ANALYSIS OF RAINFALL VARIATIONS ON SORGHUM YIELD IN NORTHERN AND WESTERN PARTS OF SOKOTO STATE, NIGERIA

BY

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CERTIFICATION

This thesis, titled: Analysis of Rainfall Variations on Sorghum Yield in Northern and Western Parts of Sokoto State, Nigeria by: HASHIDU, Usman Sadiq (M.Tech/SSSE/2007/1606) meets the regulations governing the award of the degree of Master of Technology (M.Tech.) of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Rainfall variability is the most important climatic factor influencing agricultural activities. Rainfall can vary considerably even within a few kilometers distance and on different time scales. This research aims at comparing the variations in rainfall between northern and western parts of Sokoto state and its affect on sorghum yield. Rainfall and sorghum yield data for fourteen stations distributed over the state were collected from Sokoto State Agricultural Development Programme (SADP) and Nigerian Meteorological Agency (NIMET). Statistically derived indices such as mean, standard deviation and coefficient of variation were used for this study. GIS kriging interpolations were carried out to map out the spatio-temporal variations of rainfall. Findings shows that there is a decrease in sorghum yield as a result of decrease in rainfall and increase in variability from western to the northern part of the state. The results showed that there were significant relationship between sorghum yield and total rainfall ($r=0.82$ and 0.83, northern and western parts respectively). A further regression shows a roughly linear relationship ($R^2=0.678$ and 0.683, northern and western parts respectively). It was therefore recommended that genetically drought resistant variety of sorghum should be used in the state.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Sustainable crop production in many semi-arid tropical areas of West Africa is often hindered by the erratic nature of rainfall. The total seasonal rainfall is often low, with considerable variation between and within the seasons. The variability of rainfall at the start of the season as well as mid-season breaks in the rains often result in poor crop establishment and in yield reduction. Thus, although single rains may wet the soil sufficiently for planting, these events may be followed by long dry spells (Sivakumar et al., 1979).

Rainfall variability can simply be considered as departure from the normal pattern of rainfall in its distribution, duration, amount, onset and cessation (Buba, 1992). The long-term mean precipitation amounts for a month, season, or year hardly indicate the regularity or reliability with which given amounts of rainfall can be expected. This is particularly yield is exceedingly variable over space and time. It has biggest effect in determining the crops that can be grown, the farming system, the sequence and timing of farming operations (Adejuwon, 2005). Rainfall can also be seen as the supplier of soil moisture for crops. The soil moisture supply, however, does not depend on rainfall alone, but also on various other factors concerned in the hydrological equation, such as evapo-transpiration and surface run-off (IPCC, 2000).

In many areas with alternating wet and dry seasons the annual rainfall is less than the amount of the water that a crop well supplied with water would transpire during the growing season. Theoretically, there are three different forms of rainfall variability: (a) Spatiotemporal (b) Inter-annual (c) Intra-annual variability (NEST, 2003). Spatiotemporal variability has to do with differences in total rainfall received between places structurally located with a given region over a period of time. Inter-annual rainfall variation can be defined as the annual deviation from long-term averages or the differences in rainfall variability refers. Intra-annual rainfall variability refers to the distribution of rainfall within a year (Obasi, 2003). In the last decade, inter-annual rainfall variations are causes of great stress to the farming activities, crop production and crop yield in the Guinea savanna of Nigeria (Adejuwon, 2004).

Rainfall in Nigeria is highly variable from year to year; typically over 20% of the average annual rainfall varied in some area (Oladipo, 1990). Because of the large inter-annual variability of rainfall in many parts of Nigeria, particularly the northern sector, severe and wide spread droughts may occur in some years in these areas in north western Nigeria, the variability is considered to be great both spatially and temporally and is considered to be one of the major limiting factors in agriculture. Large scale variations of rainfall in space exert a great influence upon agricultural systems and water supply. Not only do amounts depart from average condition in individual years but the way in which they vary differs from area to area (Jackson, 1989).

1.2 Statement of Research Problem

Sorghum is one of the most important cereal crops grown in all local government areas of Sokoto State. The white coloured sorghum variety has been found to produce malt with colour and consistency of honey. But for sometimes, Sokoto state has been experiencing this alarming phenomena of rainfall variability where the anticipated annual rainfall has been steadily on the decrease, thereby depleting the availability of both surface and underground natural water resources in the area.

