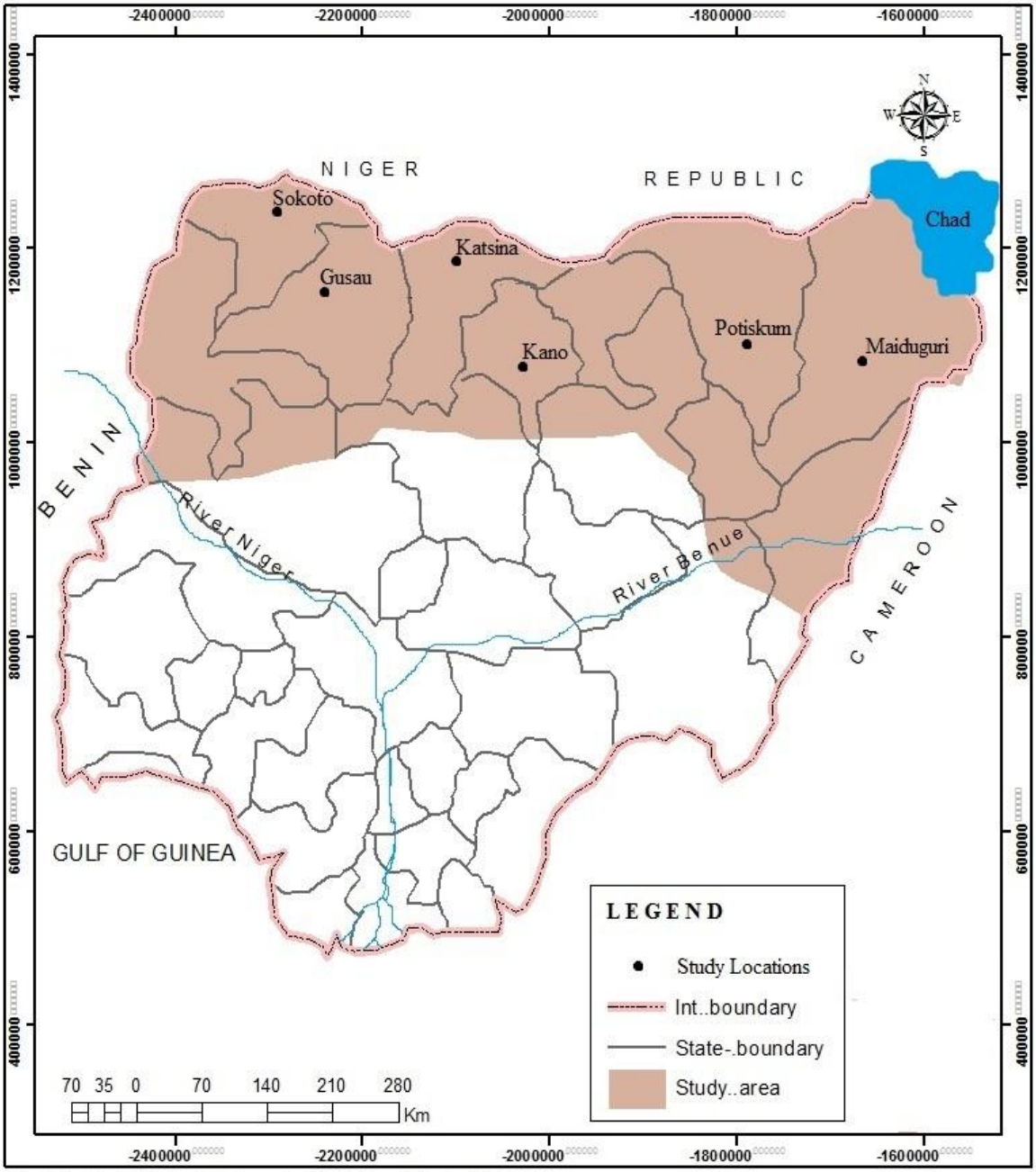

Fig.3.7: Study Area Showing the Location of Study Sites.
Source:- Les Editon (2006)

3.10 Climate

The climate of the study area is Savanna type with alternating wet and dry seasons. The rainfall in this region ranges from 450mm in the far north to 1000mm per annum in the southernmost areas in only five months in the year between May and October. Rainfall in this zone is highly variable and the onset of rain is erratic. The rainfall intensity is very high between the months of July and August. It also results in rapid surface run-off, soil erosion and water-logging (Udo, 1970). The region suffers from frequent droughts as particularly witnessed during the 1968-1974 and 1983-1987 periods.

There is spatial difference in the amount of rainfall received in the Sudan Savanna ecological zone of Nigeria. The southern part receives more rain compared to the northern section. The features of rainfall patterns in this region, as in other parts of Nigeria are usually in association with the Inter Tropical Discontinuity (ITD) (Nicholson 1983; Oladipo, 1993).

ITD is a zone where warm moisture (mT) air from the Atlantic Ocean converges with the cold, dry, and often dust-laden (cT) air from the Sahara known locally as the harmattan. During the summer the zone of Inter Tropical Discontinuity follows the sun northward. As a result the whole of Sudan Savannah of Nigeria comes under the influence of moisture-laden tropical maritime air. As summer ceases, the ITD shifts southward, bringing an end to the rainy season. The ITD fluctuates from north to south. It assumes it's northern most position around latitude 20^0N in August and attains its southern most position between latitudes 5^0 and 7^0N in January varying according to the season. In

general, its southward retreat is faster than its northward advance (Oladipo and Salau, 1993).

According to Oguntoyinbo (1993), temperatures are very high throughout the year averaging from 28^0C - 30^0C. Peak temperature occurs in April (43^0C) for places like Sokoto and Maiduguri. December/January is the coolest period. During the harmattan season, temperatures drop as low as 18^0C. Evapotranspiration in this region is high throughout the year such that it causes soil water deficit to the extent that if rain does not fall within a week, crops begin to wilt. The sunshine duration is 7-8 hours (Oguntoyinbo, 1983).

3.11 Soils and Vegetation

The greater part of the study area is covered by the ferruginous tropical soils, which are highly weathered, and markedly laterised by the loss of silica due to leaching (Areola, 1982). This is interrupted by patches of vertisols on plains and alluvial deposits particularly along the flood plains of the rivers in the area.

The vegetation of the study area is described as Sudan Savanna. It is composed of mixture of grasses and trees. This is because of the less precipitation and a prolonged dry season of about five to eight months. According to Keay (1959; Kowal and Kassam, 1973), the study area is covered by mid sub-humid wooden savanna called Sudan savanna and receives about 1000mm of rainfall and is poorly distributed between 120-140 days. The Baobab is the largest tree; it is widely distributed and valued for its inner

back (from which rope is made and its edible leaves and fruits). Other common trees are the silk cotton and locust bean (*Parkiafilicoidea*) and various species from the acacia and fig *(ficust)* families. Grasses found in this zone are not generally as tall, coarse or thick on the ground. There is continuous grass cover of the short and feathery grasses on large scale. The grass vegetation is interspersed and prolific with farms and thick bush trees such as Shea butter (*Butyrospermumparkii*) and *Acciaalbida*. It is a belt for the rearing and breeding of ruminant livestock (cattle, goats, sheep, donkey and horses).

3.12 Population

Based on NPC (2006) the total populations figure for both male and female of the six (6) selected locations based on States was estimated at 28,676,864. A total of 51.50% of this figure is male and 48.50% female. Population distributions among these locations are shown in Table 3.3. The Hausa, Fulani and Kanuri are the major ethnic groups in the study area, with Shuwa- Arab, Kakari, Margis, Baburw, Gozas among others as other minority tribes.

Table 3.3: The Estimated Population Figure of the Study Area

State	Sex		Both Sexes
	Males	Females	
Borno	2,163,358	2,007,746	4,171,104
Kano	4,947,952	4,453,336	9,401,288
Katsina	2,948,279	2,853,305	5,801,584
Sokoto	1,863,713	1,838,963	3,702,676
Yobe	1,205,034	1,116,305	2,321,339
Zamfara	1,641,623	1,672,503	3,278,873
Total	14,769,959	13,906,905	28,676,864

Source: NPC (2006)

3.13 Economic Activities

The economic activities in the study area are categorized into seven main occupational categories (NPC, 1991). They include professional/technical works, administrative/managerial works, clerical and related works, sales workers, agriculture and related works, service works, and production and related works. According to NPC (1991) the agriculture/technical works are the dominant economic activities of the people in the study area. They ranked the first. Sales workers ranked second, production and related works third; professional/technical works fourth; service works fifth; clerical and related works sixth and administrative/managerial works seventh. Under agricultural, subsistence farming and pastoralism form the major economic activities. The sedentary farming alone provides employment for over 70% of population of this area.

3. 14 Environmental Problems

The major environmental problem in the study area is desertification, which is caused by the massive cutting down of trees (deforestation) for fire woods. Bushfires are common especially during dry seasons. Over grazing and livestock migration pose a great threat to the environment. Other environmental problems include soil erosion and gully erosion droughts, dry spells and dust storms which constitute hazards to crop yields in the study area. Soil erosion causes a fall in the level of humus and nutrients of most soil in this region.

CHAPTER FOUR

4. 0 RESULTSPRESENTATION

4.1: The Onset and Cessation Dates

The derived onset and cessation dates of each location in the period of study (1981-2010) are presented in Tables 4.1 to 4.6. It could be observed that the onset and cessation dates of rainfall vary among the six locations. At Kano station, (Table 4.1) it could be observed that the onset date of growing season occurred 20 times in May, 8 in June and once in July. The cessation date of growing season was 17 times in September and 13 in October. In Table 4.2, at Katsina station, the onset of growing season stated 15 times in May, 13 in June and 2 times in July. The cessation date of growing season was 16 times in September and 14 in October. At Maiduguri, (Table 4.3) onset of growing season was 10 times in May, 19 in June and once in July. The cessation date of growing season in the station was 3 times in August, 11 in September and 16 in October.

In Table 4.4 (Potiskum station) the onset date of growing season appeared 9 times in May, 18 in June and 3 in July. The cessation date of growing season appeared once in July and August, 5 times in September and 16 October. In Table 4.5, Sokoto station, the onset of growing season occurred 10 times in May and 20 in June. The cessation date of growing season occurred once in August, 16 times in September and 13 in October. At Gusau station(Table 4.6) the onset date of growing season occurred 21 times in May, 7 in June and 2 in July. The cessation date of growing season was 3 times in August, 5 in September and 16 in October.

Beside these, the mean onset and cessation dates of growingalso vary among the six locations. The mean of these variables for each location were calculated using Julian Day Calendar Table (Appendix B). They were obtained by converting onset and cessation dates of each locationinto Julian Days within the study period (1981 to 2010). The results of each location were summed and divided by thirty (30) to obtain the mean of both onset cessation date of growing season in each location respectively. At Kano for instance, (Table 4.1) the mean onset date of growing season was found to fall on 22-May, and cessation date on 30-September. In Katsina (Table 4.2) the mean of onset date of growing season was on 1st-June and cessation date on 2-October. At Maiduguri (Table 4.3) the mean onset date of growing season was on 5-June and cessation date on 2-October.

At Potiskum station (Table 4.4) the mean onset date of growing season was on 10-June and cessation date on 7-October. In Sokoto (Table 4.5) the mean onset date of growing season falls on 3-June and cessation date on 4-October. At Gusau (Table 4.6) the mean onset date of growing season was on 23-May, and cessation date on 3-October. The mean distribution of these rainfall variables in the study area are presented in Fig. 4.1 and 4.2 respectively. Fig.4.1 illustrates the expected onset dates of growingseason and 4.2 the cessation dates.

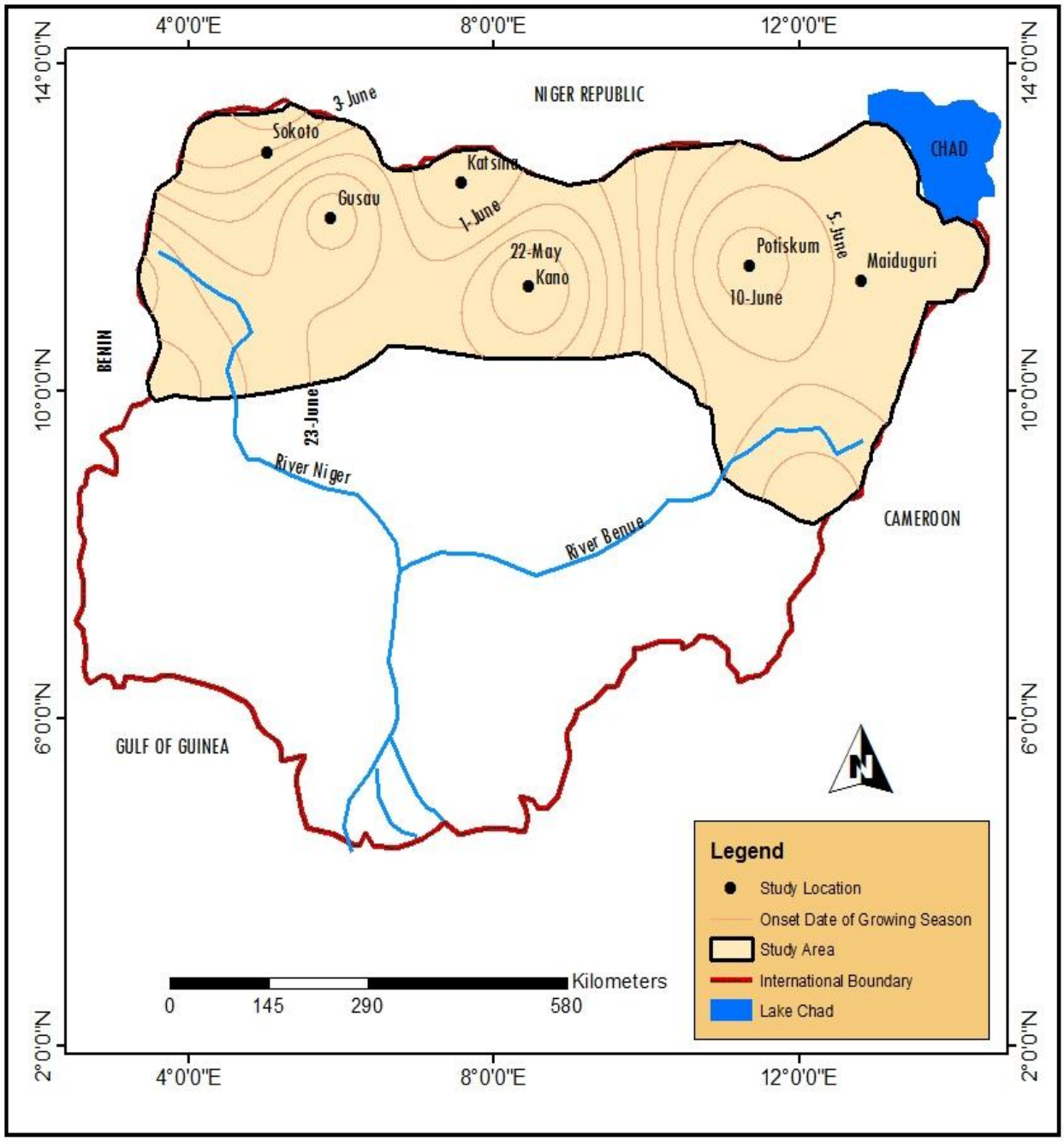

Fig. 4.1 Expected Onset Dates of Growing Season for the Study Area

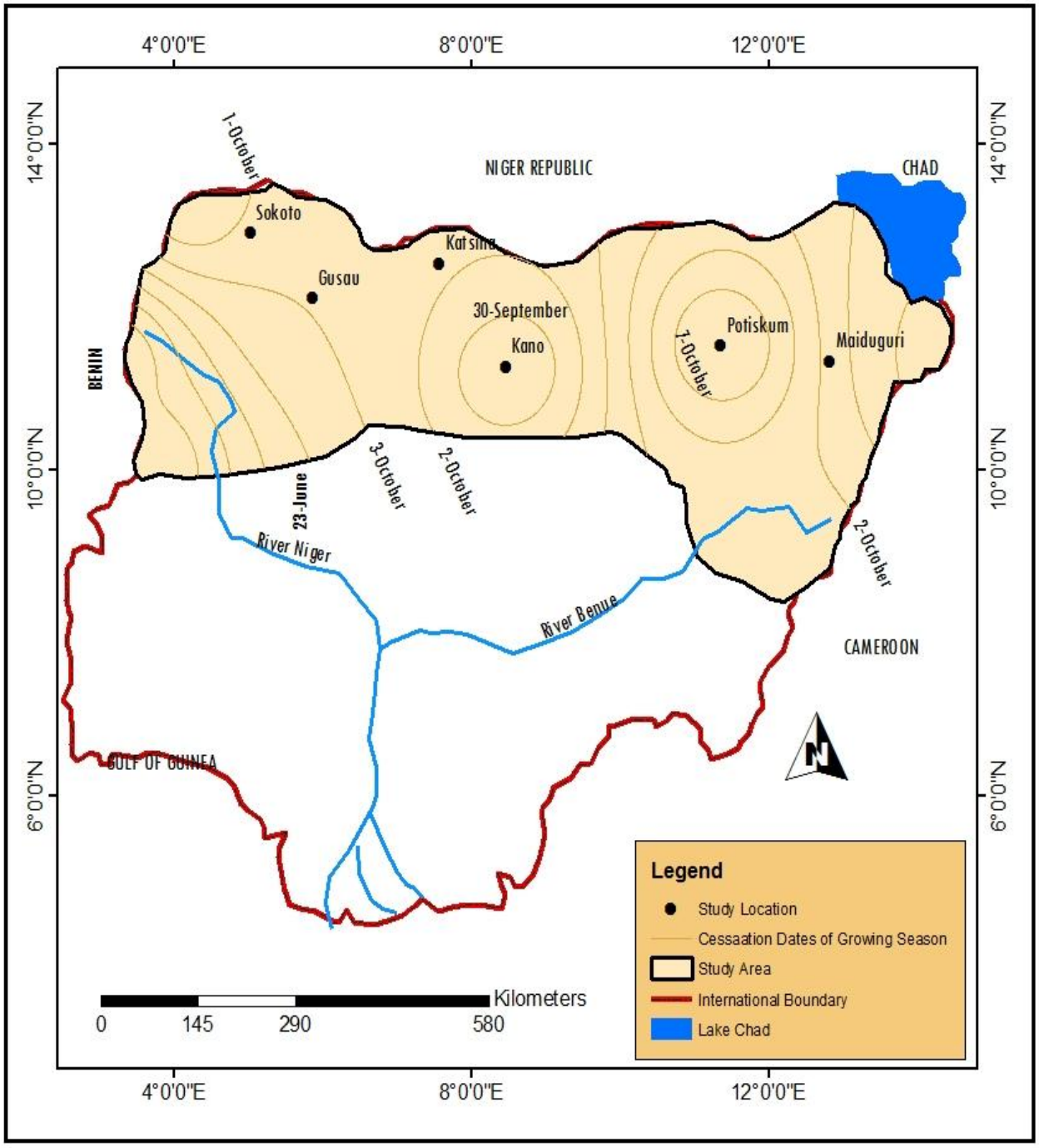

Fig. 4.2 Expected Cessation Dates of Growing Season for the Study Area

Table 4.1: The Onset and Cessation Dates at Kano (1981- 2010)

YEARS	Onset date	Cessation Date
1981	25-May	21-Sep
1982	31-May	11-Sep
1983	25-May	11-Sep
1984	5-May	6-Oct
1985	10-May	26-Sep
1986	10-Jun	21-Sep
1987	5-Jun	1-Oct
1988	5-Jun	21-Sep
1989	20-Jun	1-Oct
1990	20-Jun	11-Sep
1991	31-May	1-Oct
1992	15-May	16-Sep
1993	31-May	16-Sep
1994	10-Jul	26-Sep
1995	25-May	26-Sep
1996	25-May	11-Oct
1997	5-May	26-Sep
1998	10-May	6-Oct
1999	25-May	1-Oct
2000	31-May	6-Oct
2001	5-Jun	21-Sep
2002	31-May	1-Oct
2003	31-May	16-Sep
2004	20-May	26-Sep
2005	5-May	6-Oct
2006	15-May	26-Sep
2007	5-May	6-Oct
2008	10-Jun	11-Oct
2009	10-Jun	26-Sep
2010	30-Apr	21-Oct

Source: Field work, 2012/2013

Table 4.2: Onset and Cessation Dates at Katsina (1981-2010)

Years	Onset dates	Cessation dates
1981	30-May	25-Sep
1982	5-Jun	6-Oct
1983	15-Jun	16-Sep
1984	15-Jun	11-Oct
1985	20-May	26-Sep
1986	5-Jul	26-Sep
1987	30-May	21-Sep
1988	5-Jun	26-Sep
1989	10-Jun	6-Oct
1990	25-May	6-Sep
1991	15-May	1-Oct
1992	20-May	16-Sep
1993	30-Jun	21-Sep
1994	31-May	11-Oct
1995	20-Jun	26-Sep
1996	31-May	30-Sep
1997	25-May	26-Sep
1998	31-May	26-Sep
1999	5-Jul	6-Oct
2000	5-Jun	6-Oct
2001	31-May	16-Sep
2002	25-Jun	11-Oct
2003	31-May	11-Oct
2004	20-May	26-Sep
2005	20-Jun	1-Oct
2006	20-Jun	1-Oct
2007	20-May	21-Sep
2008	10-Jun	1-Oct
2009	25-May	16-Oct
2010	25-Jun	1-Oct

Source: Field work, 2012/2013

Table 4.3 : The Onset and Cessation Dates at Maiduguri (1981-2010)

Years	Onset date	Cessation date
1981	10-May	5-Sep
1982	10-Jun	16-Sep
1983	15-Jun	1-Oct
1984	25-May	26-Sep
1985	25-May	21-Sep
1986	10-Jun	26-Aug
1987	20-Jun	1-Oct
1988	10-Jun	26-Sep
1989	5-Jun	6-Oct
1990	30-Jun	21-Sep
1991	25-May	26-Aug
1992	31-May	11-Oct
1993	25-May	21-Sep
1994	25-Jun	16-Oct
1995	20-Jun	21-Sep
1996	15-Jun	16-Oct
1997	5-Jun	1-Oct
1998	31-May	26-Aug
1999	15-Jun	11-Oct
2000	15-Jun	1-Oct
2001	15-Jun	26-Sep
2002	25-Jun	6-Oct
2003	5-Jun	21-Oct
2004	20-May	6-Oct
2005	15-May	16-Oct
2006	31-May	6-Oct
2007	5-Jun	21-Sep
2008	25-Jun	26-Sep
2009	5-Jul	16-Oct
2010	5-Jun	1-Oct

Source: Field work, 2012/2013

Table 4.4: The Onset and Cessation Dates at Potiskum (1981-2010)

Years	Onset dates	Cessation dates
1981	5-May	6-Oct
1982	20-Jun	6-Oct
1983	31-Jul	6-Oct
1984	5-Jul	6-Oct
1985	20-Jun	16-Oct
1986	10-Jun	1-Oct
1987	10-Jun	1-Oct
1988	25-Jun	26-Sep
1989	10-May	11-Oct
1990	30-Jun	6-Oct
1991	15-May	1-Oct
1992	25-Jun	21-Sep
1993	25-May	26-Jul
1994	20-Jun	11-Oct
1995	25-Jun	1-Oct
1996	15-May	6-Oct
1997	25-May	11-Oct
1998	5-Jun	21-Sep
1999	25-Jun	11-Oct
2000	5-Jul	1-Oct
2001	20-Jun	1-Oct
2002	30-Jun	26-Sep
2003	31-May	11-Oct
2004	31-May	26-Sep
2005	10-Jun	16-Oct
2006	10-Jun	21-Oct
2007	5-Jun	26-Aug
2008	20-May	16-Oct
2009	15-Jun	21-Oct
2010	25-Jun	21-Oct

Source: Field work, 2012/2013

Table 4.5 The Onset and Cessation Dates at Sokoto (1981-2010)

Years	Onset dates	Cessation dates

1981	26-May	26-Oct
1982	20-Jun	6-Oct
1983	15-Jun	16-Sep
1984	26-May	26-Aug
1985	20-Jun	21-Sep
1986	25-Jun	21-Sep
1987	5-Jun	26-Oct
1988	10-Jun	21-Sep
1989	15-Jun	1-Oct
1990	15-Jun	11-Sep
1991	15-May	21-Sep
1992	15-Jun	11-Sep
1993	25-May	21-Sep
1994	15-Jun	16-Sep
1995	10-Jun	21-Sep
1996	20-Jun	11-Sep
1997	15-May	21-Oct
1998	20-Jun	16-Sep
1999	20-Jun	26-Sep
2000	5-Jun	21-Oct
2001	31-May	26-Sep
2002	31-May	21-Sep
2003	5-May	11-Oct
2004	15-May	26-Sep
2005	5-Jun	1-Oct
2006	10-Jun	1-Oct
2007	5-Jun	11-Oct
2008	20-Jun	1-Oct
2009	25-Jun	6-Oct
2010	31-May	26-Oct

Source: Field work,2012/2013

Table 4.6: The Onset and Cessation Dates at Gusau (1981-2010)

Years	Onset date	Cessation date
1981	31-May	26-Sep

1982	25-May	6-Oct
1983	15-Jun	16-Sep
1984	5-May	26-Sep
1985	20-May	26-Sep
1986	15-May	26-Aug
1987	31-May	26-Aug
1988	25-May	26-Aug
1989	25-May	16-Sep
1990	25-May	21-Sep
1991	10-May	1-Oct
1992	15-May	11-Oct
1993	25-May	26-Sep
1994	5-Jun	26-Oct
1995	10-May	6-Oct
1996	25-May	11-Oct
1997	5-Jul	21-Oct
1998	10-Jul	1-Oct
1999	5-Jun	26-Jul
2000	10-May	6-Oct
2001	15-May	6-Oct
2002	10-Jun	16-Oct
2003	31-May	11-Oct
2004	15-May	26-Sep
2005	15-Jun	1-Oct
2006	20-Jun	11-Oct
2007	5-Jun	16-Oct
2008	31-May	11-Sep
2009	10-May	26-Oct
2010	5-May	26-Oct

Source: Field work, 2012/2013

4.2Length of Growing Season

Length of growing season (LGS) in days for each of the six respective locations were

determined and presented in Tables 4.7 to 4.12. It could be observed that the mean of this rainfall parameter vary among the locations. In Table 4.7(Kano station) the mean length of growing season was 133 days. At Katsina (Table 4.8) the mean length of growing season was 121 days. In Maiduguri station(Table 4.9) the mean length of growing season was 120 days. From Table 4.10(Potiskum station) the mean length of growing was 121 days. At Sokoto (Table 5.11) the mean length of growing season was 120 days. At Gusau (Table 4.12) the mean length of growing season was 133 days.The mean distribution of this rainfall parameter for each location in the area is presented in Fig.4.3.