The rainfall over the study area was sometimes not only late but also sparse and erratic. This situation affects agricultural activities seriously. Although, the water requirement of sorghum is within the annual rainfall of Sokoto state, fluctuations in the annual yield of sorghum is still recorded from year to year. The drought years of 1983-1984 and 1997 resulted in low agricultural yield and affected thousands of rural poor farmers (Fasona and omojola, 2005; Obioha, 2009). Although the scientific evidence on rainfall variability with its significant impacts on crop yield is now stronger than ever (Hare, 1985, WMO, 2000, IPCC, 2001, 2004a, 2004b; Adejuwon and Odekunle, 2004, 2006), not much has been done on the impacts of variability on sorghum yield.

1.3 Aim and Objectives

The aim of this research was to compare the rainfall variations on sorghum yield between northern and western parts of Sokoto state. To achieve this broad aim, the specific objectives include to:

i. Determine the spatial and temporal variability of rainfall in northern and western parts of Sokoto State over the period of 10 years (2000-2009).
ii. Examine sorghum yield over the period 10 years (2000-2009) for the two regions of the study area.
iii. Compare rainfall and sorghum yield of the study areas.
iv. Produce a trend model of the relationship between rainfall and sorghum yield for the two sub-regions.

1.4 Justification

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). The characters of rainfall vary not only from place to place but with time at a particular place. The nature of the rainfall can vary during the growing season and this will have major implications (Jackson, 1988).

Although, the state falls within the ecological zone of Sudan savannah, the extreme northern part is a transition zone between Sahel and Sudan. This resulted into a difference in rainfall of the western and northern parts of the state as mean annual rainfall varies from 725mm around Margai to 553mm at Isa and falls during the period from April to October and seasonal rainfall results in a water deficit during the dry season. However, agricultural production is faced not only with variable amount of highly seasonal rainfall, but also variations in the onset, duration and intensity of the rains, which may be very localized at the beginning and end of the rainy season (Davis, 1982). The economy of the state depends largely on agriculture with over 85 percent of the population engaged in agriculture, which is highly sensitive to variability of rainfall across time and space.

1.5 Scope and Limitations of the Study

The scope of the study is concern with Sokoto state with regards to differences that exist in rainfall between the western and northern parts of the state and its effect on sorghum yield. With regards to the in depth of the investigation, the focus is on spatio-temporal variations of rainfall on sorghum yield.

Although, yield and climatic data records for ten years 2000-2009 from fourteen stations are available, there were no such records of data prior to year 2000 as only that of Sokoto station was available. This factor is responsible for the analysis of only ten years data instead of at least thirty year period.

1.6 Description of the Study Area.

1.6.1 Sokoto State at a Glance

A state (North-Western) based in Sokoto was established in 1967. This covered what is now Niger State, which was split off in 1976, Kebbi State (split off in 1991), and Zamfara State, which was split off in 1996. It has an area of 25,973 km square.

1.6.2 Location

The state lies between latitude $13^{0}58^{1}$N and 12^{0}N and longitude $4^{0}08^{1}$E and $6^{0}54^{1}$E, the state is bounded by Niger Republic to the north, Kebbi State to the south, Zamfara state to the east and Benin Republic to the west.

1.6.3 Population

According to the 2006 population census result Sokoto state has a population of 3,702,676 comprising 1,863,713 males and 1,838,963 females. The major ethnic groups in the state are Hausa, Fulani and Dakarkari.

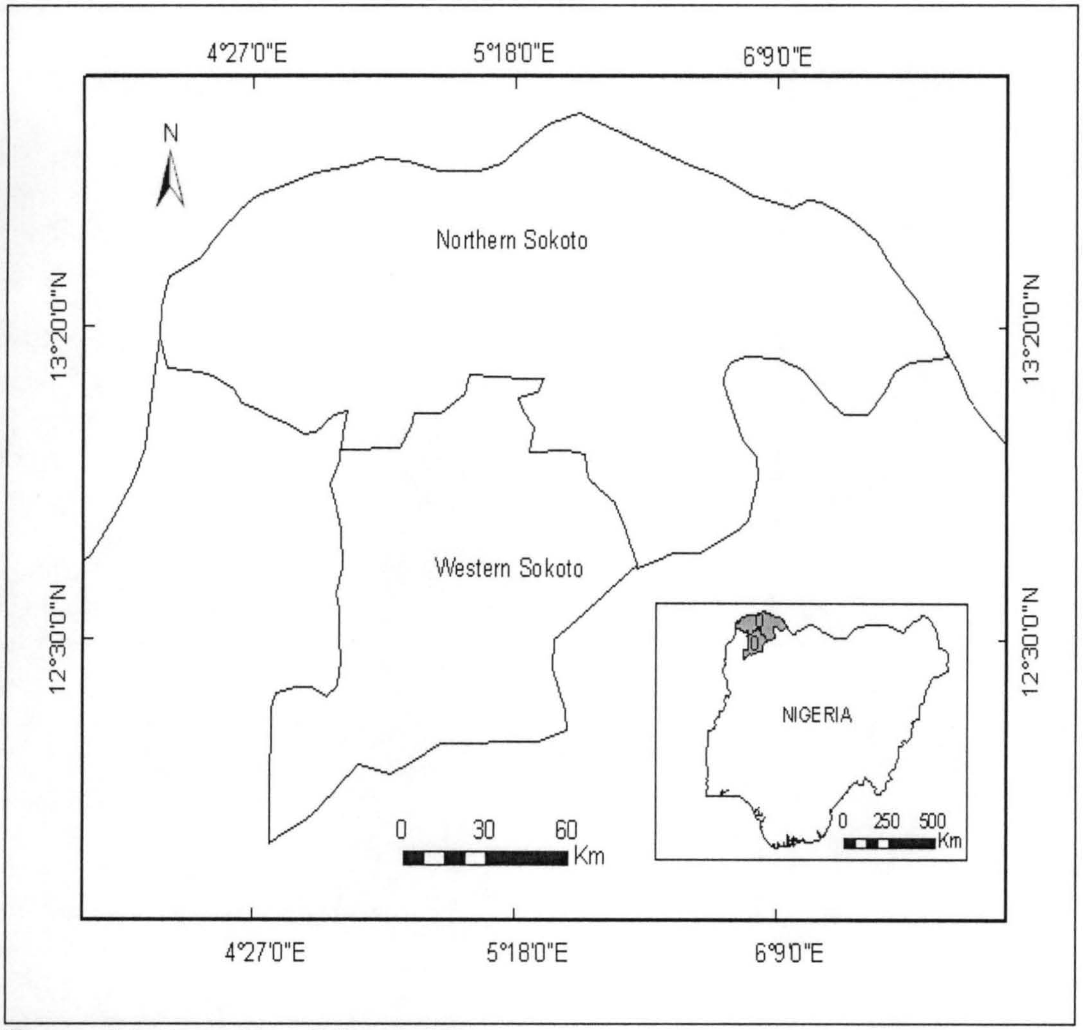


Figure 1.1: Location of the study area

Three critical factors are important in the distributional pattern of population in Sokoto state, these are the history of the state particularly that of the former Sokoto caliphate, the availability of water and fertile soils as well as the development of urban areas arising from state and local government creations (Mamman, 1991). One of the most striking characteristics of population distribution in the state, like other states, is its unevenness and variable density. For example while areas around illela area are sparsely populated, high densities of over 300 per square km can be found within the Sokoto close settled zone and even higher densities within the Sokoto home districts.

The relatively high concentration of population in these favoured areas is likely to put pressure on agricultural land although there are no conclusive evidences to prove this (Kwabe, 1991).

1.6.4 Climate

The climate of Sokoto state and indeed of much of West Africa, is largely the result of the interplay of two different air masses; the moist, tropical, maritime air mass from the Atlantic and the dry, continental air mass from the Sahara. The zone where these two air masses converge is known as the inter-tropical discontinuity (ITD), which has approximately a latitudinal surface orientation in Nigeria and which migrates north-south in accordance with the seasons.

The prevailing type of weather can be explained in terms of the weather systems associated with the ITD and its location at any given time. For much of the year it lies to the south of Sokoto state when the dry north-easterly air or Harmattan predominated. As the ITD moves north-wards, the Harmattan gives way to dry but humid weather, and then during the summer months with the ITD lying to the north, disturbance line thunderstorms form in the moist southerly air mass, bringing rain to Sokoto state. The marked seasonality and distribution of rainfall result from the north-south movement off these weather zones.