Table 4.7: Length of Growing Season at Kano (1981-2010)

YEARS	LGS (Days)
1981	156
1982	141
1983	116
1984	161
1985	146
1986	110
1987	125
1988	115
1989	110
1990	90
1991	131
1992	131
1993	116
1994	85
1995	131
1996	146
1997	151
1998	156
1999	136
2000	136
2001	115
2002	131
2003	116
2004	136
2005	161
2006	141
2007	161
2008	130
2009	115
2010	181
Mean	133

Source: Field work, 2012/2013

Table 4.8: Length of Growing Season at Katsina (1981-2010)

YEARS	LGS (Days)
1981	136
1982	130
1983	101
1984	125
1985	136
1986	91
1987	120
1988	120
1989	125
1990	110
1991	146
1992	125
1993	90
1994	110
1995	105
1996	125
1997	130
1998	125
1999	105
2000	130
2001	115
2002	115
2003	141
2004	136
2005	110
2006	110
2007	130
2008	120
2009	151
2010	105
Mean	121

Source: Field work,2012/2013

Table 4.9: Length of Growing Season at Maiduguri (1981-2010)

YEARS	LGS (Days)
1981	117
1982	105
1983	146
1984	131
1985	126
1986	85
1987	110
1988	115
1989	130
1990	90
1991	101
1992	141
1993	126
1994	120
1995	105
1996	130
1997	125
1998	96
1999	125
2000	115
2001	110
2002	110
2003	145
2004	145
2005	151
2006	136
2007	115
2008	100
2009	110
2010	125
Mean	120

Source: Field work, 2012/2013

Table 4.10:Length of Growing Season at Potiskum (1981-2010)

YEARS	LGS (Days)
1981	161
1982	115
1983	76
1984	105
1985	125
1986	120
1987	125
1988	105
1989	161
1990	105
1991	146
1992	95
1993	70
1994	120
1995	110
1996	151
1997	146
1998	115
1999	115
2000	95
2001	110
2002	115
2003	141
2004	125
2005	135
2006	141
2007	90
2008	156
2009	135
2010	125
Mean	121

Source: Field work, 2012/2013

Table 4.11: Length of Growing Season at Sokoto (1981-2010)

YEARS	LGS (Days)
1981	130
1982	115
1983	100
1984	100
1985	100
1986	95
1987	151
1988	110
1989	115
1990	95
1991	135
1992	95
1993	126
1994	105
1995	105
1996	90
1997	166
1998	126
1999	105
2000	146
2001	125
2002	120
2003	146
2004	141
2005	126
2006	120
2007	135
2008	110
2009	110
2010	157
Mean	120

Source: Field work, 2012/2013

Table 4.12: Length of Growing Season at Gusau (1981-2010)

YEARS	LGS (Days)
1981	135
1982	141
1983	105
1984	151
1985	135
1986	110
1987	95
1988	130
1989	120
1990	125
1991	151
1992	157
1993	130
1994	151
1995	157
1996	146
1997	115
1998	120
1999	59
2000	157
2001	151
2002	135
2003	141
2004	141
2005	115
2006	120
2007	141
2008	110
2009	177
2010	182
Mean	133

Source: Field work, 2012/2013

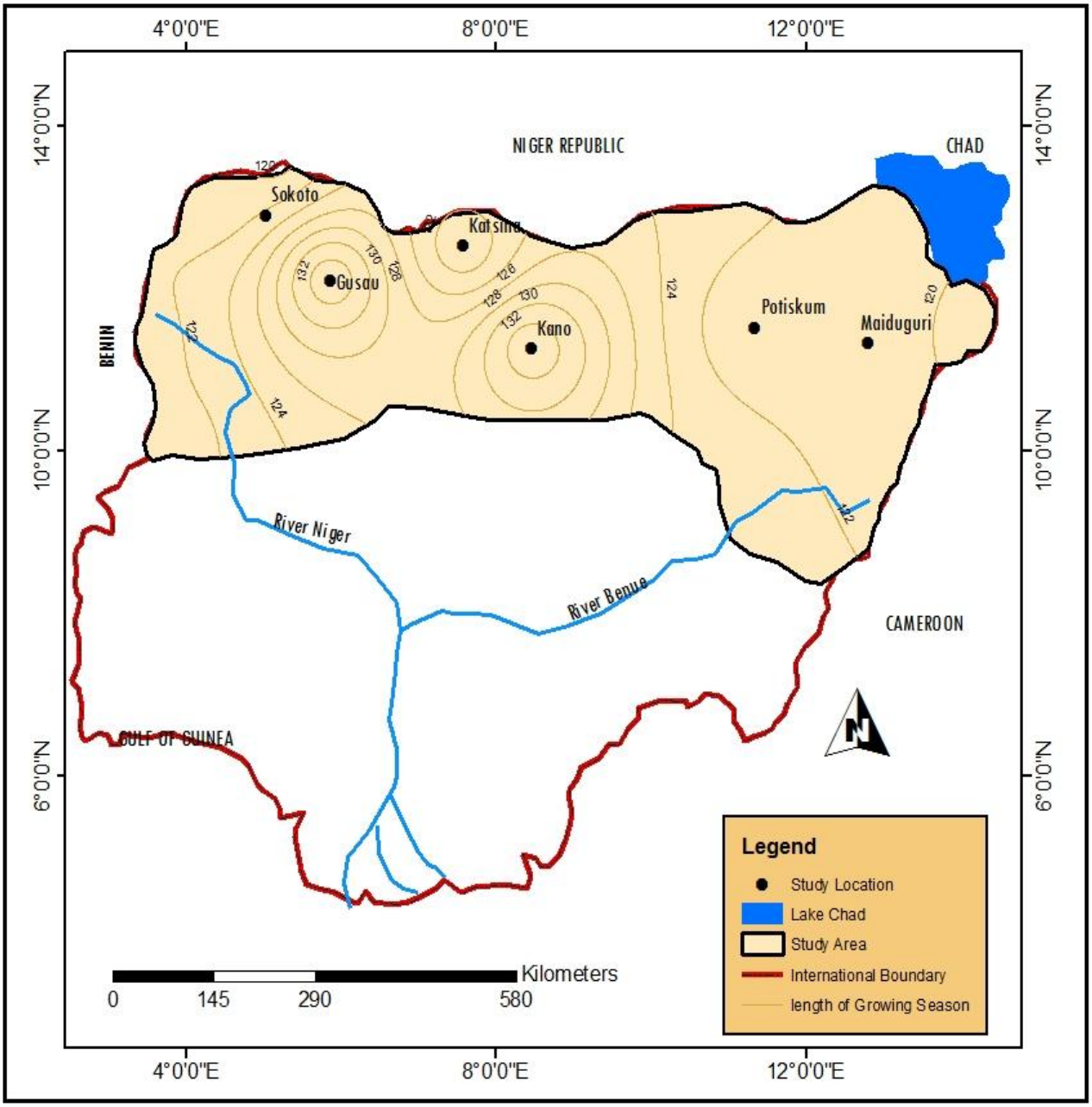

Fig.4.3 Expected Length of Growing Season in Days for the Study Area

4.3 Monthly Rainfall Amounts During Growing Season and Annual Rainfall (AR)

Monthly rainfall amounts during growing season and total annual rainfall (AR)were determined and presented in (Tables 4.13 to 4.18). From the tables, it could be observed that in the period of study (1981 to 2010) the month of May, June, July, August, September and October were the growing season months in each station. The mean rainfall of each month varies among the months of the growing season and between locations. Annual rainfall (AR) also varies among the six locations respectively. For instance, in Table 4.13 at Kano station, the mean rainfall in May was 47.397mm, June 136.0mm, July 274.1mm, August 333.56mm, September 170.1mm , October 14mm and AR 1003mm, respectively. In each location Table (4.13 to 4.18) most of the onset dates of the growing season commenced within the first two months of growing season (May or June). Similarly, most of the cessation dates of the growing season ended within the last two months of the growing season months (September or October).

The distribution of monthly rainfall in length of the growing season in the study period (1981 to 2010) for each study location is furthered illustrated using bar chart from Figs.4.4 to 4.9

Table 4.13: Monthly Rainfall (mm) of the Growing Season and Annual Rainfall (AR) at Kano (1981-2010)

Year	May	Jun.	Jul.	Aug.	Sep.	Oct	AR
1981	20.7	62.1	152.8	199.9	111.8	00	582
1982	25.7	62.3	152.9	283.8	60.5	1.3	606

1983	26.2	47.4	82.4	266.1	37	00	460
1984	42.7	114.9	198.7	53.6	118.7	17.3	547
1985	27	165.6	169.8	162.2	110.1	00	656
1986	00	135.2	258.9	157.5	105.8	4.2	676
1987	00	68.9	164.5	110.1	65.5	14.8	515
1988	00	139.2	147.1	488.5	154.1	00	1038
1989	00	32.6	142.4	382.1	84	45.3	700
1990	00	54.3	233.1	142.4	89.2	00	532
1991	104.8	148.6	287.3	455.2	26.9	00	1088
1992	122.1	45.1	191.4	324.8	205.6	0.7	927
1993	28	222.3	174.9	406.9	67.3	0.6	920
1994	00	00	146.1	325.2	156.3	00	652
1995	25.4	145	218.9	145	173.5	3.5	719
1996	12.2	143.1	253.8	392.8	235.5	4.7	1104
1997	100.6	161.4	243.9	451.4	252.1	40	1280
1998	96.6	170.1	525.4	571.8	414.1	26.6	1822
1999	44.5	101.3	527.5	466.3	223.4	5.1	1348
2000	93.5	100.2	364.2	281.8	174.4	64	1115
2001	00	231.1	604.7	521.1	205.6	00	1614
2002	00	83.6	274.9	376.6	199.9	54.1	993
2003	65.3	247.2	394	465.4	227.4	13	1424
2004	166.3	255.2	265.2	275.7	233.9	00	1206
2005	119.7	188	422	437.9	120.3	39.6	1329
2006	149.7	114.9	373.5	328.4	346	00	1313
2007	107.3	329.3	158.4	430	189.5	8.1	1280
2008	00	171.7	424.2	276.8	146.8	8.1	1039
2009	00	167.6	375.3	520.8	174.7	2.2	1266
2010	43.6	172.8	294.8	306.8	393.2	57.4	1335
Mean	47.397	136.03	274.1	333.56	170.1	14	1003

Source: Field work, 2012/2013

4.14: Monthly Rainfall (mm) of the Growing Season and Annual Rainfall (AR) at Katsina (1981-2010)

Year	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**AR**
1981	35	38.5	185	122.1	109.1	00	543.4
1982	00	102.4	129	213.8	26.1	12.3	485.8

1983	00	98.3	87.8	101.1	101.2	00	388.9
1984	00	62.3	131.4	75.4	68.1	16.1	379.8
1985	22.2	54.2	98.8	124.1	73	00	396.5
1986	00	00	314.1	183.7	64.5	00	566.1
1987	16.2	41.5	107.5	150.7	83.4	00	399.3
1988	00	120.7	103.9	188.4	203.1	00	700.8
1989	00	79.8	159.4	266.3	72.4	74.8	666.1
1990	13	57.9	197.6	246.2	34.7	00	566.3
1991	73.5	58.8	71.5	109.5	21.1	1.4	358.8
1992	31	19.9	81.4	119.4	70.7	0.2	324.8
1993	00	23.8	116.7	94.5	51.7	00	309.8
1994	12.3	42.3	109.7	174.2	106	20.3	489
1995	00	61.2	149.8	130.4	70	1	441.2
1996	22.6	44.5	38.1	78.3	67.8	00	266.5
1997	81.3	30.4	90.9	171.6	38.6	00	437.4
1998	9.1	43.4	104.5	116.6	117.2	0.8	417.6
1999	00	00	149.2	89.8	132.3	18.4	416.3
2000	00	107	300	160.2	63.1	45	676.9
2001	35	110.8	171.1	235.9	70.1	00	795.7
2002	00	86.6	170.5	147.7	197.1	62.8	722.7
2003	52.8	45.7	119.2	275	75.5	16.4	588.6
2004	74.9	151.2	151.1	284.5	42	00	704.1
2005	00	85.7	173.7	215.5	170.5	00	688.8
2006	00	48.9	62.3	255.8	144.7	00	558.2
2007	41.5	135.2	128.3	317.4	45.5	00	687.8
2008	00	60.7	172.8	213.9	67.7	4.2	546.8
2009	33.3	74.8	93.5	127.1	38.3	28.9	458.6
2010	00	62.6	264.5	354.6	72.6	44.6	881.4
Mean	18	64.97	141.1	178.2	83.27	12	528.8

Source: Field work, 2012/2013

Table 4.15: Monthly Rainfall (mm) of the Growing Season and Annual Rainfall (AR) at Maiduguri (1981-2010)

Year	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**AR**
1981	56.7	59.7	202.5	70	17.3	0.9	435.4
1982	00	26.1	139.6	67.8	1.6	00	237.4

1983	00	37.1	80.8	92.7	57.8	3.7	273.7
1984	25.9	38.9	120.1	111	16.8	00	407.4
1985	35.2	83.1	56.9	90	131.1	00	396.4
1986	00	23	166.8	145.2	00	00	335.4
1987	00	32	106.7	174.2	19.3	4.8	355.5
1988	00	85.3	181.9	192.8	146.5	00	623.5
1989	00	90.2	117	220.1	104.5	38.4	610.3
1990	00	35.8	193.7	137.7	39.7	01	436.5
1991	61.7	106.9	90.3	212.6	0.3	2.6	503.9
1992	33.8	40.5	113.3	296.4	61.9	14.7	584.2
1993	59.9	19.8	214	149.8	49.5	00	500.7
1994	00	38.2	61.3	168.4	00	22.6	317.1
1995	00	39.3	54.6	175.5	42	3.2	338.9
1996	00	50.3	195.8	176.3	137.4	24.1	630.5
1997	00	142.8	00	00	00	20.6	178.9
1998	18.2	59.8	179	266.5	00	1.2	542.7
1999	00	25.9	262.7	196.5	207.8	31.5	748.6
2000	00	112.1	201.4	253.6	61.9	32.4	676.4
2001	00	116.9	110.1	238.7	216.8	00	719.6
2002	00	31.4	111.4	179.6	125.8	26.4	496.1
2003	00	89.2	201.1	251.1	79	14.7	646
2004	53.9	69.5	124.9	307.3	41.7	11.8	616.1
2005	47.2	108.4	219.9	277.1	100.8	67.4	877.3
2006	25.9	73.9	147.7	156.9	83.5	34.2	535.1
2007	00	371.2	251	176	163.5	00	995.3
2008	00	69.3	14.8	256.9	66.9	00	584.7
2009	00	00	157.4	182.7	210.9	81.7	578.8
2010	00	138.8	257.7	96.9	141	25.4	666.2
Mean	13.95	73.85	144.48	177.33	77.51	15.44	528.29

Source: Field work, 2012/2013

Table 4.16: MonthlyRainfall (mm) of the Growing Season and Annual Rainfall (AR) at Potiskum (1981-2010)

Year	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**AR**
1981	72.4	144	161.4	202.9	65.5	17.4	676.9
1982	00	26.6	125.9	235.2	76	51.3	553.4

1983	00	00	41	213.5	161	10.3	439
1984	00	00	106	138.6	131.4	10.5	419.4
1985	00	65.1	160	204.2	67.2	15.8	536.8
1986	00	90.8	362	177.9	140.6	25	829.9
1987	00	70.6	122.9	154.6	00	13.3	368.5
1988	00	39.1	247.7	534.4	98.6	00	965.5
1989	57	47	254.2	171.7	129.4	51.3	738
1990	00	21.1	181.8	68.7	19.3	78	385.8
1991	145.2	98.7	122.2	220.9	00	27.6	685.1
1992	00	18	162.8	200.4	181.6	00	622.3
1993	20.5	103.3	203.2	00	00	00	269.5
1994	00	54.9	183.1	265.8	197.1	45.1	771.4
1995	00	50.4	256.5	115	164.6	10.6	642.8
1996	17	141.2	135.2	247.7	123	27	715.3
1997	23.5	194.9	187.1	127.1	00	28.2	614.3
1998	00	130.8	145.8	132.9	64.8	00	482.3
1999	00	24.9	308.5	273.8	84.1	40.2	747.7
2000	00	00	219.3	340.4	151.1	6.8	811.7
2001	00	89.3	255.6	366.4	00	22	774.6
2002	00	41.3	223.7	125.6	251.6	00	634.8
2003	63.3	84.2	192.2	188.8	150.1	16.8	703
2004	10.8	66.7	167.2	186.4	118.1	1.6	586.3
2005	00	126.7	82.4	285.2	57.6	102.2	641.5
2006	00	60.7	253.5	151.8	70.5	78.5	641.3
2007	00	104.1	114.5	328.1	00	00	563.9
2008	19.8	38.3	234.1	268.1	66.3	16.7	685.5
2009	00	36.5	193	150.9	158.5	52.3	667.5
2010	00	12.7	147.2	302.3	132.5	32.5	654.4
Mean	14.81	66.06	185	212.64	95.35	26.03	627.61

Source: Field work, 2012/2013

Table 4.17: Monthly Rainfall (mm) of the Growing Season and Annual Rainfall (AR) at Sokoto (1981-2012)

Year	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**AR**
1981	54	54.3	208.4	133.4	74.2	00	554.9
1982	00	15.1	169.1	263.3	18.3	1.3	525.1

1983	00	154.5	229.7	137.9	63.2	00	629.3
1984	11.8	94.7	00	125.4	00	00	248.1
1985	00	95.2	96.7	143.3	71.2	00	434.5
1986	00	36.4	151.3	139.2	124.4	00	475.8
1987	00	49.1	56.5	130.5	13.6	77	363
1988	00	105.7	168.3	227.9	187	00	701.1
1989	00	148.5	126.2	117.5	60.9	16.6	517.4
1990	00	71.1	347.4	109	71.3	00	653.6
1991	140.4	121	171.6	206.3	77.8	00	749.5
1992	00	61.9	150.9	132.5	164.8	00	548.4
1993	35.5	37.9	204.7	238.2	97.8	00	640.2
1994	00	47.4	163.7	355.6	185.5	5.5	762.1
1995	00	19.7	200.5	00	92.1	00	336.8
1996	00	81.6	193.6	189.6	74.3	00	581.9
1997	68.3	152.8	112.8	148.7	92.3	16.3	649.5
1998	55.5	58.9	38.7	339.1	94.1	00	596.3
1999	00	27.2	143.8	231.4	88.3	00	573.1
2000	00	71.8	361.6	159.8	62.3	48.6	750.6
2001	42.4	36.8	360.8	142.1	107.2	00	731.5
2002	39.1	76.9	174.3	221.1	107.1	00	631.8
2003	12.4	67.4	230.6	184.1	179.2	43.3	768.7
2004	96.4	87.5	134.1	268.4	46.4	00	662.9
2005	00	82.5	139.2	171.2	124.3	8.5	606
2006	00	40.6	153.7	314.6	187.3	30.7	706.1
2007	00	71.3	287.8	288.7	98.2	7.4	779.2
2008	00	85.4	152.2	130.2	93.9	1.6	514.6
2009	00	40	112.1	222	133.5	9.3	567.6
2010	20	39.9	251.3	274.7	200.9	99.5	975.1
Mean	19.19	71.10	176.39	191.52	99.71	12	607.82

Source: Field work, 2012/2013

Table 4.18: Monthly Rainfall (mm) of the Growing Season and Annual Rainfall (AR) at Gusau (1981-2010)

Year	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**AR**
1981	77.2	75.2	180.9	241.4	156.4	10.9	759.9
1982	69.8	119.9	187.2	200.3	0	26.2	636

1983	00	106.8	168.5	287.2	160.7	00	777.9
1984	85.2	104.6	132.5	93.2	249.8	00	667.8
1985	95.6	104.4	161.5	316.8	140.8	00	857.5
1986	45.1	119.4	182.1	194.4	00	00	553.2
1987	51.9	79.5	180.8	187.4	194.4	18.7	713.8
1988	24.3	161.3	157.8	296.2	235.1	2.1	938.8
1989	28.6	179.1	149.3	286.6	64.8	00	715.4
1990	34.4	118.8	268.9	173.5	78.4	00	715.4
1991	159.6	149.7	186	263.2	97.9	12.9	916.2
1992	138.5	138.2	289.7	387.5	399.7	0.3	1354.1
1993	85.9	208.5	249.6	371.7	272.8	00	1194.5
1994	00	168	144	530.1	402.1	119.5	1492
1995	103	73.3	162.5	181.3	138.9	16.1	683.5
1996	61	100.4	181.9	320	348.5	7.6	1070
1997	00	00	166.2	322.2	62.1	40.1	670.2
1998	00	00	192	108.4	338.9	194.2	874.4
1999	00	141.2	279.9	00	00	00	439.5
2000	63.4	60.4	284	298.8	119.7	22.8	882.1
2001	57.5	144.3	91	246.4	148.6	9.7	721.9
2002	00	124.3	124.2	235.3	126.6	167.4	806.3
2003	57.3	126.4	318.2	609	226.5	63.2	1469.6
2004	125.9	129.3	239.7	177.5	71.5	00	775.1
2005	00	119.3	211.9	228.8	179.4	23	821.6
2006	00	71.2	198.7	434.4	175.4	16.7	971
2007	00	66.3	155.3	274.2	93.4	7.5	642.8
2008	33.5	119.6	196.7	334.8	49.6	00	795.7
2009	70.4	150.8	241.9	317.9	98.6	90.6	1008.9
2010	116.2	153.1	201.4	269.2	160.6	105.8	1068.4
Mean	52.81	113.8	196.14	272.92	159.7	31.84	866.45

Source: Field work, 2012/2013

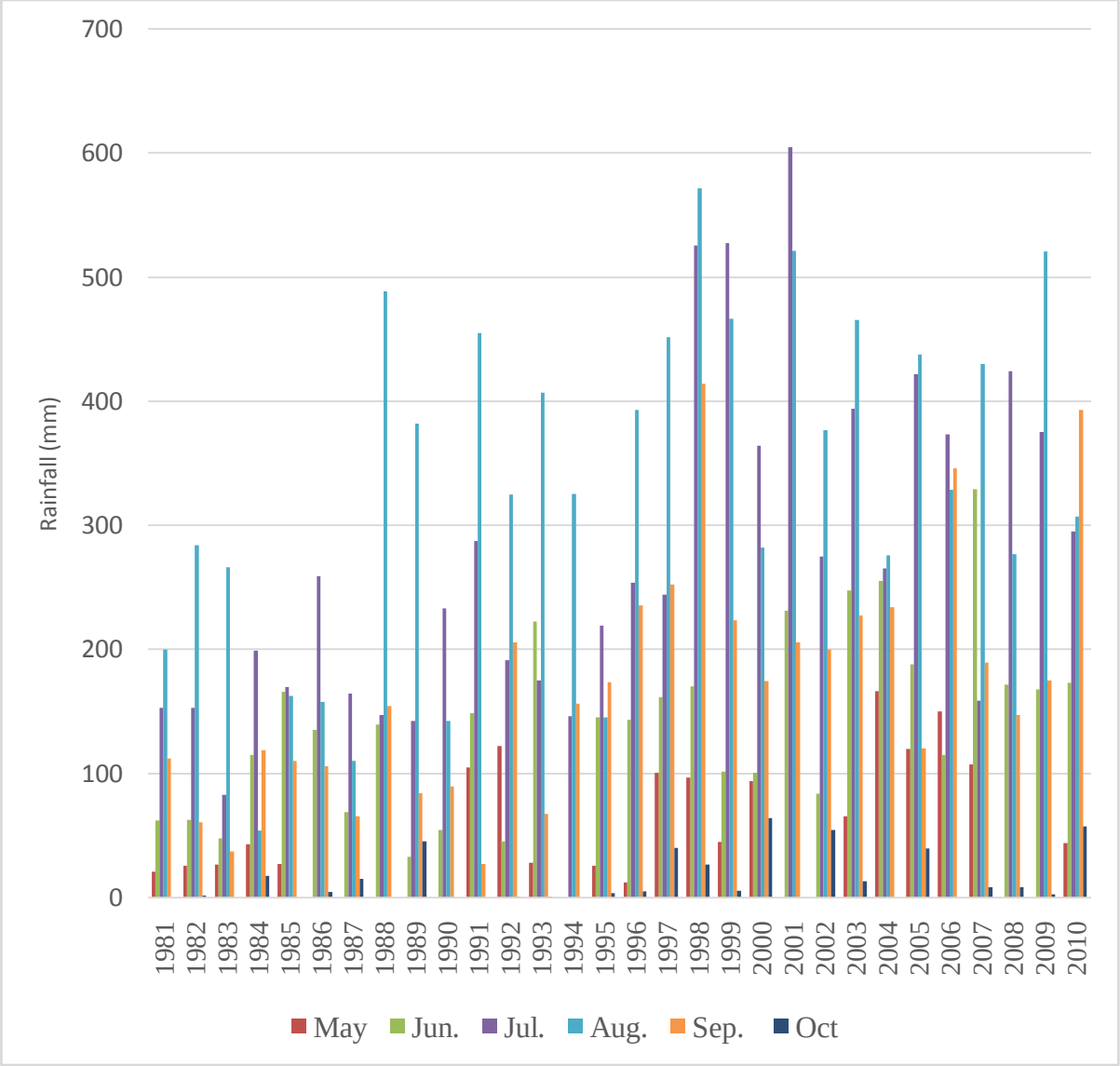

Fig.4.4: Bar Chart Showing Monthly rainfall of the growing Season at Kano (1981 -2010)

In Fig. 4.4 at Kano, it is seen that in the study period, the monthly rainfall during the growingon seas varies among the months. August recorded the highest amount of rainfall, followed by July. The highest rainfall recorded in August from 1981 to 2010 was in 2001 with 604.7mm. Number of months during the length of growing season also varies. For instance, 1981 has 5months (May – September), 1986 to 1990 5months (June to October). The least number with 3monthswas 19 94 (July to September). Years with

6months during the growing season include 1982, 1984, 1995 among others. This finding indicates general increasing pattern of monthly rainfall during the length of growing season in this location in the study period.