Average annual rainfall varies from 725mm around Margai to 553mm at Isa. There are however, some stations which records anomalously high or low amounts. Much of the rain in Sokoto state falls between April and September in the north and from March to October in other parts. A notable feature of the seasonal migration of the ITD is its irregularity. Generally it advances northwards at about 100 miles (160km) per month and retreats southwards at about 200 miles (320km) per month which explains why the ends of the rains is more abrupt than onset. However, departures from the general trend may occur within any one year and variation from year to year can be quite considerable. Consequently, the overall amount of rainfall and the pattern of distribution throughout the year at any given recording station can be very different from one year to the next.

The mean daily maximum and minimum temperatures for Sokoto, shows that the principal characteristics are the pronounced seasonal variation of diurnal range. The maximum and minimum temperatures increase during the first part of diurnal range. At all three stations daily maximum and minimum temperature increase during the first part of the year to reach a peak during the "hot season" in late March to April. The onset of the rains has a cooling effect with daily maximum temperatures, falling below 90^0F (36^0C), but at the same time cloudiness and humidity prevent back radiation at night, so that minimum temperatures remain fairly constant. Thus during the rainy season the diurnal range of temperature is comparatively small.

At the end of rainy season daily maximum temperatures rise throughout the 'little hot season' before a slight cooling around the end of October. Daily minimum temperature fall rapidly during October since the dry continental air mass from the north moves in at the ITD retreats southwards, allowing increased back-radiation daily to take place. During the Harmattan season daily minimum temperatures fall to below 59^0F (17^0C) and the diurnal range is large.

1.6.5 Vegetation

The state falls within Sudan Savanna to the south and Sahel Savanna to the north. The vegetation is characterized by thorny species with a scatter of accai specie. The river courses are lined with dum palms which are interspersed with a herbaceous cover of annual grasses.

1.6.6 Soils

Sandy top soils with clayey subsoil are common, except along the flood plains of the river valleys where alluvial soils predominate. To the north of the state especially along the border with Niger republic, the undulating plains are covered by aeolion deposits of variable depth. These support light sandy soils. However, due to its geographical location the state suffers from the scourge of desertification and occasional drought. Mineral such as clay, gold, kaolin, gypsum, marble, lignite, feldspar and limestone can be found in the state.

1.6.7 Geology

Sokoto state can be divided into two major geological regions. The south-eastern half of the state is formed of rocks which belong to the basement complex, whereas in the north-western half these rocks are overlain by the much younger sedimentary deposits of the lullemmeden basin. The boundary between the two regions runs in a north-east-south-west direction across the state. The two regions comprise different types of rocks, which were formed during different periods of geological history.

1.6.8 Relief

Sokoto state can be divided into three physiographic regions; the uplands or high plains of the east and south, the Sokoto plains of the north and centre, and the riverine lowlands of the Niger and lower Rima Valley (part of the Benue-Niger trough). In general, the land surface descends in three “steps” or erosion surface from the south-east and east towards the Rima Niger lowland.

1.6.9 Drainage

Sokoto state is drained by the Rima River and its tributaries, most of which rise in the south eastern part of the state and in the neighbouring state. While the Bunsuru, Gagare flow in a northerly direction joining the Rima near Sabon Birni the Sokoto tributaries on the other hand flow westwards to join the Rima. In their upper ridges, all the tributaries flow over basement complex rocks. Their valleys are rather narrow and restricted until the rivers enter the area of young sedimentary rocks, where they flow through broad valleys.

1.6.10 Agriculture, Forestry and other Basic Activities

Over 85 percent of the state population is engaged in agriculture. The main crops are millet, guinea corn sugar cane, beans and cereals. The state is second only to Borno in livestock production (National Livestock Survey). Although available data on cattle population are dated nevertheless, the national livestock survey showed that Sokoto state has a cattle population of nearly two million cattle, nearly 2.5 million goats 2.6 million sheep, 248000 donkeys, about 44, 000 camels and nearly 25, 000 horses.

The large livestock population of the state along with equally high density of the farming population has led not only to over-grazing and soil degradation but also to conflicts over land use between the pastoralists and farmers. This situation has been further worsened by desertification and the occurance of occasional drought; hence the precarious food situation in the state. The state is also at the fore-front in Fadama agricultural development. About 6, 280 tube wells have been sunk, making about 4, 500 hectres cultivable. Favourable irrigation sites have been developed by the construction of dams at Goranyo, Kalmalo and Wamakko.

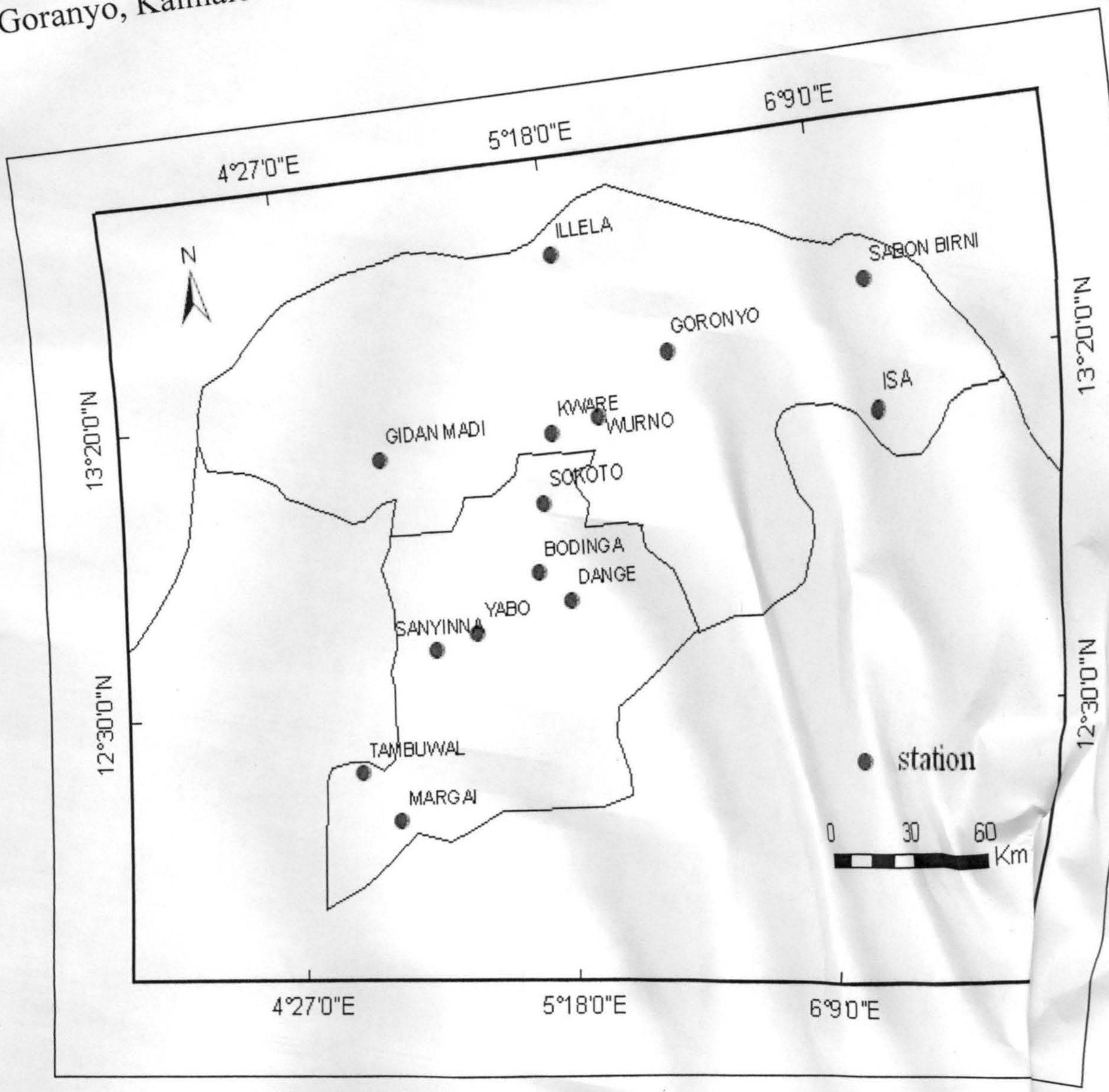


Figure 1.2: Locations of the Meteorological Stations Selected Across the Study Area

CHAPTER TWO

2.0 LITERATURE REVIEW

In recent times, deficiency in rainfall with the attendant problems of drought has been the norm over the west African region (Nicholson, 1983), Adejuwon (1988). One of the several hypotheses put forth to explain the decline of rainfall in west Africa is the reduced northward excursion of the Inter-tropical Discontinuity (ITD) during the raining season. The total rain and distribution of rains at any location determine the frequency and intensity of drought and flooding as well as the length of growing season in that location (Anuforam, 2004).