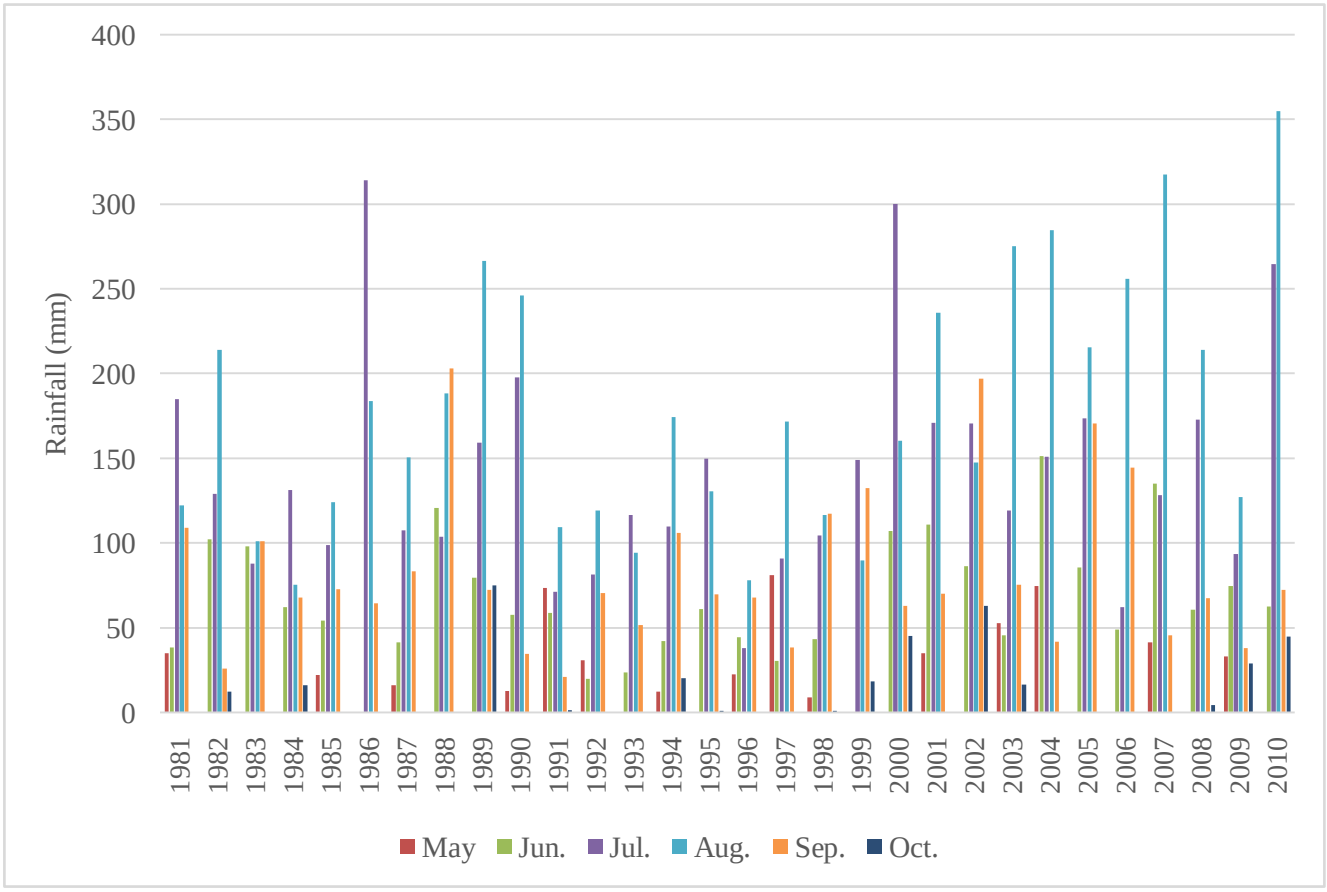

Fig.4.5: Bar Chart Showing Monthly rainfall of the growing Season at Katsina (1981 -2010)

At Katsina Fig.4.5, it could be seen the distribution of monthly rainfall during the growing indicates increasing pattern from 1981 to 1990 and decreasing from 1991 to 1999. The highest increasing pattern was from 2000 to 2010. In this location July and August were the months having highest amount of rainfall, with August being the highest in the study period. 354.6mm of rainfall was recorded in August in 2010

followed 317.4mm in 2007.

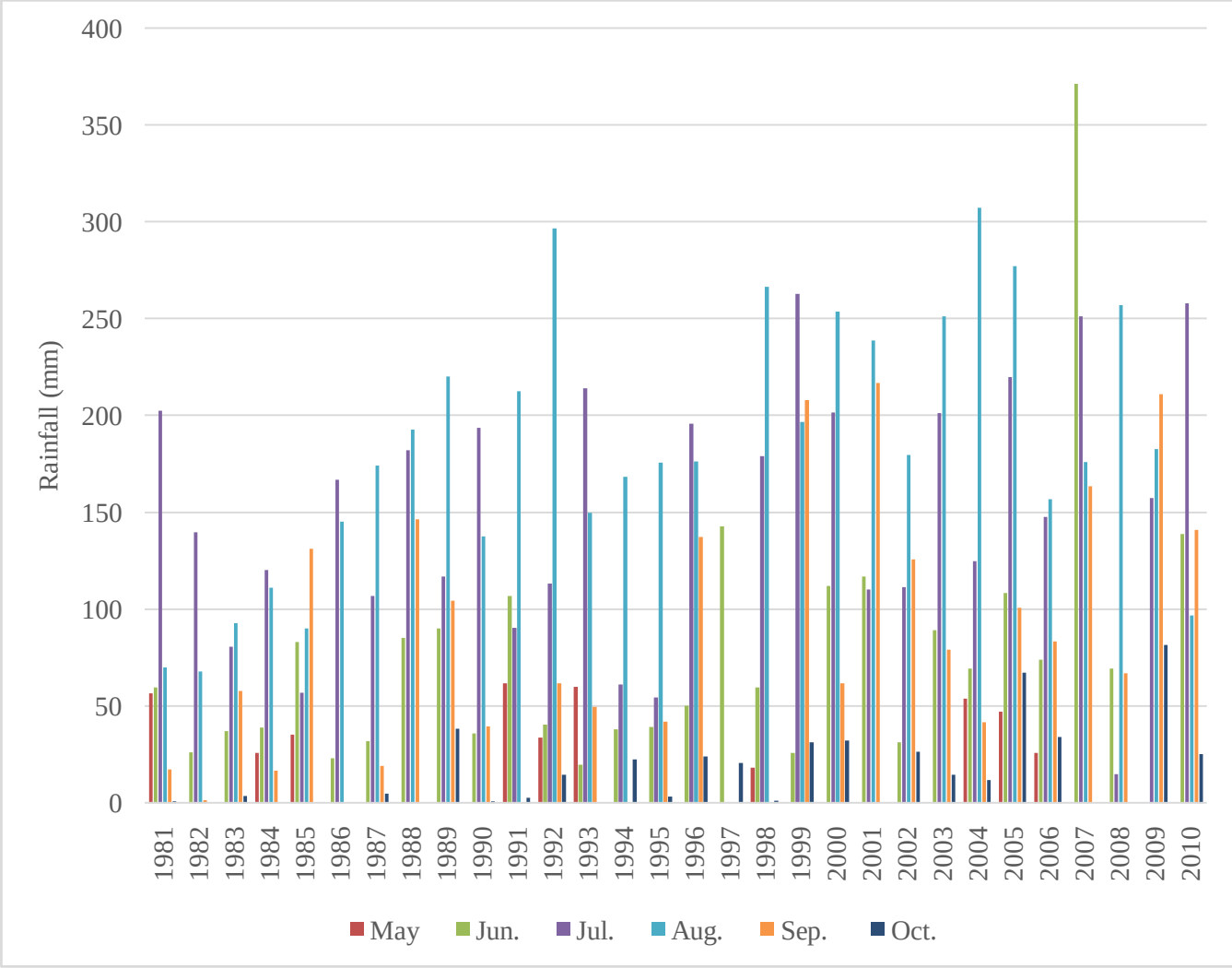

Fig.4.6: Bar Chart Showing Monthly rainfall of the growing Season at Maiduguri (1981 -2010)

In Fig. 4.6 at Maiduguri, it could be observed that the wettest months during the growing season were June and August with 371.2mm of rainfall in 2001 and 296.4mm in 1992 respectively. The pattern of monthly rainfall distribution during the growing season indicates general increasing pattern. The highest increasing pattern was from 1988 to 2007.

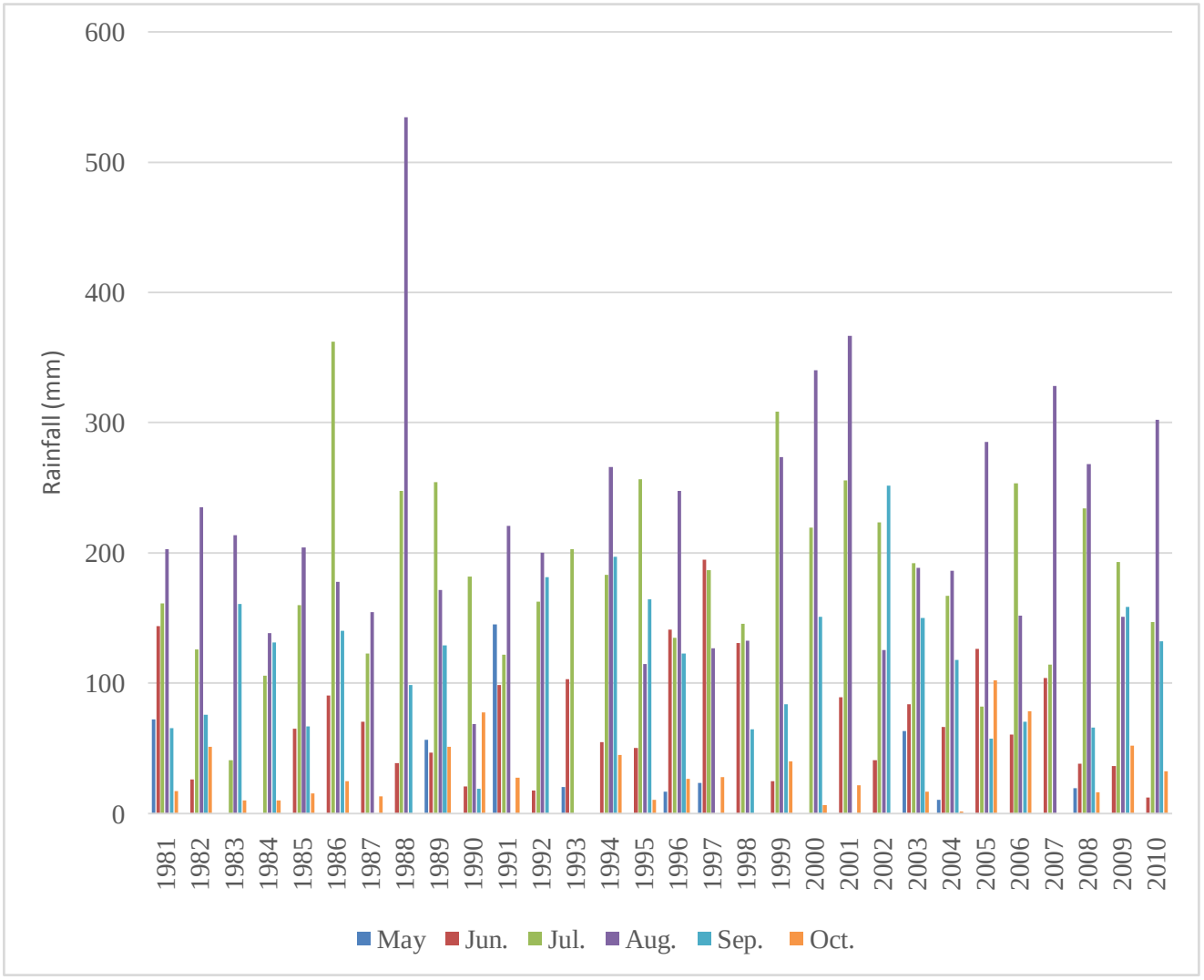

Fig.4.7: Bar Chart Showing Monthly rainfall of the growing Season at Potiskum (1981 -2010)

In Potiskum Fig. 4.7, the highest amount of rainfall was recorded in the month of August in 1988. It could be observed that months of July and August are the wettest months during the growing season. The pattern of monthly distribution indicates an increasing pattern. The zero values in the first two months (May and June) of the growing season indicate rainfall of onset dates do not fall. In the last two month (September and

October), zero values indicate rainfall of cessation dates do not fall. In comparison with the derived onset and cessation dates from Tables 4.1 to 4.6, it could be seen no onset and cessation dates recorded in these months.

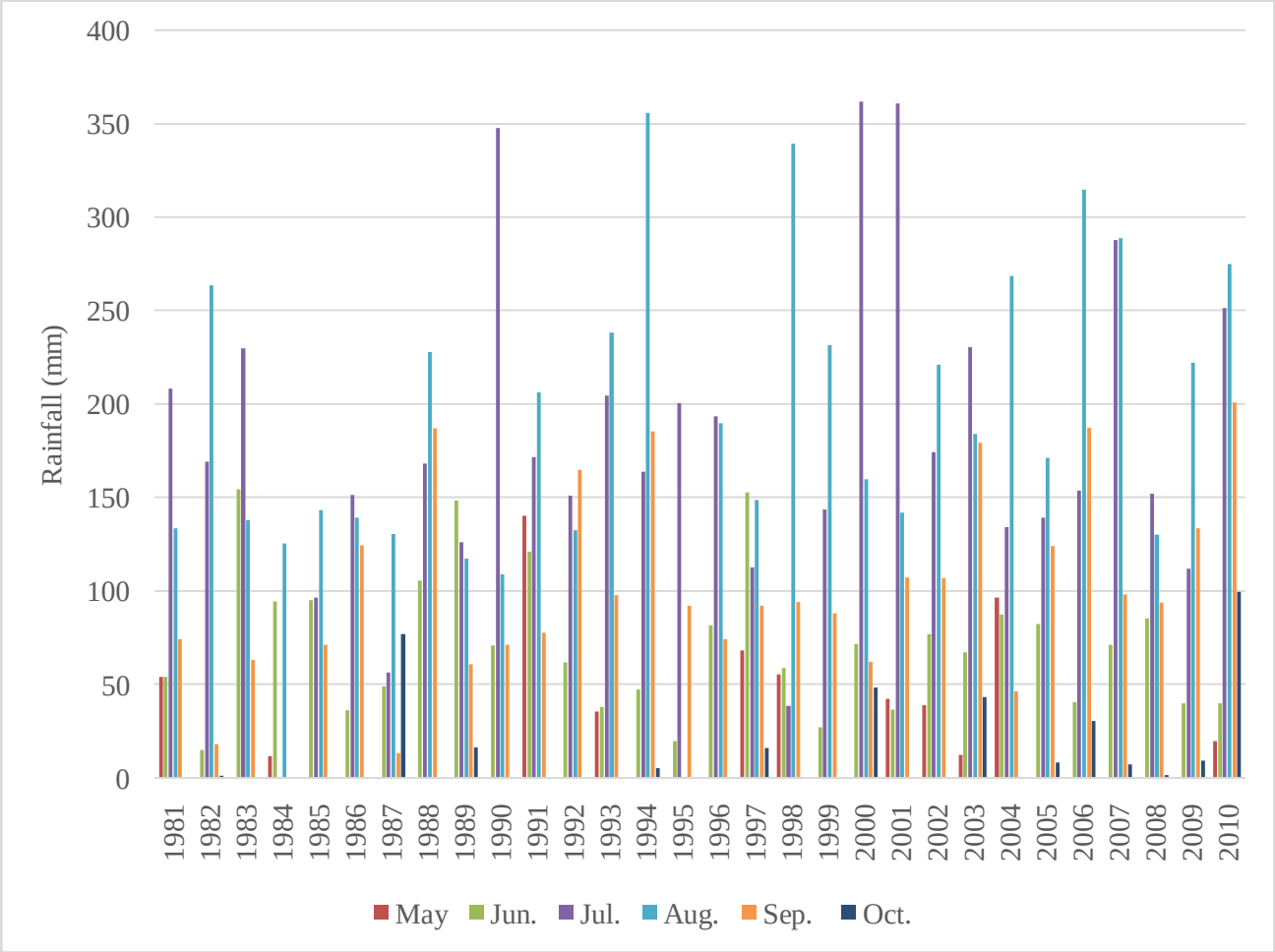

Fig.4.8: Bar Chart Showing Monthly rainfall of the growing Season at Sokoto (1981 -2010)

In Fig. 4.8 at Sokoto, in 2000 and 2001, the month of July recorded the highest amount of rainfall wiith 361.6mm and 360.8mm respectively. This finding indicates that in the study period (1981 to 2010, July was the wettest month in the location.

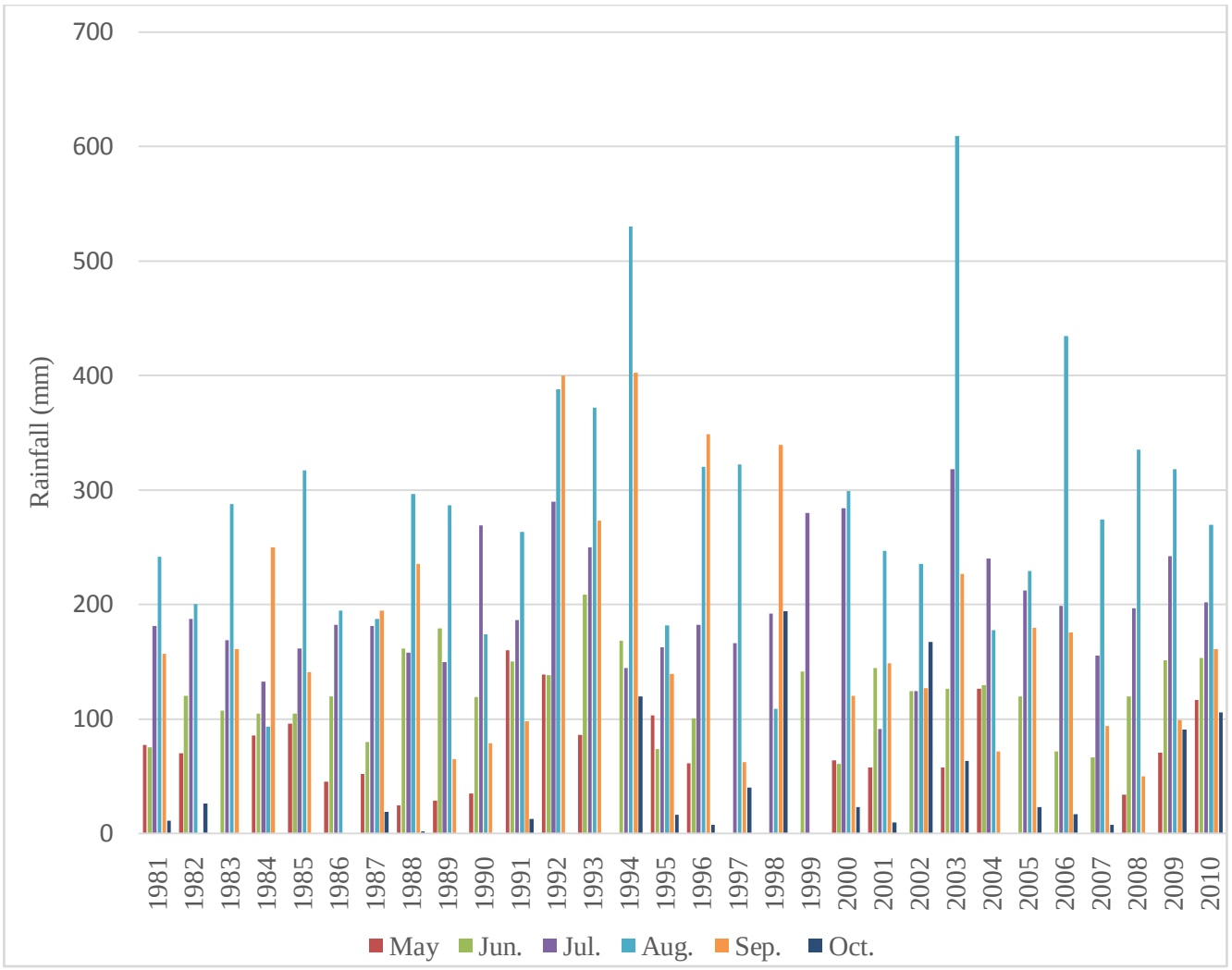

Fig.4.9: Bar Chart Showing Monthly rainfall of the growing Season at Gusau (1981 -2010)

At Gusau Fig. 4.9, it could be seen that, August is the wettest among the months of the growing season followed by July. The highest amount of 609mm of rainfall was recorded in August, 2003 and 530.1mm in1994. This finding indicates a general increasing pattern of monthly rainfall distribution in Gusau during the growing season in the study period.

4.4 Normality of Rainfall Effectiveness Parameters in the Study Area

The method after Brazel and Balling (1986) was adopted to test the normalitydistribution of the selected rainfall parameters which include onset and cessation dates, monthly rainfall, annual (AR) and length of growing season (LGS). In each location, the distribution parameters are tested for their normality using standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics. Results of the test are presented in (Tables 4. 19 to 4. 25).