2.1 Spatial Variations of Rainfall

Nicholson et al (2000) found that a substantial decrease in 1968-1997 mean rainfall relative to the 1931 – 1960 mean, was particularly noticeable for August, when the decrease in mean rainfall amount were, 55%, 37% and 26% in the Sahelo-Sahara, Sahel and Sudan zones, respectively. The onset of rains is earliest in the south and is delayed by monsoon India to over 50% in arid areas of the world. They noted that detailed examination of the precipitation in many diverse climatic regions shows that the apparent inverse relationship between annual total and variability is only very approximate. Moreover, a co-efficient of variation is 50 percent. In fact, violates statistical assumption of a formal frequency distribution on which this statistics is based Barry and Chorely (2003). Jackson (1985) observed that contrast in deviations in rainfall from the mean occur more widely in the tropics than is generally appreciated. Odekunle et al (2007) finds that rainfall variability is very high in most of northern Guinea Savanna of Nigeria with Yola, Minna, Abuja and Mokowa having values of co-efficient variation between 26-49%.

Nicholson and Palao (1993) examined spatial and temporal variability in Sahel rainfall and identified three relatively homogeneous areas. Long-term rainfall trends, inter-annual persistence, relationships between seasonal and annual fluctuations, and the contributions of low- and high-frequency variations are different in these three areas. The patterns and temporal variability of rainfall also differ in June–July and August–September. Nicholson (1989) described a small number of commonly occurring spatial rainfall patterns in Africa. The most common pattern showed negative rainfall anomalies in the subtropics with positive rainfall anomalies in the equatorial latitudes. Another frequently occurring pattern is negative anomalies throughout the continent. The inverse of these two modes constituted the remaining patterns.

The importance of changes in the spatial variability of rainfall is well illustrated in a recent study by Vinnikov et al., (1990). They have indicated that in spite of the total increase in rainfall over the USSR, the geographic and seasonal distribution was not favorable for crop production: the crop belt suffered from a severe agricultural drought, although the overall annual rainfall increased. Jackson (1986) finds consistent patterns of fewer rain days and higher mean daily intensities of rainfall at Darwin and Daly waters than elsewhere in the tropics and then confirms this with analyses of additional station across northern Australia (Jackson, 1988).

2.2 Seasonal Variations of Rainfall

Label and Lebarbe (1997) found that the decrease of the rainfall amount in the core of the rainy season (July-August) was related to the number of rain events, while mean intensity of rainfall events remained unchanged. Most annual crops in the region are particularly sensitive to dry spells in August, when they undergo the processes of stem elongation, penicle differentiation and seed set. Graef et al (1999) while evaluating land in south western Niger reveals that severe climate limitation for millet production occur only in one out of eight years and are due to unfavourable rainfall distribution rather than to the total rainfall amount.

Adams (1992) asserts that "variability of rainfall even within a single wet season represents serious problems of development planning". According to Adams (1992) he asserted that "annual rainfall averages are considerably more stable than seasonal averages and averages over a sufficient number of consecutive similar seasons (for example ten consecutive summers) to be virtually invariant. Averages over 10 fully years consecutively should be more stable". Kidson, (1977) correlated monthly vertical motion patterns and rainfall over Africa between 1951 and 1975 for January, April, July, and October. Correlations exceeding the 95% confidence limit existed over much of the area affected by the seasonally migrating rain belt. With the annual cycle removed, correlations were ''barely significant'' and vertical motion data were not sufficient to indicate relationships between rainfall departures and departures from seasonal vertical motion (Kidson 1977).

2.3 Rainfall Variability Linkages

According to Bello (1997), in assessing rainfall variability in Nigeria, the three major producing weather system (local thunderstorms, line-squall and ordinary monsoons) associated with the seasonal monsoons and the ascillating inter-tropical discontinuities are considered. Rainfall data over nineteen synoptic stations for the period 1960-1989 was used.

Correlation results between each of the rain producing weather systems and total rainfall gave an insight into the dominant system(s) responsible for rainfall variability in different parts of the country. The co-efficient of variation was also estimated.

Cane et. al (1994) in their study of potential impact of ENSO on agriculture in Zimbabwe found that SSTs in the $NINO_3$ regions were a good predictor of national-level Zimbabwean maize yields. Years in which the SST anomaly was strongly positive (El Nino years) were associated with lower than average precipitation and maize yields; years with negative SST anomalies (called here, "LaNina" years) were associated with higher than average rainfall and maize yields.