Table 4. 19: Normality Test of Rainfall Parameters at Kano

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
May	.854	-.534
Jun.	.448	.166
Jul.	.901	.125
Aug.	-.278	-.805
Sep.	.897	.794
Oct.	1.436	.715
AR	.222	-.757
LGS	-.058	.043

Data Source: Field work, 2012/2013

Table 4.20: Normality Test of Rainfall Parameters at Katsina

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
MAY	1.341	.848
JUN	.442	-.087
JUL	1.189	1.546
AUG	.603	-.480
SEP	1.208	1.056
OCT	1.979	3.264
AR	.366	-.657
LGS	-.138	-.290

Data Source: Field work, 2012/203

Table 4.21: Normality Test of Rainfall Parameters at Maiduguri

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
MAY	1.232	-.042
JUN	3.119	13.045
JUL	-.193	-.602
AUG	-.282	-.197
SEP	.650	-.575
OCT	1.769	3.370
AR	.321	.271
LGS	-.013	-.573

Data Source: Field work, 2012/2013

Table 4.22: Normality Test of Rainfall Parameters at Potiskum

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
MAY	1.131	-.032
JUN	.723	.152
JUL	.384	.455
AUG	.906	2.503
SEP	.138	-.624
OCT	1.304	1.396
AR	-.362	.404
LGS	-.172	-.303

Data Source: Field work, 2012/2013

Table 4.23: Normality Test of Rainfall Parameters at Sokoto

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
MAY	.516	-.546
JUN	-.667	.937
JUL	.544	-.139
AUG	.566	1.702
SEP	.714	.018
OCT	2.028	3.413
AR	1.075	.986
LGS	-.672	1.732

Data Source: Field work, 2012/2013

Table 4.24: Normality Test of Rainfall Parameters at Gusau

Rainfall Parameters	Skewness (Z_1)	Kurtosis (Z_2)
MAY	.423	-.456
JUN	1.321	3.309
JUL	1.316	3.310
AUG	.814	.782
SEP	1.180	1.930
OCT	2.757	9.929
AR	1.207	1.854
LGS	.030	.112

Data Source: Field work, 2012/2013

It could be observed from (Tables 4. 19 to 4.25) that most values of coefficient of Skewness (Z_1) and Kurtosis (Z_2) of the observed rainfall parameters in each location lie within the limits of normal distribution. At 95% significant level the values of Z_1 and Z_2 are less than 1.95 except few cases in some locations. For instance, at Katsina (Table 4. 20) only values of Z_1 and Z_2 for October is greater than 1.95. In Maiduguri (Table 4.21) few values of Z_1 and Z_2 for June rainfall and Z_2 for October are greater than 1.95. These findings indicate that the rainfall parameters observed are normality distributed in the study area. Based on these, the rainfall effectiveness parameters observed were not to be transformed to normal distribution.

4.5 Trends in Onset and Cessation Dates of Rains

In order to identify trends in onset and cessation dates of the rains, trend lines and linear trend line equations of these rainfall variables in each of six locations were drawn withthe Excel Software.

4.5.1 Trends in Onset and Cessation Dates of Rains at Kano

The combined linear trendsfor onset and cessation dates of the rains at Kano are presented in figures 4.10

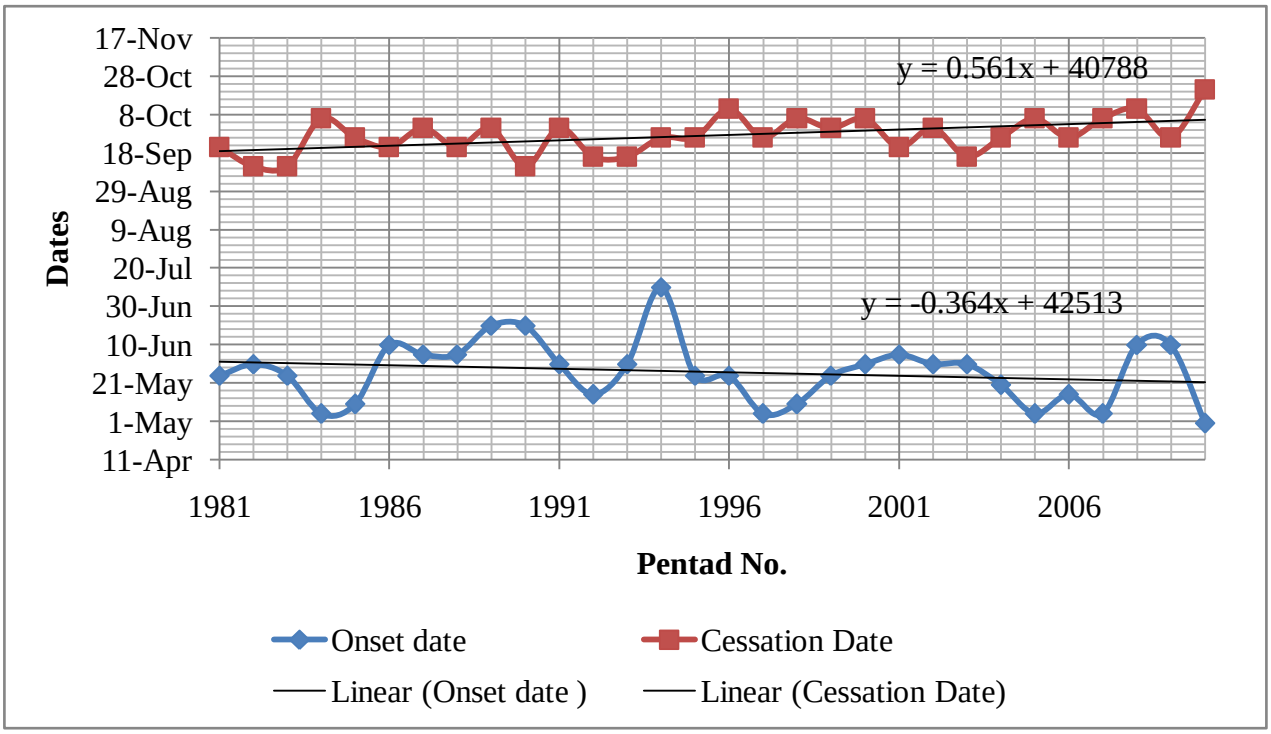

Fig: 4.10: Trend of Onset and Cessation Dates at Kano (1981-2010)

It could be observed from fig.4.10that the trend line of onset dates of rains indicates decreasing trend and cessation dates increasing at Kano. Onset date trend line equation is given as Y = -0.3646x + 42513 and cessation date is Y = 0.5617x + 40788. The perpendicular distance between each onset point to cessation on the two graphs indicates the length of growing season. It this seen that the longest length of growing at Kano from 1981 to 2010 was in 2010 and the shortest was in 1994. These findings indicate that onset date of rains at Kano is commencing earlier and cessation date of rains is occurring later. This implies trends in the onset and cessation dates of rains are increasing at Kano. These findings are further supported by the higher frequency in the occurrence of onset

dates in the month of May and higher frequency of occurring of cessation dates in the month of September at Kano (Table 4.10).

4.5.2 Trends in Onset and Cessation Dates of Rains At Katsina

The combinedtrends of onset and cessation dates of rains at Katsina were determined and presented in Figs.4.11

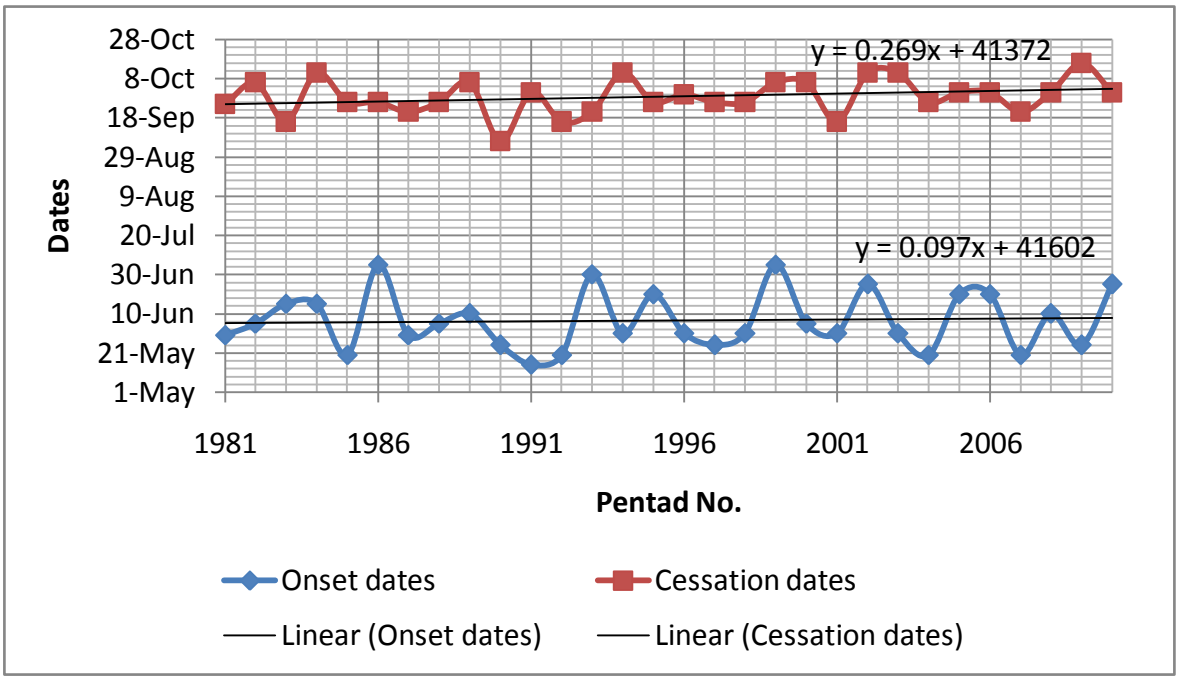

Fig. 4.11: Trend of Onset and Cessation Dates at Katsina (1981-2010)

In fig. 4.11 the trendline and linear trend line equations of onset and cessation dates of rains at Katsina are in positive direction, which indicate late onset and late cessation. They are presented by the equations Y = 0.0977x + 41602 and Y = 0.2699x + 41372 respectively. It could be seen that the longest length of growing season was in 2009 and the shortest in 1993. These findings indicate Katsina is experiencing later onset dates and later cessation dates of rains.

4.5.3 Trends in Onset and Cessation Dates of Rains at Maiduguri

Trends in onset and cessation dates of rains at Maiduguri are presented in figure 4.12. The trends line equation of onset dates rains is Y = 0.2928x + 4121, and that of cessation dates is Y = 0.7335x + 40446. The longest length of growing between the onset and cessation graphs was in 2005 and the shortest was in 1986. This finding is supported by the results of Table 4.9. These equations indicate increasing trends. These indicate that Maiduguri is experiencing later onset and cessation dates of rains.

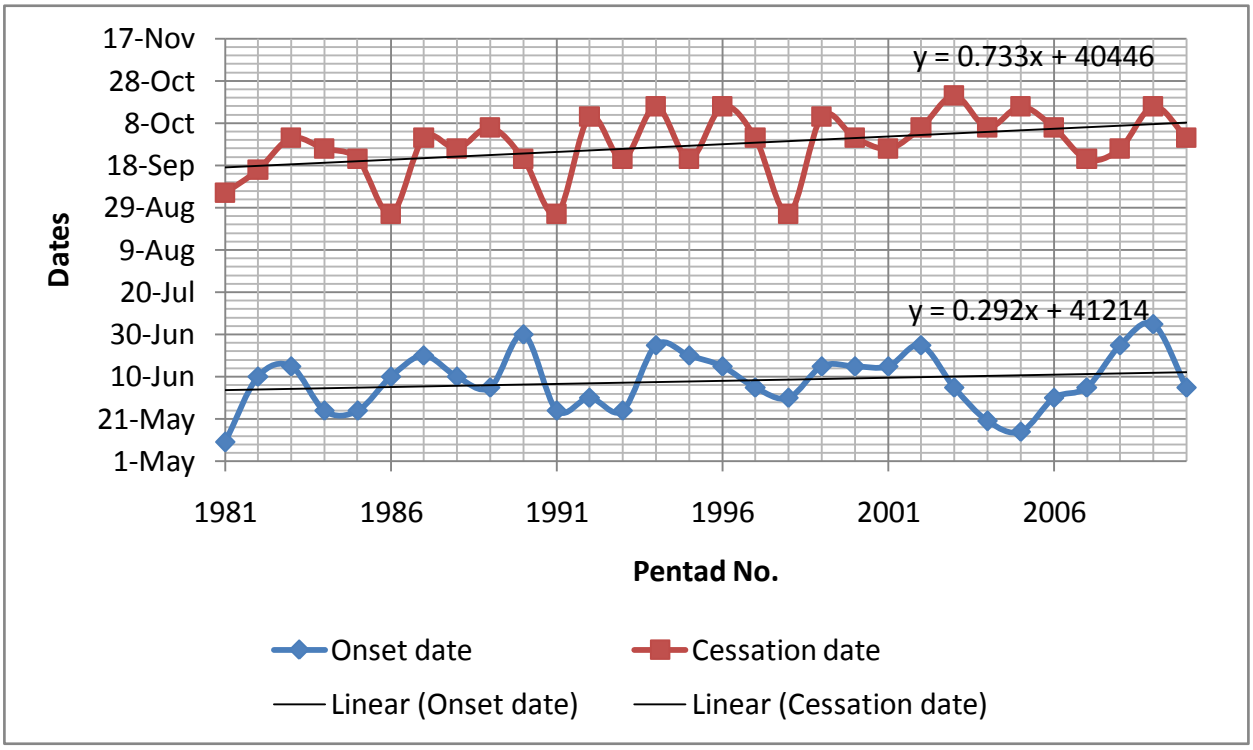

Fig. 4.12: Trends of Onset and Cessation Dates at Maiduguri (1981-2010)

4.5.4 Trends in Onset and Cessation Dates of Rains at Potiskum

Trends in onset and cessation dates at Potiskum are presented in figure 4.13. The trend line equations of the two variables are negatives. The trend line equation of onset of rains is Y = - 0. 212x +4225, and cessation dates of rains was Y = 0.1907x + 41534.

These equations indicate decreasing trends in onset and increasing in cessation dates of rains at Potiskum. The longest length of growing season was in 1981 and shortest in1993. They are presented by 161 and 70 days respectively in Table 4.10. These findings indicate that onset dates of growing season at Potiskum are commencing earlier and cessation dates later

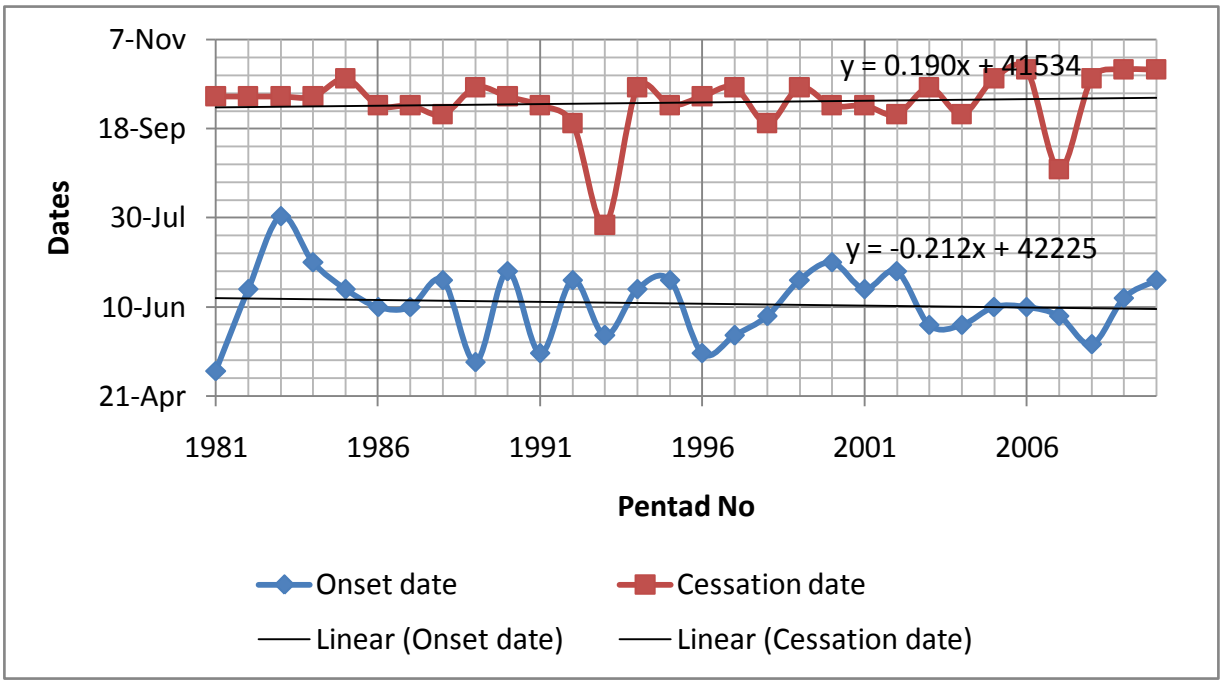

Fig. 4.13: Trend of Onset and Cessation Dates at Potiskum (1981-2010)

4.5.5Trends in Onset and Cessation Date of Rains at Sokoto

The trends in onset and cessation dates of rains at Sokoto are presented in figs. 4.14

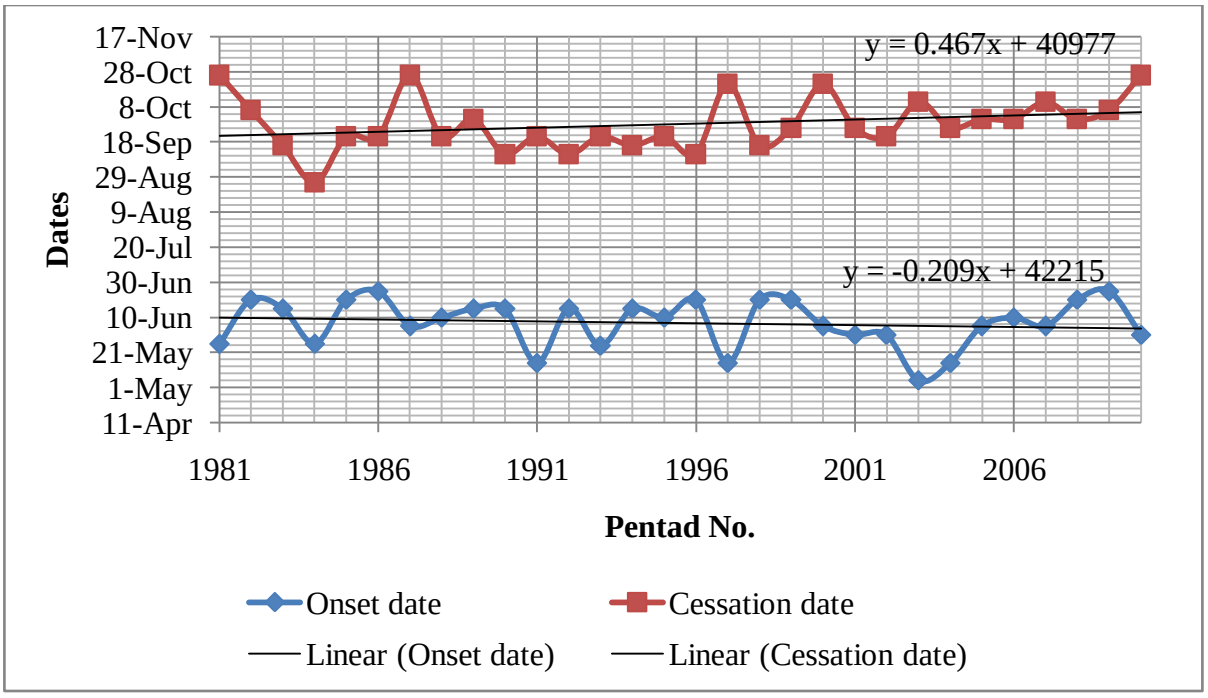

Fig.4.14: Trend of Onset and Cessation Dates Rains at Sokoto (1981-2010)

From fig. 4.14 it is seen that the line equation of onset dates of rains at Sokoto is Y = -0.2093x + 42215 and for cessation dates of rains is Y = 0.4679x + 40977. This indicates decreasing trends (earlier onset) in the onset date of rains and increasing (later) in the cessation dates of rains at Sokoto. The longest length of growing season was in 1997 with 166 days and the shortest in 1996 with 90 days (Table 4.11). These findings indicate earlier occurring of onset and late cessation dates of rains at Sokoto.

4.5.6: Trends in Onset and Cessation Dates of Rains at Gusau

The trends in onset and cessation dates of rains at Gusau are determined and presented in Figs. 4.15

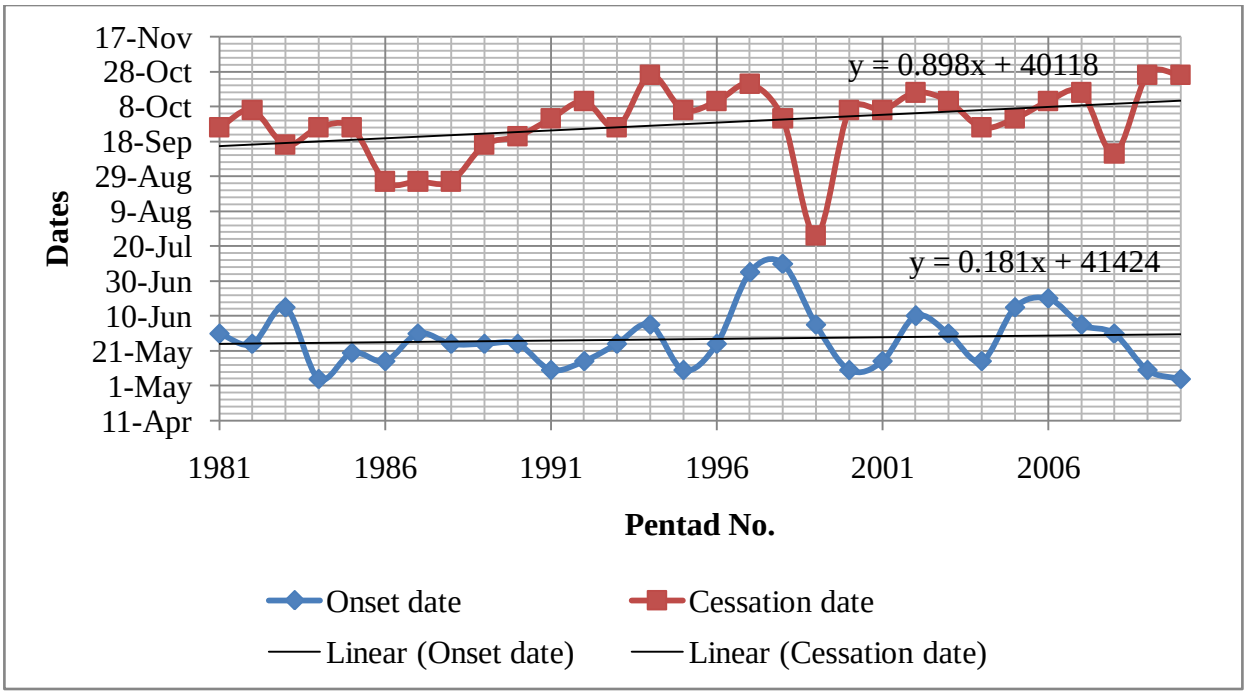

Fig. 4.15: Trend of Onset and Cessation Dates of Rains at Gusau (1981-2010*)*

At Gusau in Fig. 4.15, it could be observed that the linear trend line equation of onset dates of rains (Y = 0.1818x + 41424)and cessation (Y = 0.8981x + 40118) are in positive direction. This implies that bothonset and cessation dates of rains occur later at Gusau. The longest length of growing season was in 2010 which corresponds to 182 days in Table 4.12. The shortest length of growing season was in 1999 and corresponds to 59 days (Table 4.12)

4.6 Trends in Annual Rainfall (AR) and Length of Growing Season (LGS) in the Study Area

In order to indicate whether AR and LGS are increasing or decreasing in each location during the period of study, trend lines and linear trend line equations of these rainfall parameters were also determined and presented in figures.

4.6.1 Annual Rainfall Trends at Kano

The trend line and linear trend line equation of annual rainfall at Kano are presented in fig.4.16

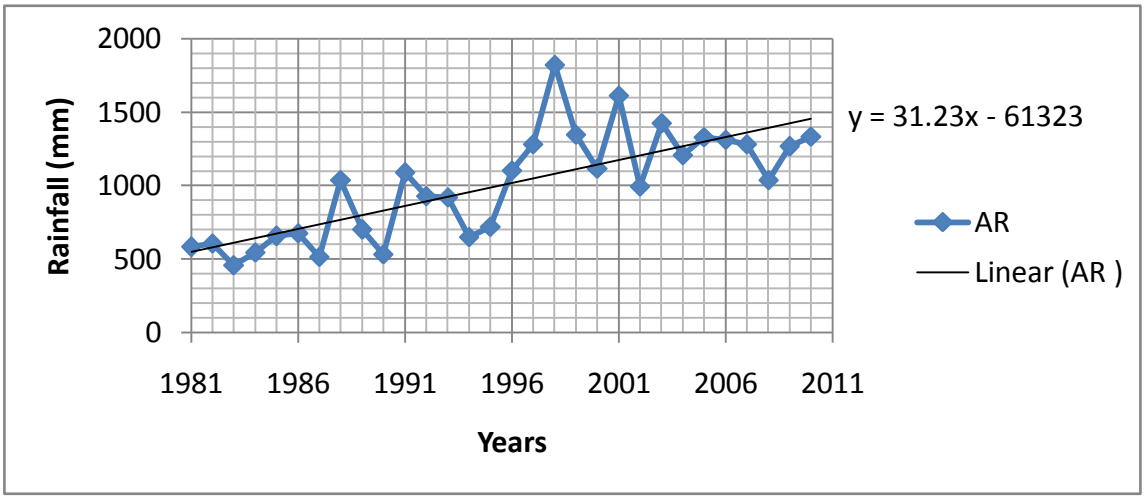

Fig. 4.16: Trend of Annual Rainfall (AR) at Kano (1981-2010)

In fig.4.16 it could be seen that the linear trend line equation of annual rainfall at Kano is positive(Y = 31.23x – 61323). This indicates increasing trend in annual rainfall.