Shaw (1985) concluded that the nineteenth century high stands of Lake Ngami required that it receives only about 11% of the Okavango's current total inflow, implying a rainfall increase of about this same order of magnitude. Owen et al. (1990) calculated that a 120-m transgression of Lake Chilwa could have been produced by a 30% to

50% increase in rainfall, compared to the present century, if these conditions persisted for about a century. Fontaine et al. (1995) related rainfall anomalies to wind behavior in the Sahel and Guinea coast. They observed that rainfall anomalies in these two regions were often of opposite sign. In addition, the Sahel drought–Guinea flood scenario corresponded to an increased, southward, low-level, meridional temperature gradient and a stronger wind velocity at the AEJ's southern border.

Shanko and Camberlin, (1998) have shown that years exhibiting the consecutive occurrence of several tropical depressions over the southwest Indian Ocean (SWIO) coincide with the drought years (e.g. 1972, 1984) in Ethiopia. In contrast, years of abnormally low frequency of tropical cyclones are associated with heavy rainfall in Ethiopia. They further shown that *Belg* rainfall is influenced much more by the cyclonic activity than *Kiremt* rainfall, which occurs outside the cyclonic season of the SWIO. On a daily basis, rainfall activity during the *Belg* period is significantly reduced when a tropical depression is observed in the SWIO, before picking up again a few days later. Shanko and Camberlin, (1998) found no systematic time lag between the cyclone occurrence and the decrease in daily rainfall amounts. However, they indicated that, at inter-annual time scales, a higher (lower) frequency of tropical depressions during the months of November–January tends to be followed by abnormally low (high) *Belg* rainfall.

Tessema and Lamb, (2003) have studied the inter-annual variability of *Kiremt* onset, cessation and growing season over the drought-prone northeastern part of Ethiopia. They have found that:

1. *Kiremt* onset is positively correlated with preceding December–February sea-surface temperature (SST) over the equatorial central and eastern Pacific Ocean; the pattern persists through April–June, but diminishes significantly during July–September.

2. *Kiremt* cessation correlates poorly with SST in the tropical Atlantic and Pacific basins, but more strongly (positively) with SST in the western Indian Ocean and Arabian Sea. This positive relation indicates that warm SSTs in the Indian Ocean and Arabian Sea are likely to be associated with delayed *Kiremt* cessation, and hence prolonged rain, perhaps in association with an increase in tropical storms/depressions over the Arabian Sea near the end of *Kiremt*.
3. Effective *Kiremt* growing length is significantly correlated with tropical Pacific SST.

2.4 Fluctuations and Trends of Rainfall

Jensen (1990) noted a long-term (45-78years, depending on record length) negative trend averaging 10mm year^{-1} (1960-1983) in rainfall records in northern Nigeria, shortening of growing seasons and south ward movement of agro-ecological zones. Subsequent studies showed the same pattern throughout the Sahel (sivakumar, 1993; Hulme and

Jones, 1994; Fontaine and Janicot, 1996; L. 'Hote and Mahe, 1996; Diouf et al, 2000; Traore et al, 2000).

Bunting et al, (1976) noted that the period 1931-1960 (previously used as a standard for comparison of climatological data) was one of greater than 'average' rainfall in West Africa generally, and Hulme (1992) found that, considering the following 30 years period mean seasonal rainfall in the Sahel had fallen by as much as 30%. Nicholson (1989) identified a steady downwards trend in annual rainfall totals in the Sahel and Sudan zones of West Africa since the 1950s with a long sequence of dry years commencing around 1968. Servat et al (1997) and Paturel et al (1997) showed that there had been a significant decrease in rainfall amounts during the decades, from 1950s to 1980, along the Gulf of Guinea, with Nigeria having and extreme variation. The zonal variability of rainfall especially, is observed to bring about not only the differences in the types of crops cultivated but also the rate of yield of such crops (Osagie, 2002; Adejuwon and Odekunle, 2006).

Obasi, (2003a: 2003b) noted that the increased yield of maize recorded in 1990 to 2000 in Guinea Savanna of northern Nigeria may be attributed to the increase in rainfall during the planting season within the period. The years 1983 and 1993 experienced very low rainfall during planning season that had been due to greater number of drought episodes.