4.6.2 Annual Rainfall Trend at Katsina

Trend line and linear trend line equation of annual rainfall at Katsina arepresented in fig.4.17

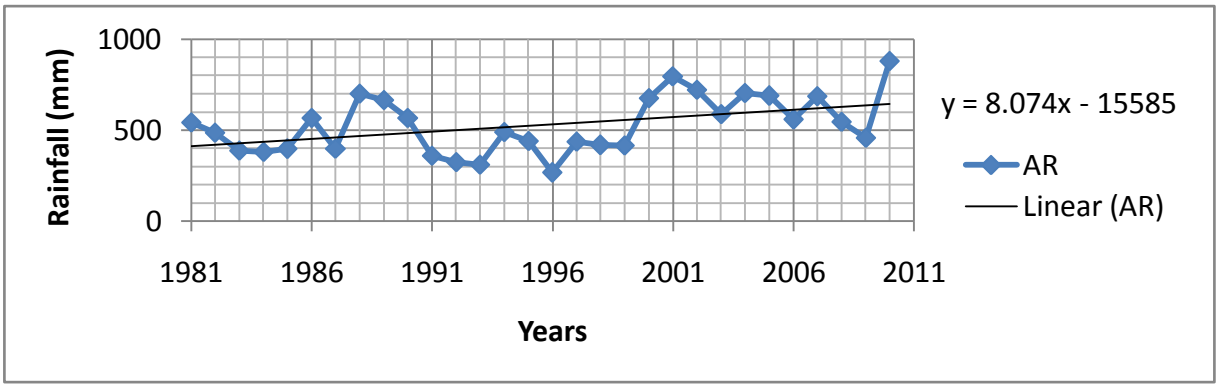

Fig. 4.17: **Trend of Annual Rainfall (AR) at Katsina (1981-2010)**

At Katsina (Fig.4.17) the linear trend line equation of annual rainfall is Y = 8.074x - 15585. This equation indicates increasing trend in annual rainfall at Katsina.

4.6.3 Annual Rainfall Trend at Maiduguri

The trend line and linear trend line equation of annual rainfall at Maiduguri are presented Fig.4.18.

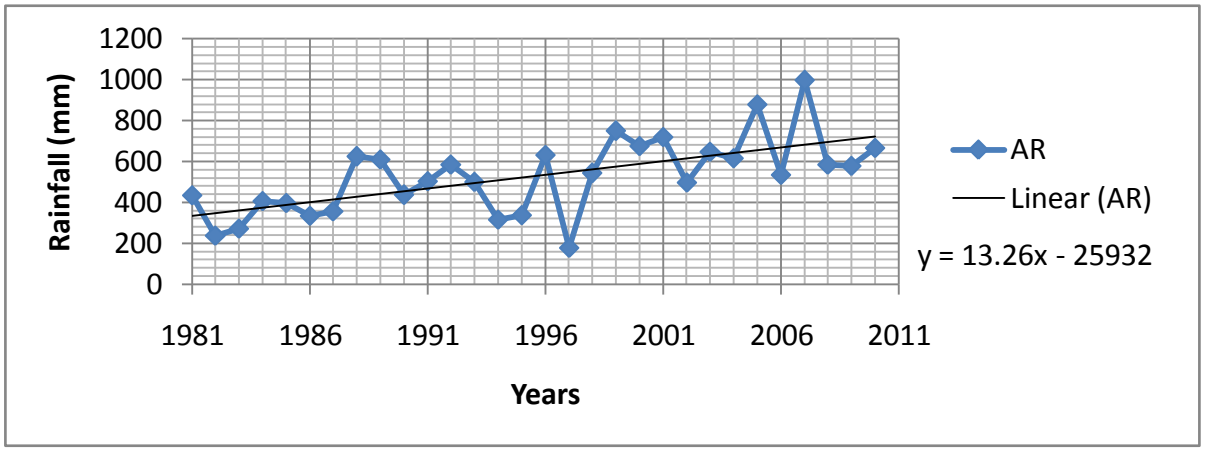

Fig. 4.18: Trend of Annual Rainfall at Maiduguri (1981-2010)

It could be observed from Fig.4.18 that the linear trend line equation of annual rainfall at Maiduguri indicates positive trend. The trend line equation is Y = 13.26x – 25932. This equation indicates that annual rainfall at Maiduguri is on the increase.

4.6.4 Annual Rainfall trend at Potiskum

The trend line and linear trend equation of annual rainfall at Potiskum are presented in Fig.4.19. The linear trend line equation is given as Y = 3.539 x – 6436 and it indicates increasing trendin annual rainfall at Potiskum..

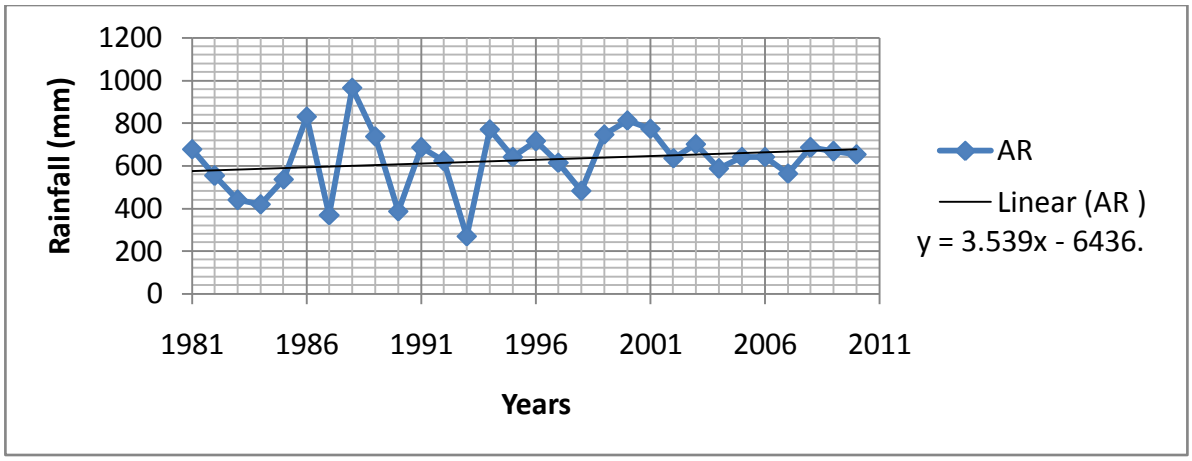

Fig 4.19: Trend of annual rainfall (AR) at Potiskum (1981-2010)

4.6.5 Annual Rainfall Trend at Sokoto

Trend in annual rainfall at Sokoto for the study period were derived and presented in fig.4.20

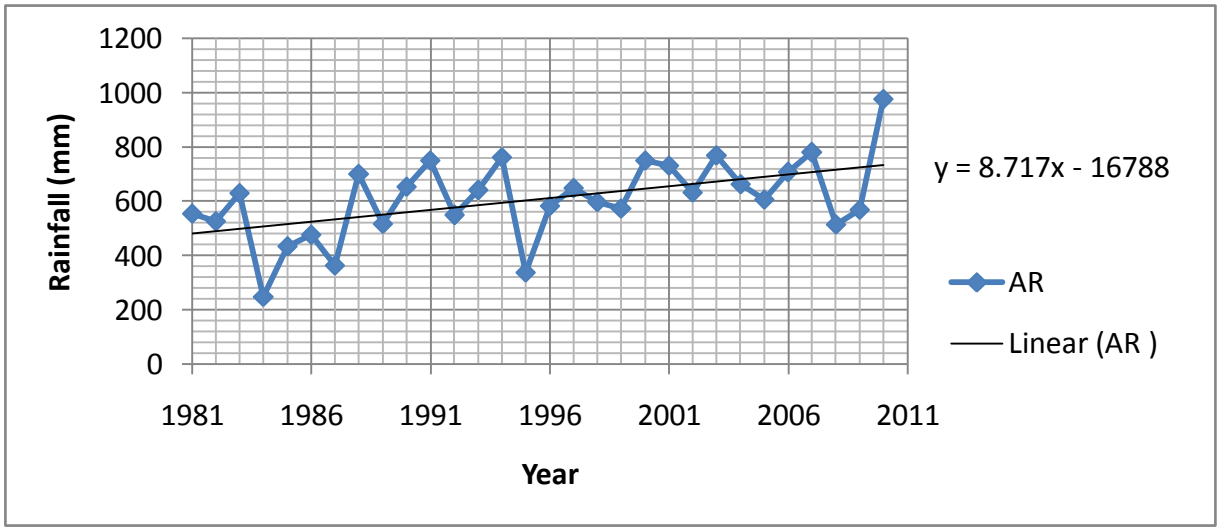

Fig.4.20: Trend of Annual Rainfall (AR) at Sokoto (1981-2010)

It could be observed from Fig.4.20 that the linear trend line equation of annual rainfall at Sokoto is Y = 8.717x – 16788 and it indicates increasing trend in annual rainfall.

4.6.6 Annual Rainfall Trends at Gusau

Trend in annual rainfall at Gusau from 1981 - 2010 is presented in Fig.4.21

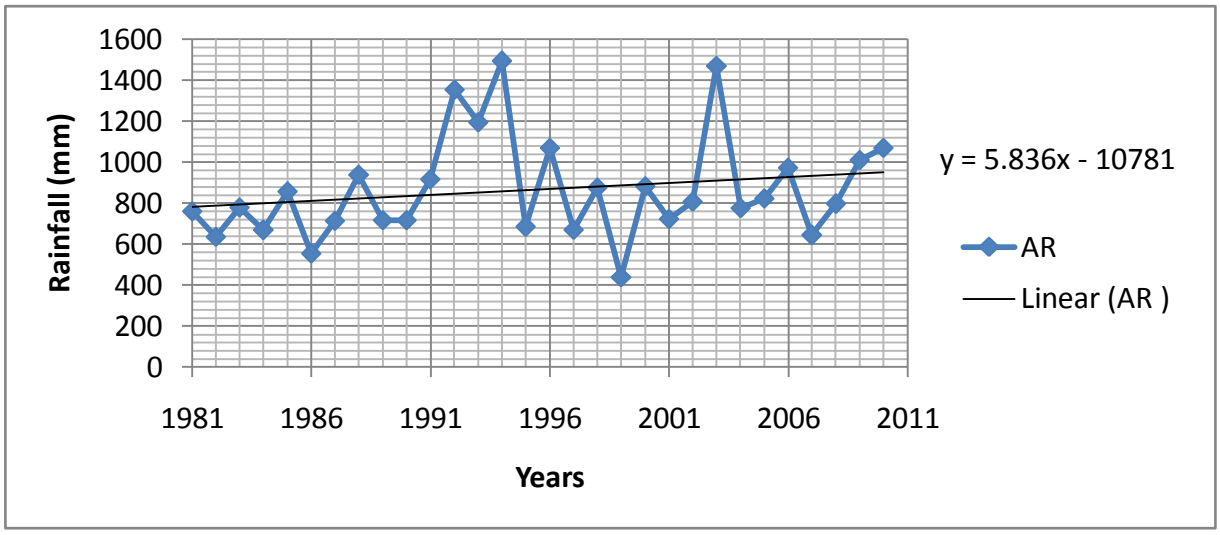

Fig.4.21: Trend of Annual Rainfall (AR) at Gusau (1981-2010)

It could be observed from Fig. 4.21 that the linear trend line equation of annual rainfall at Gusau is Y = 5.836x – 10781. This indicates increasing trend in annual rainfall at Gusau.

4.7 Trends in Length of Growing Season (LGS) in the study Area

Trends in the length of growing season (LGS) in the study area are presented in Figs. 4.22 to 4. 27

4.7.1Trends inLength of Growing Season at Kano

The trend in length of the growing season (LGS) at Kano is presented in Fig.4.22

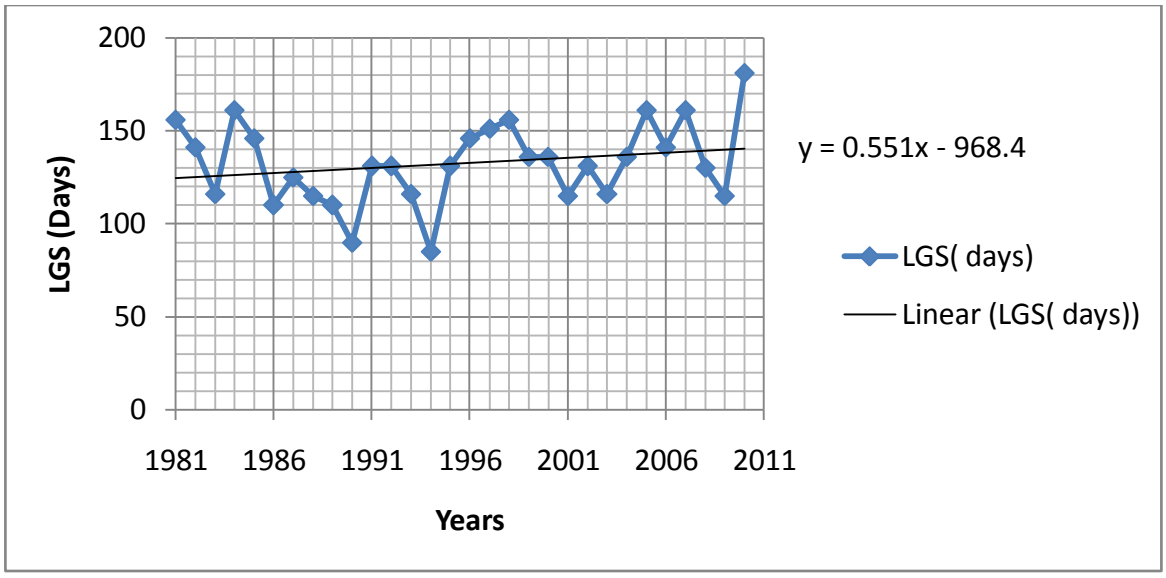

Fig.4.22: Trendin Length of Growing season in Kano (1981-2010)

Fig. 4.22 shows that the linear trend equation of length of growing season at Kano isY = 0.551x – 968.4 and It indicates an increase in the length of growing season.

4.7.2Trend in Length of Growing Season at Katsina

The line and linear trend line equation of length of growing season at Katsina is presented in Fig. 4.23. It could be observed that the slope of the linear trend line equation of length of growing season (Y = 0.127x - 134.7) at Katsina indicates positive direction. This implies increasing trend in the length of growing season.

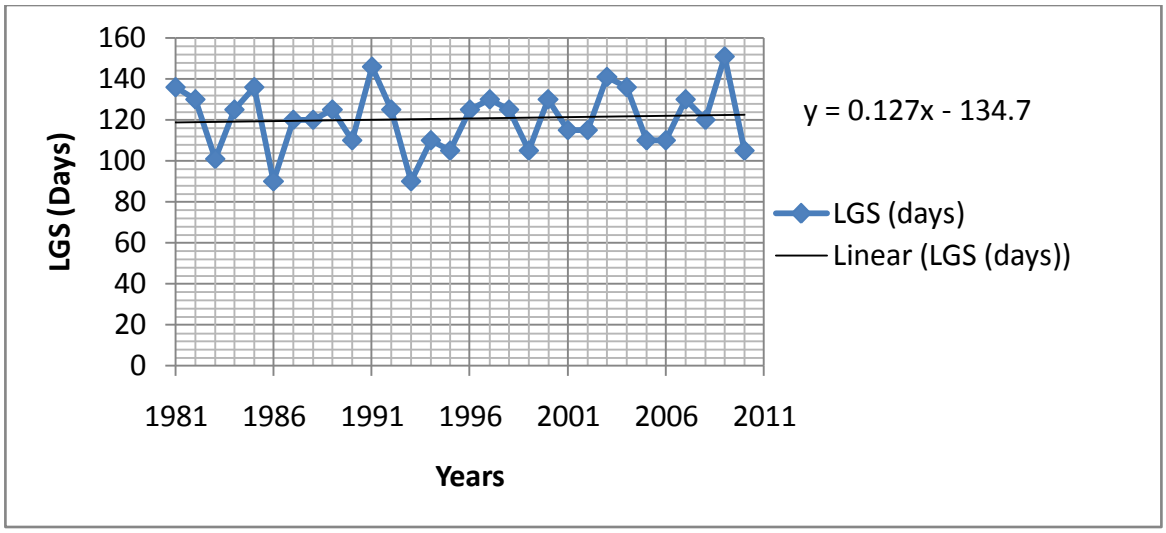

Fig.4.23: Trend in Length of Growing season at Katsina (1981-2010)

4.7.3 Trend in the Length of Growing Season at Maiduguri

The trend line and linear trend line equation of length of growing season at Maiduguri are presented in Fig.4.24.

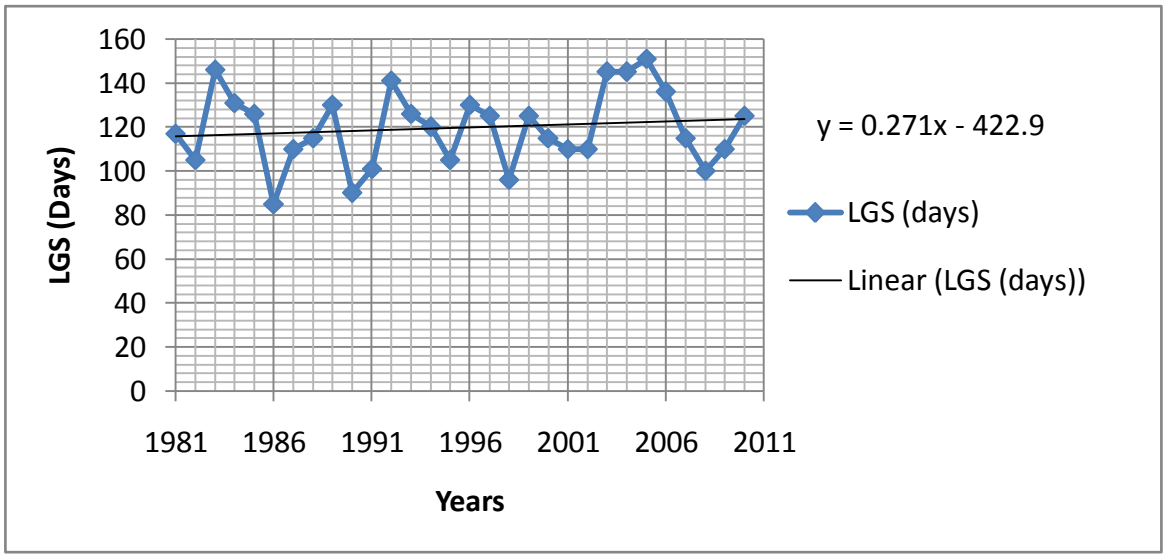

Fig.4.24: Trend in Length of Growing season at Maiduguri (1981-2010)

At Maiduguri in (Fig.4.24) it could also be observed that the linear trend line equation of the length of growing season is positive(Y = 0.271x – 422.9) and it indicates increasing trends in the length of growing season.

4.7.4 Trend in Length of Growing Season at Potiskum

Trend in the length of growing season at Potiskum is presented in Fig.4.25

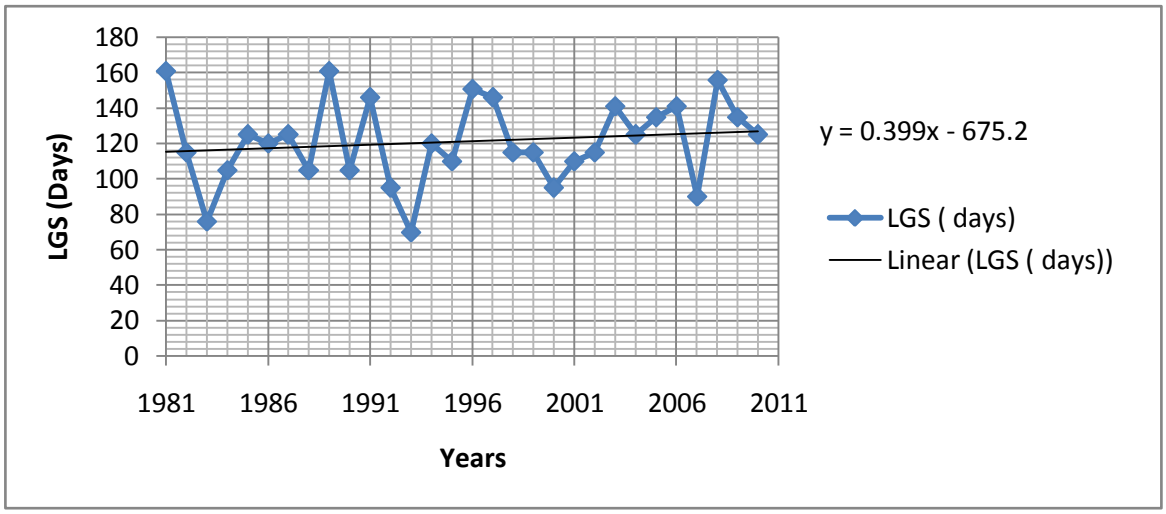

Fig.4.25: Trend in Length Growing Season at Potiskum (1981-2010)

Fig.4.25 shows that the linear trend line equation of length of growing season at Potiskum is also positive(Y = 0.3991x – 675.29) This equation indicates increasing trends in the length of growing season.

4.7.5 Trendin Length of Growing Season at Sokoto

The line and linear trend line equation of length of growing season are presented in Fig. 4.26.

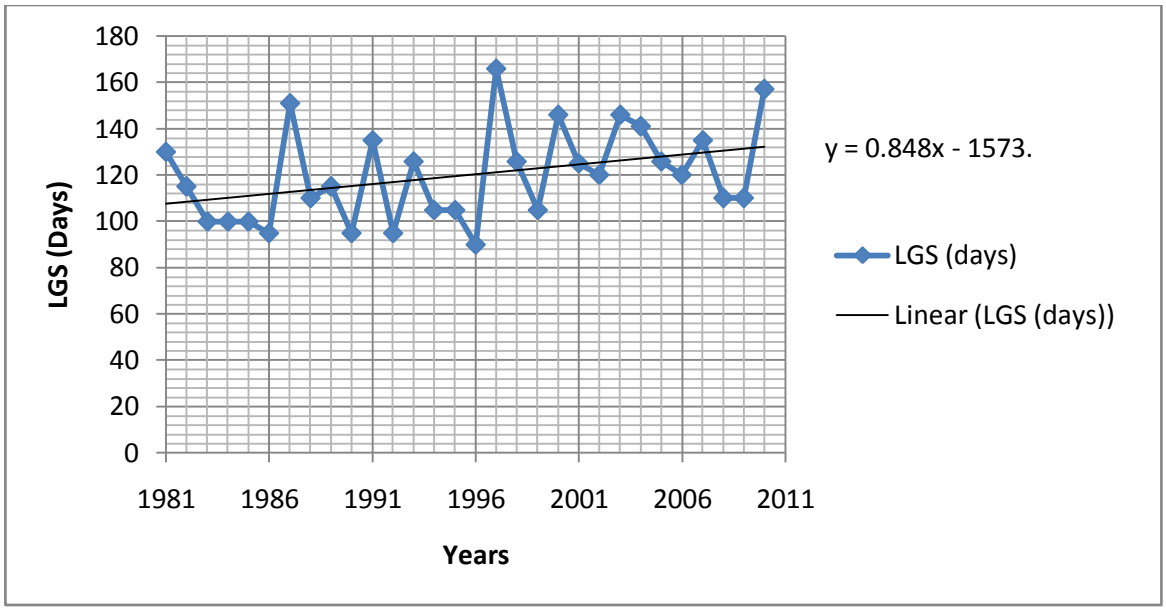

Fig. 4.26: Trendin Length of Growing Season at Sokoto (1981-2010)

At Sokoto in Fig.4.26, it could be seen that the linear trend line equation of length of growing season is Y = 0.848x – 1573.2. This finding indicates increasing trends in length of growing season in this location.

4.7.6 Trend in Length of Growing Season at Gusau

Trend in the length of growing season at Gusau were determined and presented by line and linear trend line equation in Fig.4.27

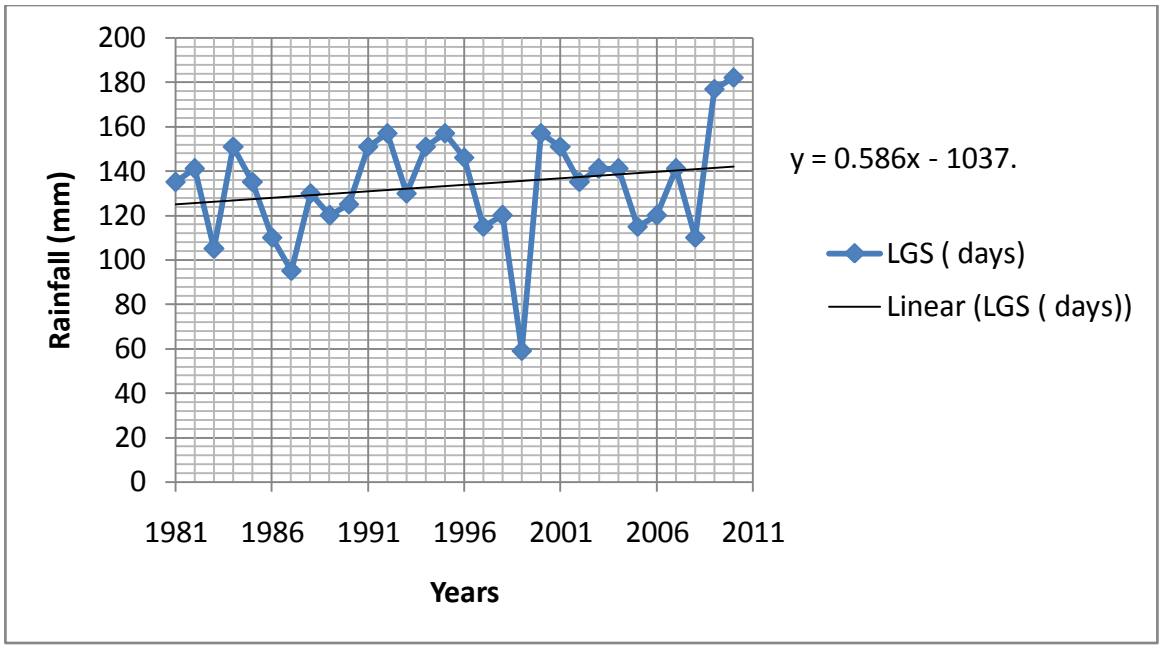

Fig. 4.27 : Trendin Length of Growing Season at Gusau (1981 – 2010)

It could be observed from Fig.4.27 that the linear trend line equation of length of growing season rainfall at Gusau is Y = 0. 586 - 1037 and it indicates increasing trends.

4.8 Trend in Millet Yield in the Study Area

In each of the six sampled locations, the yield record per hectare obtained for millet do not cover the entire period of study as the case for the rainfall due to inadequate record keeping as seen in (Table 3.2). Therefore, trend line and linear trend line equations for the available yield records of millet in each location arepresented in figures Figs 4.28 to 4. 33

4.8.1 Trend in Millet Yield at Kano

Trend in millet yield at Kano from 1982 – 2010 is presented in Fig. 4.28

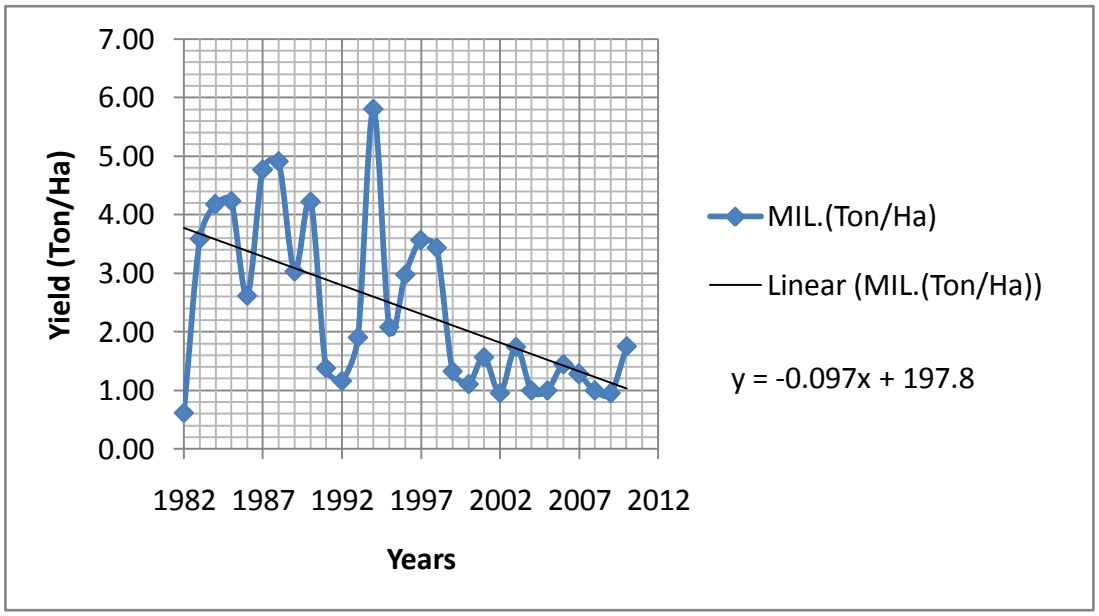

Fig 4.28: Trend of Millet Yields in Kano (1982-2010)

It could be observed from Fig.4.28 that the linear trend line equation of millet yield at Kano was Y = -0.097x + 197.8 and it indicates decreasing trend in millet production at Kano.

4.8.2 Trend in Millet Yield at Katsina

Trend in millet yield at Katsina from 1991-2001 is presented in Fig.4.29

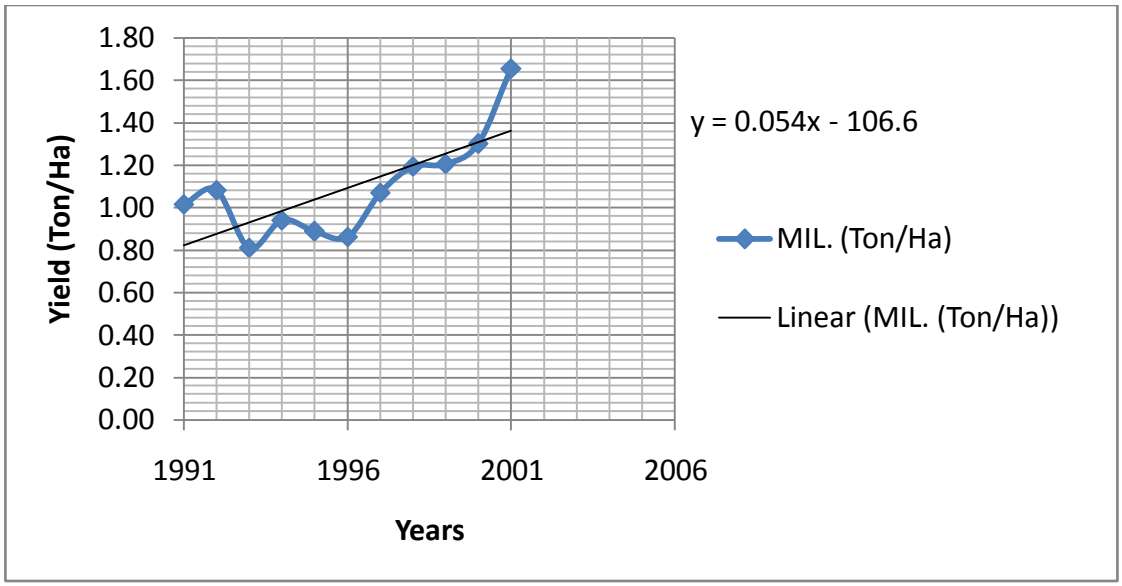

Fig.4.29: Trend of Millet Yields in Katsina (1991-2001)

At Katsina in (Fig.4.29) the slope of linear trend lineequation of millet yield indicates increasingtrend from 1991-2001.

4.8.3 Trend in Millet Yield at Maiduguri

Trend in millet yield at Maiduguri from 1993 - 2009 is presented in Fig. 4.30

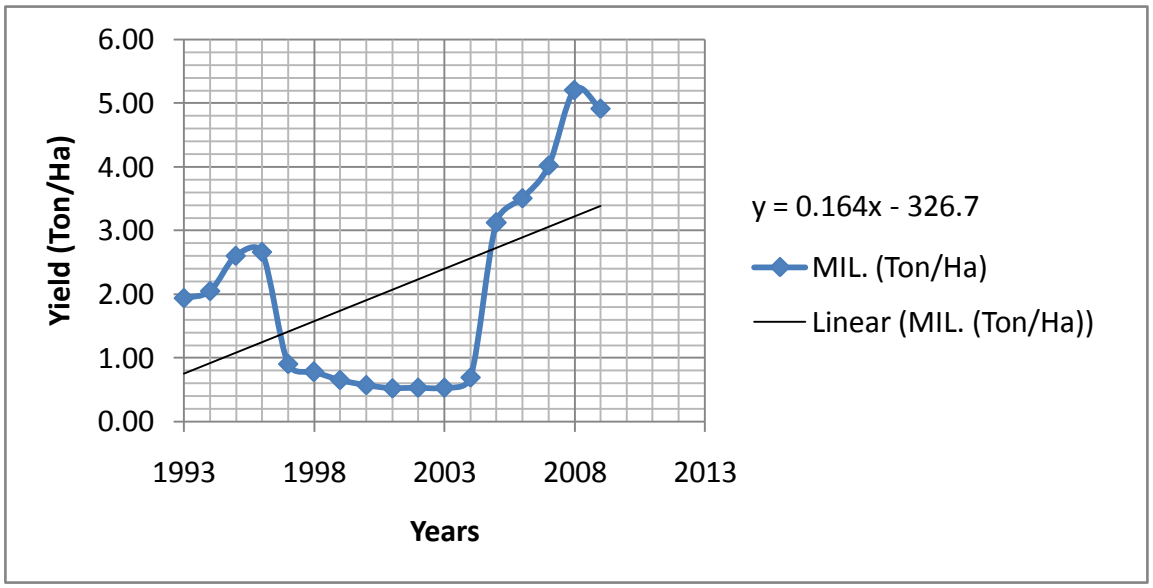

Fig.4.30: Trend of Millet yield in Maiduguri (1993-2009)

It could be observed from Fig.4.30 that the linear trend line equation of millet yield at Maiduguri is Y = 0.1643x – 326.73 implying increasing trend in yield from 1993 – 2009.

4.8.4 Trend in Millet Yield at Potiskum

Trend in millet yield at Potiskum from 1999-2009 is presented in Fig.4.31. From Fig.4.31 the linear trend line equation of millet yield in Potiskum is Y = 0.0063x – 11.69and it indicates increasing trend in millet yield. .

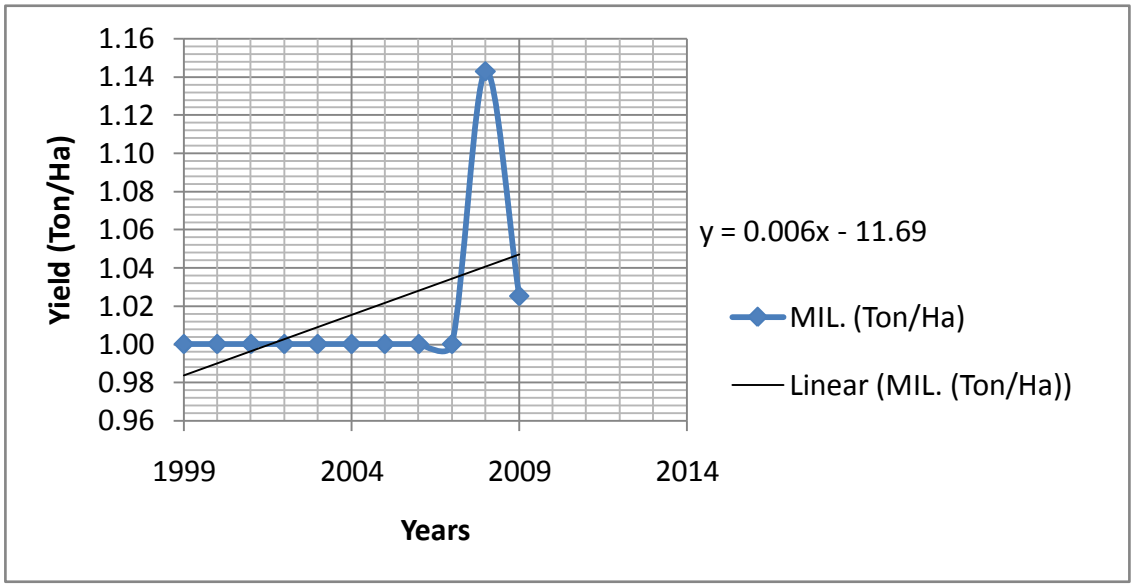

Fig.4.31: Trend of Millet Yield in Potiskum (1999-2009)

5.8.5 Trend in Millet Yield at Sokoto

The trend of millet yield at Sokoto from 1993 – 2008 is presented in Fig.4.32

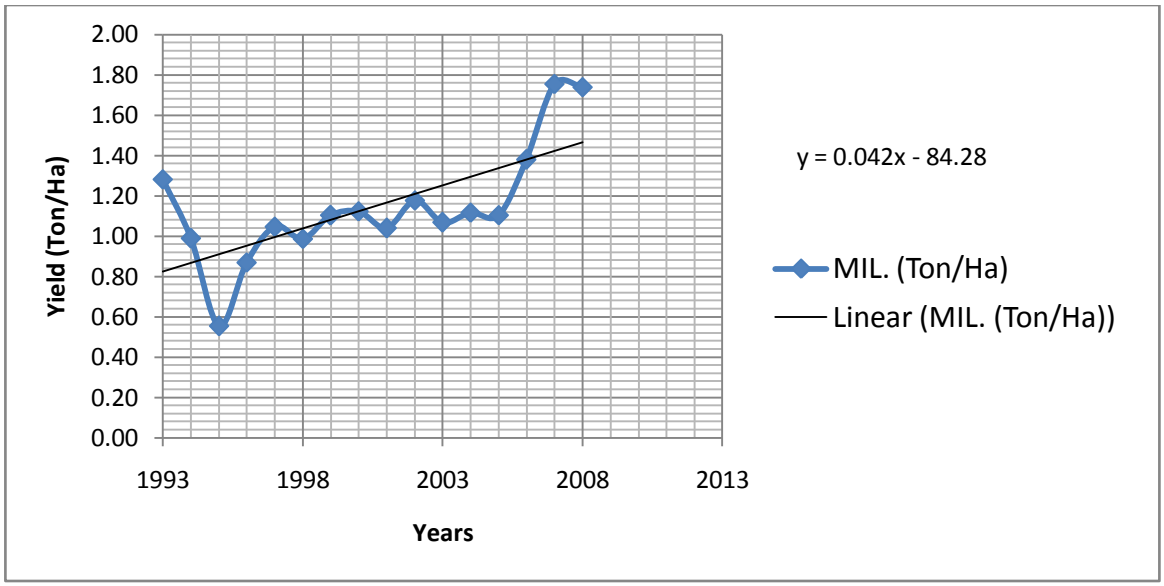

Fig.4.32: Trend of Millet Yield at Sokoto (1993-2008)

Fig.4.32 shows that the slope of linear trend line equation of millet at Sokoto indicates increasing trend. It is Y = 0.042x – 84.28

4.8.6 Trend in Millet Yield at Gusau

Trend in millet yield at Gusau from 1999-2009 is presented in Fig.4.33

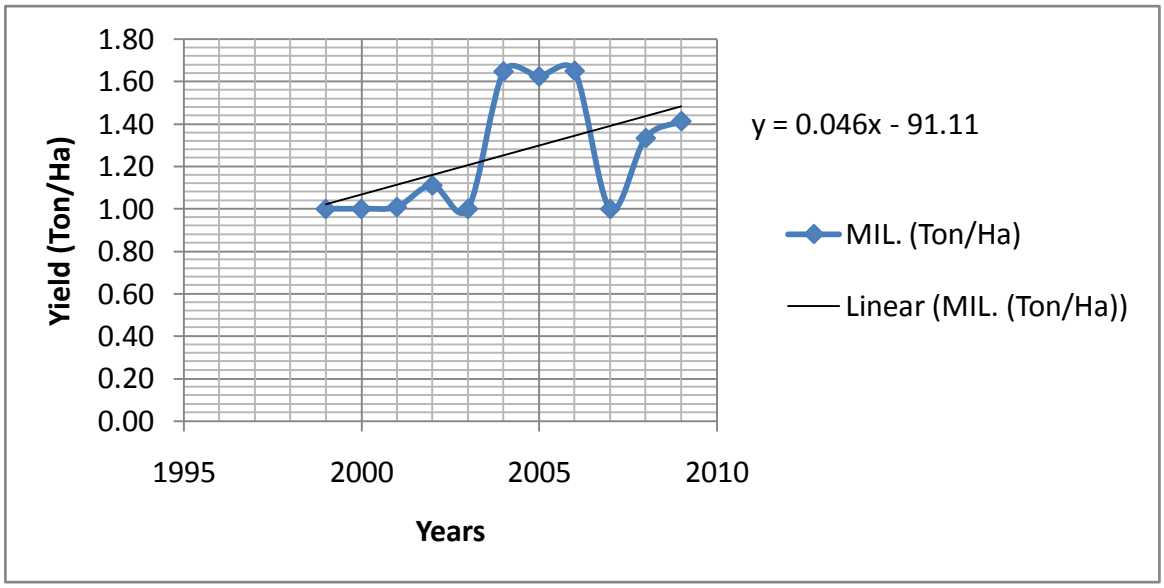

Fig.4.33: Trend of Millet Yield in Gusau (1999-2009).

At Gusau in (Fig.4.31) the linear trend line equation of Millet yield is Y = 0.046x – 91.11. This equation indicates increasing trend in millet yield in the area.

4.9 Trend of Sorghum Productionin The Study Area

The available sorghum yields per year records obtained for each of the six sampled locations do not match the rainfall records in the study period (Table 3.2). The linear trend line equations ofSorghum yieldsare presented from Figs. 4.34 to4. 39

4.9.1 Trend in Sorghum Yield at Kano

Trend in the yield of sorghum at Kano from 1982 – 2010 is presented in Fig. 4. 34

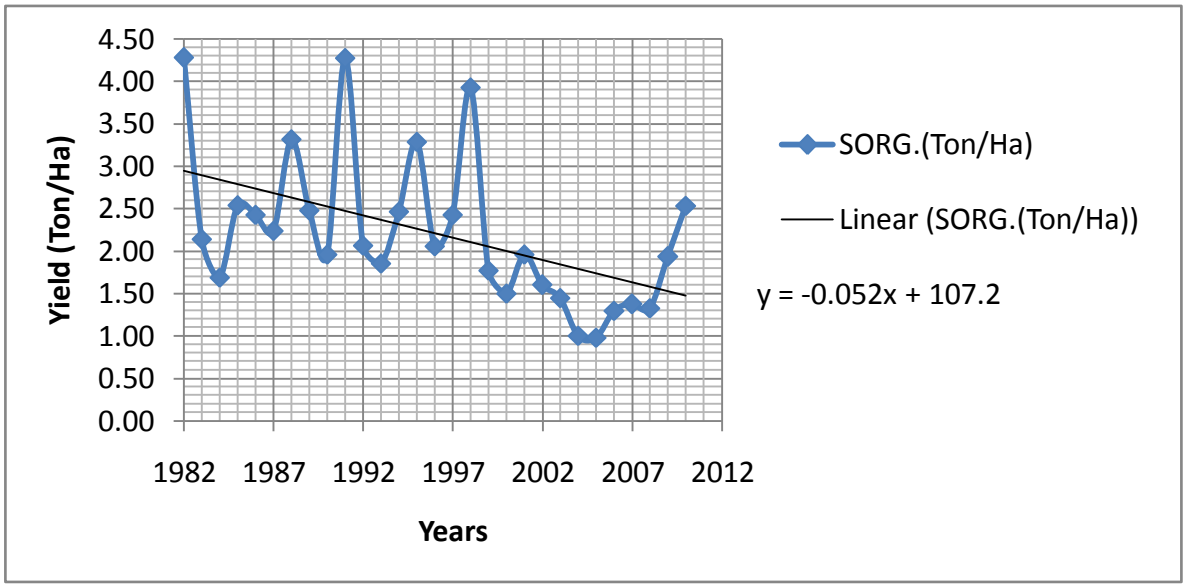

Fig.4.34: Trend of Sorghum Yield at Kano (1982-2009)

At Kano in (Fig. 4.34) it could be observed that the linear trend line equation of sorghum yield is Y = -0.052x +107.2 and it indicates decreasing trend in sorghum yield is inthis location.

4.9.2 Trend in Sorghum Yield at Katsina

Trend in Sorghum yields at Katsina from 1991 – 2001 is presented in Fig. 4.35

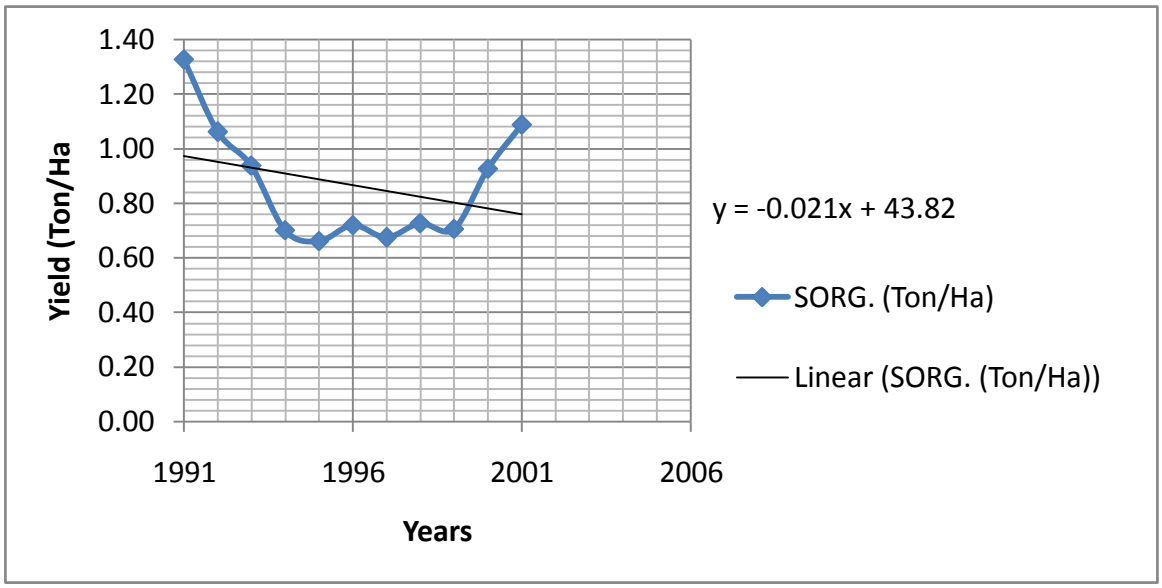

Fig: 4.35: Trend of Sorghum Yield at Katsina (1991-2001)

It could be seen from Fig. 4.35 that the higher production of Sorghum at Katsina occurred in 1991 and the lowest in 1995. The linear trend line equation of Sorghum yields is negative(Y = -0.0215x +43.82) indicating decreasing trend in the yield of sorghum.

4.9.3 Trend in Sorghum Yield at Maiduguri

Trendin Sorghum yield at Maiduguri from 1993 - 2009 is presented in Fig.4.36

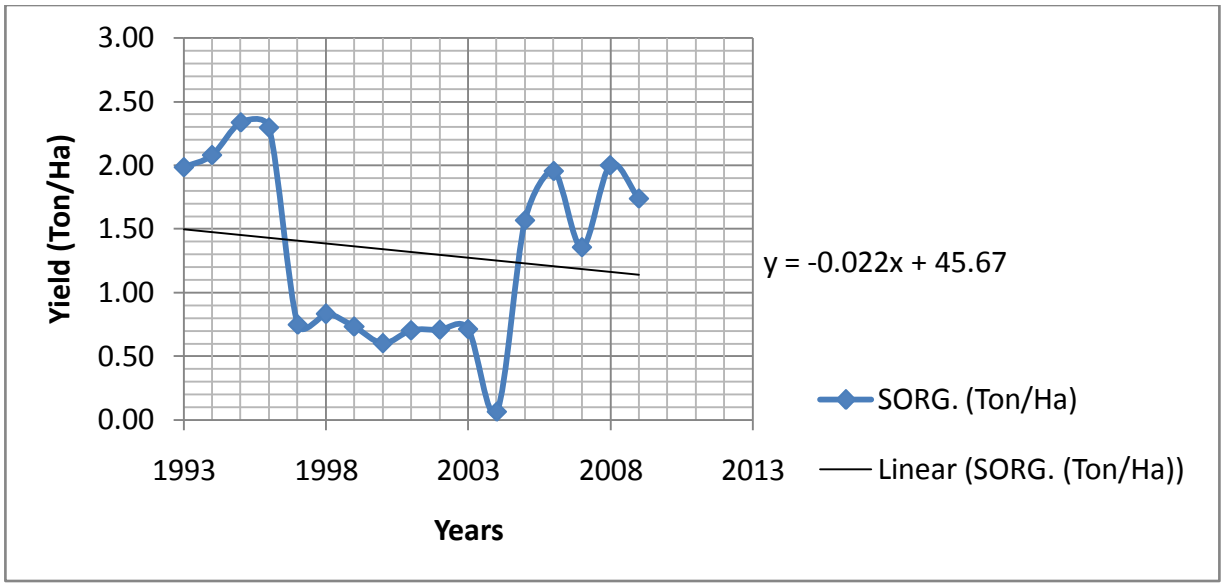

Fig. 4.36 Trend of Sorghum Yield at Maiduguri (1993-2009)

Fig.5.36 reveals that the highest yield of sorghum at Maiduguri was in 2008 and lowest in 2004. The linear trend line equation of sorghum yield is Y = -0.0222x +45.67 showing a decreasing trend in sorghum yield between 1993 and 2009.

4.9.4 Trend in Sorghum Yield at Potiskum

The trend of sorghum yield at Potiskum from 1999 – 2009 are presentedin Fig. 4.37

It could be seen from Fig.4.37 that the highest yield of Sorghum at Potiskum between 1999 and 2009 was in 2009 and lowest in 2004.

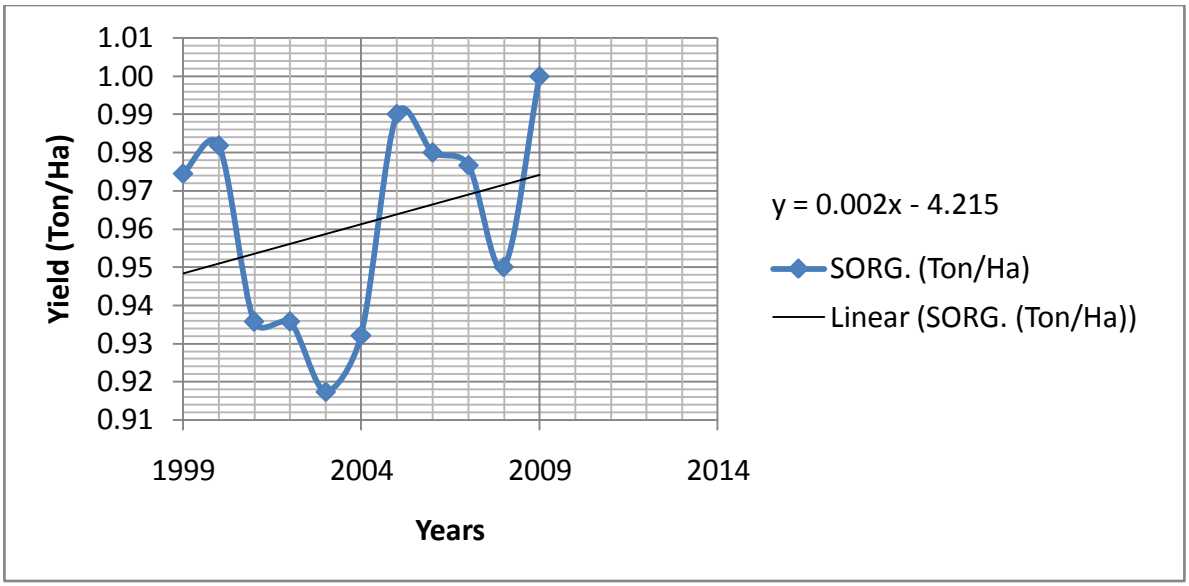

Fig. 4.37: Trend of Sorghum Yield at Potiskum (1999-2009)

The linear trend line equation of Sorghum yield was positive (Y = 0.0026x – 4.2159)indicating increasing trend in sorghum yields.

4.9.5 Trend in Sorghum yield at Sokoto

Trend in Sorghum yield at Sokoto from 1993 - 2008 is presented in Fig. 4. 38

Fig. 4.38 indicates that the highest yield of Sorghum at Sokoto was in 1994 and lowest in 2001 and 2002 respectively. The linear trend line equation of Sorghum yields isnegative (Y = -0.116x + 233.11). The slope of this trend line indicates decreasing trend in sorghum yield in the area.

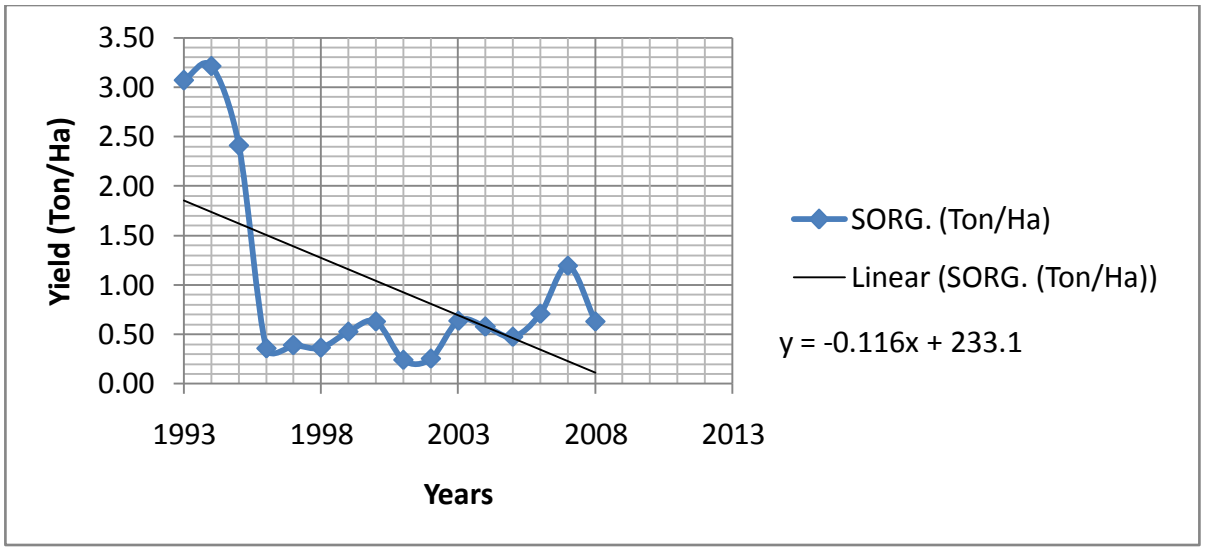

Fig.4.38: Trend of Sorghum Yield at Sokoto (1993-2008)

5.9.6 Trend in Sorghum Yield at Gusau

The trend equation of sorghum yield at Gusau from 1999 - 2009 is presented in Fig. 4.39.

From Fig.4. 39, it could be seen that the highest sorghum yield at Gusau was in 2009 and lowest in 2003. The linear trend line equation is Y = 0.0551x – 108.97 and it indicates increasing trend in yield.

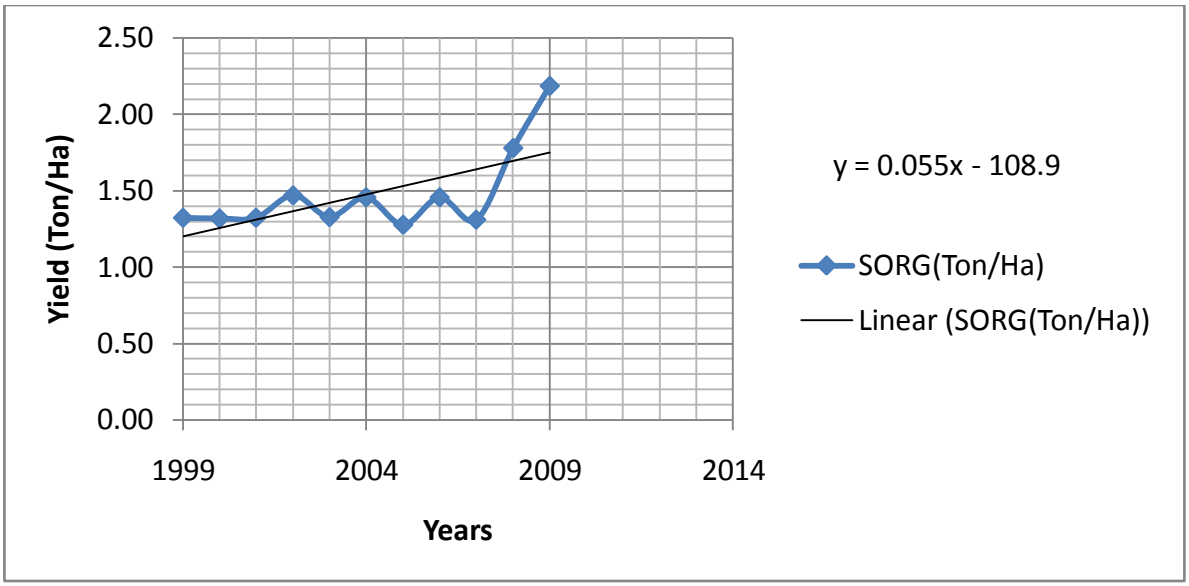

Fig. 4.39: Trend of Sorghum Yield in Gusau (1999-2009)

4.10 Relationships between Crop Yields and Rainfall Parameters in the Study Area

In order to determine relationship between millet and sorghum yields and rainfall parameters in the study area, correlation analysis was carried out using SPSS Software. In each location records of the two crops (millet and sorghum) were correlated with monthly rainfall amounts during growing season, annual rainfall and length of the growing season. Results obtained were presented in Tables.

4.10.1: Relationship Between Millet and Sorghum Yields with Rainfall Parameters at Kano

The available millet and sorghum yield records were correlated with rainfall parameters using product – moment correction test. Results obtained are presented in Table 4.25

Table 4.25: Correlation of Millet and Sorghum Yields with the Rainfall Parameters at Kano

Rainfall parameters	Millet Yield	Sorghum yield
May	-.310	-.296
Jun	-.288	-.321*
Jul	-.487**	-.407*
Aug	-.226	.003
Sept	-.182	-.268
Oct	-.157	-.134
AR	-.411*	-.312*
LGS	-.326*	-.326*

Source : Field work, 2012/2013

*. Correlation is significant at the 0.05 level (1-tailed).

**. Correlation is significant at the 0.01 level (1-tailed).

At Kano (Table 4.25) it could be observed at 0.01 significant level that milletyields is significantly correlated with July rainfall, annual rainfalland LGS at 0.05 significant levels.

The null hypothesis for millet yield is rejected with July rainfall, annual rainfall and length of growing season and accepted the null hypothesis against the remaining rainfall parameters. This indicates that there is significant highly negative relationship between millet yield with July and annual rainfall and length of growing season. There is no significant relationship between millet yield and others rainfall parameters. The correlation between sorghum yield and June, July, AR and LGS was significant and negative. The null hypothesis against these rainfall parameters with sorghum yield is therefore rejected. This indicates there is significant relationship between sorghum yield and these rainfall parameters at Kano

4.10.2: Relationship between Millet and Sorghum Yields with Rainfall Parameters

at Katsina

Millet and Sorghum yields records at Katsina were correlated with rainfall parameters. Results of the relationships are presented in Table 4.26

Table 4.26: Correlation of Millet and Sorghum Yields with Rainfall Parameters at Katsina

Rainfall parameters	Millet Yield	Sorghum Yield
May	.098	.305
Jun	.218	.210
Jul	.464	-.118
Aug	.409	-.055
Sept	.364	-.237
Oct	.270	-.131
AR	.591*	-.155
LGS	.295	.312

Source : Field work, 2012/2013

*. Correlation is significant at the 0.05 level (1-tailed).

It could be seen from Table 4.26 that millet yield at Katsina is significantly correlated with annual rainfall (AR) at 0.05 significant level.

The null hypothesis for millet yield with rainfall parameter ARis rejected while the alternative hypothesis is accepted. This indicates that at 0.05 significant levels there is significant relationship between millet yield and rainfall parameterof annual rainfall. Sorghum yield is not significantly correlated with any of the observed rainfall parameters. There is however, low association between sorghum yields with the observed rainfall parameters

4.10.3: **Relationship Between Millet and Sorghum Yields with Rainfall Parameters at Maiduguri**

The relationship between millet and sorghum yields with rainfall parameter at Maiduguri was derived. Results of this analysis are presented in Table 4.27

Table 4.27: Correlation of Millet and Sorghum Yields with Rainfall Parameters at Maiduguri

Rainfall Parameters	Millet Yield	Sorghum Yield
May	.091	-.029
Jun	-.103	-.395
Jul	-.034	-.179
Aug	-.196	-.481*
Sept	.048	-.119
Oct	.089	-.046
AR	-.052	-.375
LGS	-.058	-.139

Source : Field work, 2012/2013

*. Correlation is significant at the 0.05 level (1-tailed).

At Maiduguri(Table 4.27) it could be observed that at the 0.05 significantlevels Sorghum yield is correlatedwith August rainfall. The null hypothesis for sorghum yield with this rainfall parameter is rejected at the 0.05 level of significance and retained the alternative hypothesis. This indicates 95% occurrence of sorghum yield at Maiduguri is not by chance, but rather due to the association with August rainfall. There is no any rainfall parameter that is significantly correlated with millet yield in this location (Table 4.27). This indicates very low association between the observed rainfall parameter and millet yield.

4.10.4: Relationship between Millet and Sorghum Yields with Rainfall Parameters

at Potiskum

The relationship between millet and sorghum yield and rainfall parameters at Potiskum is presented in Table 4.28.

Table 4.28: Correlation of Millet and Sorghum Yields with Rainfall Parameters at Potiskum

Rainfall Parameters	Millet Yield	Sorghum Yield
May	-.344	-.804**
Jun	.121	-.175
Jul	-.418	-.244
Aug	-.337	.156
Sept	.040	.207
Oct	.055	.400
AR	-.674*	-.253
LGS	-.523*	-.285

Source : Field work, 2012/2013
*. Correlation is significant at the 0.05 level (1-tailed).
**. Correlation is significant at the 0.01 level (1-tailed).

At Potiskum (Table 4.28) it could be observed that at the 0.05 significance level millet yield is significantly and negatively correlated with annual rainfall and the length of growing season. Sorghum yield is significantly and negatively correlated with May rainfall at the 0.01 significant level

The null hypothesis for millet yield at Potiskum (Table 4.28) with rainfall parameters of AR and LGS is rejected and accepted the alternative hypothesis. This implies that 95% occurrence of millet yield is not by chance, but due to, AR and LGS. Similarly, the null hypothesis for sorghum yield with Mayrainfall yield is also rejected and retained the alternative hypothesis. This indicates that 99% occurrence of sorghum yield is not by

chance, but due to May rainfall at potiskum.

4.10.5: Relationship between Millet and Sorghum Yields with Rainfall Parameters at Sokoto

The relationship between available records of millet and sorghum yields with rainfall parameters at Sokoto is presented in Table 4.29.

Table 4.29: Correlation of Millet and Sorghum Yields with Rainfall Parameters at Sokoto

Rainfall parameters	Millet Yield	Sorghum Yield
May	.055	.069
Jun	-.277	-.272
Jul	.038	.052
Aug	.124	-.162
Sept	-.276	.141
Oct	-.267	-.008
AR	-.340	-.082
LGS	-.113	-.235

Source : Field work, 2012/2013

From Table 4.29 (Sokoto) it could be observed that nosignificant correlation exits between the two crop yields (millet and sorghum) with any of the observed rainfall parameters.

The null hypothesis for the two crops yields (millet and sorghum) with the rainfall effectiveness parameters is accepted.These findings indicate that there is very low correlation between millet and sorghum yields and the identified rainfall parameters in

Sokoto.

4.10.6Relationship between Millet and Sorghum Yields with Rainfall Parameters at Gusau

The relationship between millet and sorghum yields with rainfall parameters at Gusau is presented in Table 4.30

Table 4.30: Correlation of Millet and Sorghum Yields with Rainfall Parameters at Gusau

Rainfall parameters	Millet yield	Sorghum yield
May	.127	.357
Jun	.112	.382
Jul	-.229	-.018
Aug	-.042	.377
Sept	.103	-.221
Oct	.000	.176
AR	.229	.372
LGS	-.132	.107

Source : Field work, 2012/2013

At Gusau (Table 4.30) it is seen that no any strong relationship exists between the two crops yields and the identified rainfall effectiveness parameters.

The null hypothesis of millet and sorghum yields with the identifiedrainfall parameters in Table 4.30 is retained.This indicates very low association between the two crops yields and rainfall parameters at Gusau

4.11 Forecast Models for Millet and Sorghum Yields Based on Rainfall Parameters

The method of Adebayo andAdebayo (1997) was adopted to develop yield forecast models for the two crops in each location. Rainfall parameters which were significantly correlated with the yield of the two crops (millet and sorghum) among the six locations were subjected to Stepwise Multiple Regression. In Kano,total rainfall in June and July, AR and LGS were subjected into stepwise multiple regression model. At Katsina, AR was subjected. In Maiduguri, total rainfall in May was subjected. At Potiskum, AR, LGS and total rainfall in May were subjected into stepwise multiple regressions. At the three locations, Kano, Katsina and Potiskum only total annual rainfall (AR) entered into millet yield forecast model.Other Parameters were excluded by the model. Similarly, of all the correlated rainfall parameters that showed with Sorghum yields in these locations only total rainfall in May at Potiskum entered into stepwise multiple regression models. The model excluded the remaining parameters in thefive locations.

Results of the analysis produced four yield forecast models; three for millet yields at Kano,Katsina and Potiskun and one for sorghum yield at Potiskum: There is no millet yield forecast model produced at Maiduguri.No rainfall parameter entered the Stepwise multiple regression for Sokoto and Gusau. Similarly there is no sorghum yield forecast model produced for Kano, Katsina, Maiduguri, Sokoto and Gusau. Because no rainfall parameter that showed significant relationship with sorghum yield entered into the stepwise multiple regression models in these locations. The four yields developed forecast models are presented in Table 4.31

Table 4.31 Millet and Sorghum Yields Forecast Models

Locations	Millet Yield Forecast Model	R^2%
Kano	$Y = -0.733\log_{10}AR + 2.483$	19.7
Katsina	$Y = 0.503\log_{10}AR - 1.292$	61.7
Potiskum	$Y = -0.185\log_{10}AR + 0.529$	43.0
----------	**Sorghum Yield Forecast Model**	R^2%
Potiskum	$Y = -0.008\log_{10}M - 0.018$	68.1

Whereby, y = Millet and Sorghum Yields (ton/ha)
AR = Log_{10}Total Annual Rainfall
M = $\log_{10}$ Total Rainfall in May

The findings in (Table 4.31) indicate that nineteen point seven percent(19.7%) of the variance of Millet yield at Kano was accounted for by variations in annual rainfall. Sixty one point seven percent (61.7%)of the variance in millet yield at Katsina was accounted for by variations in annual rainfall. Forty three percent(43.0%) of the variations in millet yield at Potiskum was accounted for by variations in annual rainfall. Sixty eight point one percent (68.1%) of the variations in sorghum yield at Potiskum was accounted for by variations in total rainfall in May.

4.12 Appropriateness of CropYield Models

Yield records for two years for each station (Appendix D1 and D2) were used to check the appropriateness of the developed yield forecast models.

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4.12.1: Appropriateness of Developed MilletYield Forecast Modelfor Kano

At Kano Millet yield records for 2006 and 2007 are used to verify the appropriateness of the developed yield forecast model. Results of validation are presented in Table 4.32

Table 4.32: Validity of Millet Developed Yield Forecast Model for Kano

Crop	Yield Forecast Model	R^2 (%)	Year	Observed yield (Tons/ha)	Forecast yield (Ton/ha)	FE (%)
Millet	$Y = -0.733\log_{10}AR + 2.483$	19.7	2006	1.45	1.58	-9.0
			2007	1.28	1.60	-25.0

Data Source: Field work, 2012/2013

Where by AR = Log_{10} Total Annual Rainfall.

It could be observed from Table 4.32 that the percentage indices of FE ratiosfor millet developed yield forecast model in 2006 and 2007are -9.0% and -25% respectively. These values are less than 25% and they indicate that the model is appropriate for forecasting the yield of millet base on annual rainfall in these periods at Kano.

4.12.2: Appropriateness of Millet Yield Forecast Model for Katsina

The two years Millet yields records (2000 and 2001) at Katsina were used to check the appropriateness of thedeveloped millet yield forecast model.Results of the verification are presented in Table 4.33.

Table 4.33: Validity of Developed millet Yield Forecast Model for Katsina

Crop	Yield Forecast Model	R^2 (%)	Year	Observed yield (Ton/ha)	Forecast yield (Ton/ha)	FE (%)
Millet	$Y= 0.503\log_{10}AR-1.292$	61.7	2000	1.30	1.36	-5.0
			2001	1.65	1.47	11.0

Data Source: Field work, 2012/2013

Where by AR= Log_{10}Total AnnualRainfall.

At Katsina (Table 4.33) it could be seen that -5.0% and 11.0% indicate the ratios of

forecasting errors (FE) percentages of 2000 and 2001 for developed millet yield forecast model.These values are in the range of FE ≤25%. This finding indicates that the developed millet yield forecast mode isvalid for Katsina. It could be used for forecasting the yield of millet on the basis of total annual rainfall in this location.

4.12.3 Appropriateness of the Developed Forecast Modelsfor Millet and Sorghum Yields at Potiskum

Two years milletrecords (2003 and 2004) and sorghum (2006 and 2007) yields in Tons/ha are respectively used to verify the goodness fit of the twodeveloped crop yield forecast models. Results of this verification are presented in Table4.34

Table 4.34: Validity of the Developed Millet and Sorghum Yields Forecast Models for Potiskum

Crop	Yield Forecast Model	R^2 (%)	Year	Observed yield (Ton/ha)	Forecast yield (Ton/ha)	FE (%)
Millet	Y= $-0.185\log_{10}AR + 0.529$	43.0	2003	1.00	1.01	-1.00
			2004	1.00	1.02	-2.00
Sorghum.	Y= $-0.008\log_{10}M - 0.018$	68.1	2006	0.98	1.02	-4.08
			2007	0.98	1.0	-2.04

Data Source: Field work, 2012/2013

Whereby AR= $\log_{10}$Annual Rainfall, M= Log_{10}Total Rainfall inMay

In Table 4.34, atPotiskum, it could be observed that the FE% value for the developed

millet yield forecast model is -1.00% in 2003 and -2.00% in 2004. It is -4.08% and -2.04% for the developed sorghum yield forecast model in 2006 and 2007 respectively.It is seen that the FE% value for each respective observed year is less than 25%. This indicates that the two crops developed yields forecast models($Y = -0.185\log_{10}AR + 0.529$ for millet and$Y = -0.008\log_{10}M - 0.018$ for sorghum) fit Potiskum. They could be used to forecast the yields of the two crops based on total annual rainfall and total rainfall in May, respectively.

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Characterization of Rainfall Parameters

The study determined the onset and cessation dates, length of growing season, annual rainfall and monthly rainfall amounts during the growing season in each of the six selected locations in the Sudan Savanna ecological zone of Nigeria from 1981-2010.

It was observed that in each location, there are six months of growing season starting from May to October. This finding agrees with the findings of Anyadike (1993) that 1st May to 3rd October is the period when most stations in Sudan Savannah ecological zone of Nigeria receive about 95% of their total annual precipitation. This period also corresponds to the growing season where rainfall distribution is suitable for crop germination, establishment and full development (Odekunle, 2004)

It was observed that onset and cessation dates of the rains vary among the six locations. Onset dates are mostly within the first two months of rainy season (May or June) and cessation dates lie mostly within the last two months of the growing season (September or October) in each location as observed from(Tables 4.1 to 4.6). It was also observed that,mean length of the growing season also vary among the individual locations (Tables 4.7 to 4.12). Similarly, mean monthly rainfall amounts during growing season and annual rainfall differ among locations as observed from (Tables 4.13 – 4.18). These variations were probably due to global average that hides significant differences in regional precipitation patterns, with some regions showing increase and some decrease because of temperature increases from 1.5^{0}C to 3.5^{0}C which often leads to considerable inter-annual

variability as observed by Schneider *et al*.(1990) and IPCC (1996)

5.2 Trends in Rainfall Parameters

The study analyzed trends in the observed rainfall parameters in the study area. It was observed that there is a decreasing trend in onset and increasing in cessation dates at Kano in Fig.4.10 This finding indicates earlier onset and late cessation dates at Kano. At Katsina in (Fig.4.11and Maiduguri in (Fig.4.12) both onset and cessation dates of rains indicated an increasing trend. This implies that Katsina and Maiduguri are experiencing later onset and cessation dates of rains. At Potiskum in Fig.4.13 onset date of rains was decreasing and cessation date increasing, which means onset dates of rains commenced earlier and cessation dates later in this location. At Sokoto in Fig.4.14 there is decreasing trend in onset dates of growing season and increasing in cessation dates. This indicates that onset dates of rains commenced earlier but cessation dates of the rains later. At Gusau(Fig.4.15) trend of onset and cessation dates of rains are increasing .It means both onset and cessation date of rains arecommencing later in this station.

The results obtainedfrom Figs, 4.10 to 4. 15 generally indicate that there is a shorter length of growing season in the study area. This statement is supported by the mean length of growing season derived for each location from Tables4.7 – 4. 12. For instance, the mean length of growing season at Kano was 133 days, 121 days at Katsina, 120 days at Maiduguri, 121 days in Potiskum, 120 days at Sokoto and 133 days at Gusau. .

In most cases it is observed that the longer length of growing season among the six

locations; the more yields of the two crops (millet and sorghum), and the shorter the less yields of the two crops. In Table 4.7 (Kano) for instance, in 1982 the LGS was 141 days and was corresponded to 0.62ton/ha of millet and 4.28ton/ha of sorghum yields (Appendix D1). In 1983, however, the LGS was 116 days and was corresponded to 3.59Ton/ha of millet and 2.14ton/ha of sorghum yields. At Gusau (Table 4.12), in 1999 the LGS was 115 days and was corresponded to 1.00ton/ha of millet and 1.32ton/ha of sorghum respectively (Appendix D2). In comparison with 2000, the LGS was 95 days which corresponded to 1.00 and 1.32tons/ha millet and sorghum yields, respectively. This finding indicates that long LGS has an effect of producing more crop yields than a short one.

With regards to annual rainfall and length of growing season it is observed that these variables showed increasing trend in each location in the period of study. The increasing trend may be probably as a result of an increase in global mean precipitation of between 3% and 15% as temperature increases from 1.5^{o}C to 3.5^{o}C as observed by (Schneideret*et al* 1990; IPCC, 1996). With this finding, it means that annual rainfall and the length of growing season areincreasing in the Sudan Savanna ecological zone of Nigeria in the period of study (1981-2010). The finding is however contrary with the assertion made by Aliyu (2009) that there was a downward trend in the duration of the growing season in some locations in northern Nigeria from 1978-2007), with a significant variability in most of the stations north of latitude 9^{0}N in Nigeria.

5.3 Trends in Crop Yield

Thestudy also looked at the trend in millet and sorghum yields records of each of the six locations respectively. Results obtained showed that at Kano (Fig.4.28) millet yield indicates decreasing patternand increasing at Katsina in (Figs.4.29). At Maiduguri (Fig.4.30), Potiskum (Fig.4.31), Sokoto (Fig.4.32) and Gusau (Fig.4.33) millet yield indicates increasing trend in these locations. At Kano (Fig.4.34) and Katsina (Fig.4.35) the trend of sorghum yield indicates decreasing trend in these locations respectively. In Maiduguri (Fig. 4.36) and Potiskum (Figs.4.37) the yield of sorghum indicates increasing trend. At Sokoto (Fig.4.38) sorghum yield decreases while it increases at Gusau (Fig.4.39).

Based on these findings, it means the yields of millet and sorghum were decreasing in Kano and Katsina, and increased in Maiduguri and Potiskum. At Sokoto the yield of millet increases but sorghum decreases in the period of study. At Gusau both yields of millet and sorghum are increasing. This is due to the fact that, high amount of rainfall leads to waterlogging, erosion, leaching of nutrients leading to low yield. More rainfall, on the other hand, that promotes absorption of nutrients and metabolic activities of plants could lead to high yield.

5.4 Correlation between Crop Yield and Rainfall Parameters

Relationships between the two crops (millet and sorghum) yields and rainfall parameters are also studied in each of the six locations. Eight rainfall parameters were correlated with the yields of the two crops in each location. It could be observed that at Kano in

Table 4.25, the determinants factors of millet yields were total July rainfall, annual rainfall and the length of growing (LGS). Millet yield is positively and significantly correlated with July rainfall at 1% level, negatively and significantly correlated with AR and LGS at 5% level. This indicates it requiresadequate distribution of rainfall throughout its phonological stages. In the case of sorghum, the most determinants rainfall parameters for its germination (Table 4.25) are: totalsrainfall in Jun, July and annual rainfall (AR). This is because at 1% level, totals rainfall in June, July, AR and LGS are negatively and significantly with sorghum yield at 1% level. This shows that rainfall supply during pre-sowing and grain filling stage are very important for sorghum yield. This could be probably because field crop depends almost entirely on rainfall as its moisture supply throughout its length of growing season.

At Katsina in (Table 4.26) yieldof millet is determined significantly by the rainfall of annual rainfall (AR). This rainfall parameter is positively and significantly correlated with millet yield at 5% level. These indicate that rainfall supply during pre-sowing stage and all the year round are very important for millet yield at Katsina. Total rainfall in May, June, July, August, September and October; and LGS are positively and insignificantly correlated with millet yield. It is observed in (Table 4.26) that the eight identified rainfall parameters are insignificantly correlated with sorghum yield in this location

In Table 4.27 (Maiduguri), millet yield is positively and insignificantly correlated with total May rainfall, September and October; and negatively with total June rainfall, July, August and AR and LGS. For Sorghum, the determinant factor for its yield is the August

rainfall. This finding indicates that sorghum yield is negatively and significantly correlated with August rainfall at 5% level. This shows that rainfall supply in August is very important for sorghum yield at Maiduguri which is normally a flowering development phase of sorghum as observed by Kassam and Andrews (1975).

At Potiskum in (Table 4.28) the determinants of millet yield are AR and LGS. Millet yield is negatively and significantly correlated with these rainfall parameters at 5% level in this location. There is low correlation between the millet yield and the total rainfall in May, June, July, August, September and October. The determinant of rainfall parameter for Sorghum yield at Potiskum is total rainfall in May. It is negatively and significantly correlated with sorghum yield at 1% level of significant. There is positive but insignificant correlation between sorghum yield and August, September and October rainfall, negative and insignificant correlation with July and annual rainfall and LGS. These findings indicate that rainfall supply throughout length of growing season is very important for millet yield, and rainfall supply in May is important for sorghum yield at Potiskum.

At Sokoto and Gusau in (Tables 4.29 and 4.30) respectively there is no any rainfall parameter significantly correlated with the yields of the two crops (millet and sorghum). At sokoto (Table 4.29) for instance, total May rainfall is positively and insignificantly correlated with millet yield, negatively and insignificantly correlated with the remaining nine rainfall parameters. Similarly, sorghum yield is positively and insignificantly correlated with totalrainfall in July and September. It is negatively and insignificantly

correlated with the remaining six rainfall parameters. The non- significant but positive correlation of total rainfall in July and September with sorghum yield is an indicative that they are important rainfall variables influencing the sorghum yield at Sokoto. Similarly, total May rainfall which is non- significant but has positive correlation with millet yield is an indicative that it is important rainfall variable influencing millet yield at Sokoto.

In Table 4.30 at Gusau, total rainfall in May, June, September and annual are positively and insignificantly correlated with millet yield. Total rainfall in May, June, August and September and LGS are positively and insignificantly correlated with the sorghum yield.These findings indicate that the combine rainfall parameters of May, June, August and September rainfall and LGS are important variables influencing sorghum yield at Gusau. The combined totals rainfall in May, June, September and annual are important parameters influencing millet yield in this location.

5.5 Developed Forecast Models

Beside these, the study also determined the yield forecast model for millet and sorghum yield using rainfall parameters. Parameters which were significantly correlated with the yield of the two crops (millet and sorghum) in each station were subjected to Stepwise Multiple Regression Analysis. Results of this analysis indicate that annual rainfall (AR) entered into stepwise multiple regressions model for millet yield at Kano, Katsina and Potiskumand total rainfall in Mayfor sorghum yield at Potiskum. This implies that there would be no millet yield forecast model developed at Maiduguri, Sokoto and Gusau and no sorghum yield forecast model for Kano, Katsina, Maiduguri, Sokoto and Gusau, since

no parameters entered the model at these locations.

The three millet yield forecast modelsdeveloped are: at Kano is $Y = -0.733\log_{10}AR + 2.483$ with coefficient of determination (R^2) = 19.7%, Katsina is $Y = 0.503\log_{10}AR - 1.292$ with coefficient of determination (R^2) = 61.7% and Potiskum is $Y = -0.185\log_{10}AR + 0.527$ with percentage coefficient of determination (R^2) = 43.0%. The only sorghum yield forecast developed is at Potiskum and it is $Y = -0.008\log_{10}M - 0.018$ with coefficient of determination (R^2) = 68.1%. Where by AR indicates $\log_{10}$total annual rainfall and M $\log_{10}$ totalrainfall in May. The value of R^2 explained the total variations accounted for by each of the two yield forecast models.

These findings indicate that millet yield forecast model developed at Katsina and sorghum at Potiskum ($Y = 0.503\log_{10}AR - 1.292$ and is $Y = -0.008\log_{10}M - 0.018$) respectively are the best fitted yield forecast models. This is because they both indicate high percentage coefficient of determination {(R^2) = 61.7% and (R^2) = 68.1 %.} respectively than the other. (R^2) = 61.7% indicates that 61.7% variation of millet yield is accounted for by the millet yield forecast model. (R^2) = 68.1 % indicates that 68.1% variation of sorghum yield is accounted for by the sorghum yield developed forecast model.

The appropriateness of each model in each location is checked using the value of forecast error percentage (FE %). Two years yield data for millet and sorghum are used in each location to verify the goodness fit of each model. Results obtained from checking indicate

that the developed yield forecast models fitted each station based on the identified rainfall parameters.

It could be observed that all the yield forecast models of millet and sorghum were developed based on the rainfall parameters using stepwise multiple regression analysis. They are contrary to those developed by Sawa and Ibrahim (2011) using double log-multiple regressions. Theirs models arebased on occurrence of dry spells of 5, 7, 10 and equal to greater than 15 consecutive days during the growing season. Results of theirs two crops yield forecast models indicated that about 54.5% variation in millet yield is accounted for by occurrences of dry spells during the growing season, while 63.2% variation in Sorghum yield is due jointly to the occurrence of 5-dry spells in May and total dry spells in the growing season. The developed millet yield forecast model in this study indicates that annual rainfall is the function of high yield variations, while that of sorghum indicates that total rainfall in May is the function of high yield variations.

CHAPTER SIX

6. 0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

This study achieved set of objectives. These include the determination of the onset and cessation dates, length of growing season (LGS), and monthly rainfall amounts during growing season and annual (AR) of each location for 30 years (1981- 2010). Itanalyzed the trend of onset and cessation dates, length of growing season and annual rainfall for the study period. It also examined the current trends of millet and sorghum yield in each location. Others are establishing the relationship between the yields of millet and sorghum with monthly rainfall amounts during the growing season, AR and LGS in each location. It developed models for predicting millet and sorghum yields on the basis of rainfall parameters.

Methods used to investigate these set of objectives areogive of cumulative pentad rainfall, trend lines, and linear trend line equations, product- moment correlation coefficient (r) , bar chart and stepwise multiple regression analysis. Resultsobtained indicate significant variation in the onset and cessation dates, monthly rainfall amounts during the growing season, annual rainfall and length of the growing season within the study locations. There was an increasing trend in onset dates of the growing season, annual rainfall, length of the growing season, millet and sorghum yields, and decreasing in cessation dates of the growing season. Monthly rainfall amounts during growing season have generally indicated an increasing pattern in the study areas. Most of the rainfall parameters observed such as in May, June, July, August, September, October and

annual rainfall and length of the growing season are significantly correlated at 0.05 levels of significance and few at 0.01 with the yield of the two crops (millet and sorghum).Results for stepwise multiple regression analysis gave four (4) yield forecast models, three (3) for millet at Kano ($y = 0.733\log_{10}AR + 2.483$), Katsina ($y = 0.503\log_{10}AR - 1.292$), Potiskum ($y = -0.185\log_{10}AR + 0.529$) and the last for sorghum at Potiskum ($y = -0.008\log_{10}M - 0.018$). The two (2) best fitted crops yield forecast models among these for the study area are $y = 0.503\log_{10}AR - 1.292$ for millet yield at Katsina and $y = -0.008\log_{10}M - 0.018$ for sorghum yield at Potiskum.

6.2 Conclusion

In conclusion the results of this study have revealed empirically thatrainfall is the most important climatic factor that influencing the production of millet and sorghum in the Sudan Savanna ecological zone of Nigeria. Its variability distributions should be put into consideration in planning and managing agricultural activity in this zone.

6.3Recommendations

Based on the findings of this study, it is recommended that farmers should:

i. Be guided to plant their field crops on the derived mean onset date of 22-May at Kano, 1-June at Katsina, 5-June in Maiduguri, 10-June at Potiskum, 3-June at Sokoto and 23- May at Gusau.

ii. Be made aware that the length of growing season in the Sudan Savanna is generally short, onset dates commences on June or May and cessation date ends in the month of September or October

iii. Obtain early maturing seed varieties before the onset date of rainy season

iv. Obtain fertilizer, herbicides and insecticides before the onset of wet season

v. Apply the two derived yield forecast models to predict the future yields of the two crops based on the identified rainfall effectiveness parameters

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Appendix A: Pentad Calendar Table

JANUARY		FEB		MARCH		APRIL	
Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates

1	$1^{st} - 5^{th}$	7	$1^{st} - 5^{th}$	13	$1^{st} - 5^{th}$	19	$1^{st} - 5^{th}$
2	$6^{th} - 10^{th}$	8	$6^{th} - 10^{th}$	14	$6^{th} - 10^{th}$	20	$6^{th} - 10^{th}$
3	$11^{th} - 15^{th}$	9	$11^{th} - 15^{th}$	15	$11^{th} - 15^{th}$	21	$11^{th} - 15^{th}$
4	$16^{th} - 20^{th}$	10	$16^{th} - 20^{th}$	16	$16^{th} - 20^{th}$	22	$16^{th} - 20^{th}$
5	$21^{st} - 25^{th}$	11	$21^{st} - 25^{th}$	17	$21^{st} - 25^{th}$	23	$21^{st} - 25^{th}$
6	$26^{th} - 31^{st}$	12	$26^{th} - 28^{th}$	18	$26^{th} - 31^{st}$	24	$26^{th} - 30^{th}$

MAY		JUNE		JULY		AUGUST	
Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates
25	$1^{st} - 5^{th}$	31	$1^{st} - 5^{th}$	37	$1^{st} - 5^{th}$	43	$1^{st} - 5^{th}$
26	$6^{th} - 10^{th}$	32	$6^{th} - 10^{th}$	38	$6^{th} - 10^{th}$	44	$6^{th} - 10^{th}$
27	$11^{th} - 15^{th}$	33	$11^{th} - 15^{th}$	39	$11^{th} - 15^{th}$	45	$11^{th} - 15^{th}$
28	$16^{th} - 20^{th}$	34	$16^{th} - 20^{th}$	40	$16^{th} - 20^{th}$	46	$16^{th} - 20^{th}$
29	$21^{st} - 25^{th}$	35	$21^{st} - 25^{th}$	41	$21^{st} - 25^{th}$	47	$21^{st} - 25^{th}$
30	$26^{th} - 31^{st}$	36	$26^{th} - 30^{th}$	42	$26^{th} - 31^{st}$	48	$26^{th} - 31^{st}$

SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates	Pentad No.	Dates
49	$1^{st} - 5^{th}$	55	$1^{st} - 5^{th}$	61	$1^{st} - 5^{th}$	67	$1^{st} - 5^{th}$
50	$6^{th} - 10^{th}$	56	$6^{th} - 10^{th}$	62	$6^{th} - 10^{th}$	68	$6^{th} - 10^{th}$
51	$11^{th} - 15^{th}$	57	$11^{th} - 15^{th}$	63	$11^{th} - 15^{th}$	69	$11^{th} - 15^{th}$
52	$16^{th} - 20^{th}$	58	$16^{th} - 20^{th}$	64	$16^{th} - 20^{th}$	70	$16^{th} - 20^{th}$
53	$21^{st} - 25^{th}$	59	$21^{st} - 25^{th}$	65	$21^{st} - 25^{th}$	71	$21^{st} - 25^{th}$
54	$26^{th} - 30^{th}$	60	$26^{th} - 31^{st}$	66	$26^{th} - 30^{th}$	72	$26^{th} - 31^{st}$

APPENDIX B: Julian Day Calendar Table

Dates	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335

2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	223	253	283	314	344
11	11	42	70	101	131	162	192	224	254	284	315	345
12	12	43	71	102	132	163	193	225	255	285	316	346
13	13	44	72	103	133	164	194	226	256	286	317	347
14	14	45	73	104	134	165	195	227	257	287	318	348
15	15	46	74	105	135	166	196	228	258	288	319	349
16	16	47	75	106	136	167	197	229	259	289	320	350
17	17	48	76	107	137	168	198	230	260	290	321	351
18	18	49	77	108	138	169	199	231	261	291	322	352
19	19	50	78	109	139	170	200	232	262	292	323	353
20	20	51	79	110	140	171	201	233	263	293	324	354
21	21	52	80	111	141	172	202	234	264	294	325	355
22	22	53	81	112	142	173	203	235	265	295	326	356
23	23	54	82	113	143	174	204	236	266	296	327	357
24	24	55	83	114	144	175	205	237	267	297	328	358
25	25	56	84	115	145	176	206	238	268	298	329	559
26	26	57	85	116	146	177	207	239	269	299	330	360
27	27	58	86	117	147	178	208	240	270	300	331	361
28	28	59	87	118	148	179	209	241	271	301	332	362
29	29		88	119	149	180	210	242	272	302	333	363
30	30		89	120	150	181	211	243	273	303	334	364
31	31		90		151		212	243		304		365

Note: The figures in the first column are the days of the month and those from second column and the subsequent ones are Julian days

APPENDIX C1: 1981 DAILY RAINAFALL DATA IN MILIMETERS AT KANO

MONTHS/DAYS	J	F	M	A	M	J	J	A	S	O	N	D
1					9.3							

2							1.6					
3					6.2			40.6	4.3			
4									16.2			
5							13.5					
6								64.2				
7									19.7			
8									2.5			
9									9.3			
10												
11						1.2	8.3	0.7				
12							18.7					
13									51.6			
14												
15					1.2		9.9	5.4				
16							6.3	8.4				
17						23.4	11.0					
18							12.6		1.9			
19						8.0	2.0					
20					4.4		2.8					
21								9.4				
22				3.3			1.7		6.3			
23				8.9		12.2		37.6				
24							8.1					
25								15.9				
26					15.1			11.5				
27							8.0	8.8				
28				7.3			48.3					
29												
30						12.2						
31												

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX C2: 1981 DAILY RAINAFALL DATAIN MILIMETERS AT KATSINA

MONTHS/DAYS	J	F	M	A	M	J	J	A	S	O	N	D
1								0.3	0.4			

2												
3								0.3	0.2			
4									3.2			
5							3.9					
6							31.7	44.4	20.1			
7												
8												
9									18.4			
10						1.0						
11						11.5	1.4	0.3				
12							18.3	28.5				
13									20.5			
14							15.0					
15						5.2						
16						3.9	79.5		14.9			
17					19.6	7.4		0.3				
18					4.6	1.7	0.3	11.9				
19					0.4				8.3			
20						45.9						
21					4.0	3.9	22.7					
22									22.0			
23								24.5				
24							9.4					
25					6.3							
26					2.6			0.9				
27								7.0	1.1			
28				11.0		1.0	2.8	3.5				
29								0.4				
30												
31												

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX C3: 1981 DAILY RAINAFALL DATAIN MILIMETERS AT MAIDUGURI

MONTHS/DAYS	J	F	M	A	M	J	J	A	S	O	N	D
1					2.7			11.2				

2					1.2			8.2				
3									0.6			
4					5.5				1.5			
5							19.9					
6						9.4						
7						0.8			10.1			
8							5.3					
9					8.3	10.2			2.1			
10								7.1				
11							8.0					
12						3.1		6.3	3.0			
13												
14												
15												
16							1.5					
17												
18						6.0	66.3	3.8				
19								0.8				
20					6.6	0.6	11.6					
21								1.7				
22						28.3						
23					0.7	2.6	2.6					
24							31.2	10.8				
25												
26								11.5				
27					45.6	2.7	42.0					
28							15.0					
29				3.9		8.0						
30				17.7								
31												

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX C4: 1981 DAILY RAINAFALL DATAIN MILIMETERS AT POTISKUM

MONTHS/DAYS	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**

1					37.4		14.6					
2							1.5	7.5				
3									14.3			
4					4.0			19.9	3.0			
5										18.8		
6							45.2			3.6		
7									24.9			
8												
9						2.2	28.3		8.0			
10								36.5				
11												
12							11.5	1.8				
13									2.5			
14						30.3		14.2	2.0			
15								57.6	1.0			
16						6.3		1.8	10.0			
17							8.9					
18						16.2	2.0		5.6			
19												
20						28.5	11.4					
21								11.5				
22						2.9	3.5					
23				3.5				15.4	1.9			
24						14.4	38.5					
25												
26							2.1	16.1				
27				2.6			17.3					
28				3.7	28.1		6.3	3.0				
29						53.2						
30												
31												

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX C5: 1981 DAILY RAINAFALL DATAIN MILIMETERS AT SOKOTO

MONTHS/DAYS	J	F	M	A	M	J	J	A	S	O	N	D
1								1.9				

2												
3								30.1	1.4			
4									16.6			
5												
6							52.8	1.3	22.2			
7												
8								39.4	7.4			
9							3.1		5.2			
10												
11							24.5					
12								1.4				
13							1.4	3.8	0.3			
14												
15												
16					3.3	0.6	30.3		9.8			
17												
18					27.3		24.7		9.4			
19							1.8	3.7				
20												
21					50.0		5.1					
22					1.8							
23						17.4	3.5	24.7				
24												
25						1.1	14.4					
26						10.9	2.4	9.9				
27					2.2		0.4	17.1	3.9			
28						24.7	17.1	0.1				
29												
30												
31							26.9					

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX C6: 1981 DAILY RAINAFALL DATAIN MILIMETERS AT GUSAU

MONTHS/DAYS	J	F	M	A	M	J	J	A	S	O	N	D
1												

2							7.4					
3							1.3	53.7	7.4			
4							15.0	1.5	33.5			
5									30.5			
6							8.8	22.4				
7												
8									2.3			
9							8.1	9.9	16.3			
10					1.8	0.0	0.3					
11						2.5	7.6		3.3			
12					4.3		10.2					
13							0.3		6.4			
14												
15												
16					18.5	3.6	54.4	8.4				
17						14.9		18.3				
18				22.1	15.1	0.3	2.0	0.3				
19					0.3		11.2	23.2				
20												
21						29.7	8.2	2.4				
22							16.3					
23						5.6		52.6	42.9			
24									2.8			
25					21.8		29.5					
26					5.8	3.3						
27				0.6				19.3	10.9			
28						10.7	0.3	24.2				
29								2.8				
30					15.5	3.8		8.4				
31												

Source: Nigerian Meteorological Services Department Oshodi, Lagos**.**

APPENDIX D1: MILLET AND SORGHUM YIELD IN Ton/HaAT KANO, KATSINA AND MAIDUGURI

Stations:	Kano		Katsina		Maiduguri	
Yrs	Millet	Sorghum	Millet	Sorghum	Millet	Sorghum
1981	NA	NA	NA	NA	NA	NA
1982	0.62	4.28	NA	NA	NA	NA
1983	3.59	2.14	NA	NA	NA	NA
1984	4.17	1.69	NA	NA	NA	NA
1985	4.24	2.54	NA	NA	NA	NA
1986	2.62	2.43	NA	NA	NA	NA
1987	4.77	2.24	NA	NA	NA	NA
1988	4.91	3.31	NA	NA	NA	NA
1989	3.04	2.48	NA	NA	NA	NA
1990	4.22	1.96	NA	NA	NA	NA
1991	1.38	4.27	1.02	1.33	NA	NA
1992	1.17	2.07	1.08	1.06	NA	NA
1993	1.90	1.85	0.81	0.94	1.93	1.98
1994	5.81	2.46	0.94	0.70	2.05	2.08
1995	2.08	3.29	0.89	0.66	2.60	2.34
1996	2.98	2.06	0.86	0.72	2.66	2.30
1997	3.56	2.42	1.07	0.67	0.90	0.75
1998	3.44	3.93	1.19	0.73	0.78	0.83
1999	1.33	1.77	1.21	0.70	0.65	0.73
2000	1.11	1.50	1.30	0.93	0.57	0.60
2001	1.57	1.96	1.65	1.09	0.52	0.70
2002	0.96	1.60	NA	NA	0.53	0.71
2003	1.75	1.44	NA	NA	0.53	0.71
2004	1.00	1.00	NA	NA	0.69	0.06
2005	1.00	0.98	NA	NA	3.12	1.57
2006	1.45	1.29	NA	NA	3.51	1.95
2007	1.28	1.37	NA	NA	4.02	1.35
2008	1.00	1.33	NA	NA	5.21	2.00
2009	0.95	1.93	NA	NA	4.92	1.74
2010	1.75	2.53	NA	NA	NA	NA

NA: *NOT AVAILABLE*

SOURCE: *KNARDA, KTARDA, AND BOSADP*

APPENDIX D2: MILLET AND SORGHUM YIELD IN Ton/Ha AT POTISKUM,SOKOTO AND GUSAU

Stations:	Sokoto		Potiskum		Gusau	
Yrs	Millet	Sorghum	Millet	Sorghum	Millet	Sorghum

1981	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA
1983	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA
1990	NA	NA	NA	NA	NA	NA
1991	NA	NA	NA	NA	NA	NA
1992	NA	NA	NA	NA	NA	NA
1993	1.28	3.07	NA	NA	NA	NA
1994	0.99	3.21	NA	NA	NA	NA
1995	0.55	2.41	NA	NA	NA	NA
1996	0.87	0.36	NA	NA	NA	NA
1997	1.05	0.39	NA	NA	NA	NA
1998	0.99	0.36	NA	NA	NA	NA
1999	1.10	0.53	1.00	0.97	1.00	1.32
2000	1.12	0.63	1.00	0.98	1.00	1.32
2001	1.04	0.24	1.00	0.94	1.01	1.32
2002	1.18	0.26	1.00	0.94	1.11	1.47
2003	1.07	0.64	1.00	0.92	1.00	1.33
2004	1.12	0.58	1.00	0.93	1.65	1.46
2005	1.10	0.48	1.00	0.99	1.62	1.28
2006	1.38	0.71	1.00	0.98	1.65	1.46
2007	1.75	1.19	1.00	0.98	1.00	1.31
2008	1.74	0.63	1.14	0.95	1.33	1.78
2009	NA	NA	1.03	1.00	1.41	2.19
2010	NA	NA	NA	NA	NA	NA

NA: *NOT AVAILABLE*

SOURCE: *SOSADP,YOSADP AND ZARDA*