Janicot and Sultan (2001) have documented 10–25-day rainfall fluctuations, pointing out that this intra-seasonal variability corresponds to large and coherent fluctuations in the rainfall and atmospheric signal over all of West Africa. Indeed, Ingram et al. (2002), in a recent study on several villages of Burkina Faso, classified in order of declining priority the most salient rainfall parameters in agricultural strategy for farmers. They were (1) timing of the onset and end of the rainy season, (2) rainfall distribution and water deficits within the season, and the lowest priority, (3) total amount of rainfall. Grove (1972) shows that the Nile discharge during the period ca. 1880–1895 was about 35% greater than for the period 1910–1940. In West Africa, rainfall at

Freetown, Sierra Leone, declined by a comparable amount during the same period (Nicholson, 1981a, b). This is comparable to the 15% to 35% increase that the model of Hastenrath and Kutzbach (1983) indicated would sustain the high early Holocene stands of the East African lakes.

2.5 Rainfall Probability and Reliability

According to Phillips et al. (1997) rainfall variability is critical in determining agricultural yields. In more stable environments, even if rainfall is relatively low, farmers can tune their cropping systems to optimize resources. But if the pattern of precipitation from the time of planting onward is unknown, farm management is likely to be aimed at minimizing risks, which often means settling for low inputs and low but stable yields. Mabbutt (1989) observes that, in regions with short growing seasons and rainfall as a limiting factor, the climatic limit of regular cropping tends to be set by the level of probability of inadequate seasonal rainfall. Hence, probabilities are essential for the examination of variability.

Changes in annual rainfall have been studied based on area-averaged rainfall data for the north central highlands of Ethiopia (e.g. Osman and Sauerborn, 2002; Seleshi and Demar′ee, 1995). This analysis indicated that the second half of the 20th century suffered predominantly negative rainfall anomalies, with *Kiremt* ('main rains', June–September) values frequently being lower than the long-term average. Conway (2000), however, found no recent trends in rainfall over the northeastern Ethiopian Highlands. According to Goldreich (1995) applying Gaussian statistics to annual rainfall data in Israel should be undertaken with some caution due to right skewed distributions, and the use of standard deviations to predict probable values (above or below a certain threshold) is not recommended.

2.6 Methods used in Assessing the Impact of Rainfall Variability on Crops Yield

In the literature, different methods/models have been employed by research workers in many areas to evaluate the impact of rainfall variability on crops yield. Among such models are the parametric, GIS-based, the non-parametric, time-time analysis, the theory-based, CV (Coefficient of Variation) based, the PCA (Principal Components

Analysis) and ICA (Independent Components Analysis) models. Gommes (2006) has argued that among the many models, "parametric models" are considered to be those that attempt to interpret and to quantify the causality links that exist between crop yields and environmental factors (mainly weather), farm management and technology. They include essentially crop simulation models and statistical "models" which relate crop yield with assumed impacting factors.

On the other hand, crop-yield-weather simulation belongs to Armstrong's Theory-based Models. Non-parametric forecasting methods are those that rely more on the qualitative description of environmental conditions and do not involve any simulation as such (Armstrong's expert systems and analogies). There are few explicit applications of non-parametric forecasting methods to agricultural yields, among others because of differing usage of the term "non-parametric (*e.g.* in Orlandini et al., 2004). Some methods are described by Gommes et al., 2007.

Singh and Singh (1996) while analyzing the space-time variation and regionalization of seasonal and monthly summer monsoon rainfall of the sub-Himalayan region and Gangetic plains of India uses principal component analysis (PCA), a multivariate statistical procedure, commonly been used to identify the dominant patterns of spatio-temporal variability in climate data. This procedure not only identifies the important patterns of spatio-temporal variability but also determines the variance explained by them. Westra and Sharma (2005) in their study of seasonal rainfall variability in Australia explore the potential of a relatively new technique known as independent component analysis (ICA), which has been developed as a means to separate mixtures of signals when little is known about either the original signals, or the manner in which they have been mixed. This is a problem that occurs frequently in the climate field, where one understands the factors that contribute to the dynamical nature of a given set of observations.

In recent assessments of climate change impacts on U.S. agriculture, Reilly et al. (2001) and Thomson et al. (2005) relied heavily on process-based crop models, which emphasize physiological controls on plant growth but do not consider the effects of crop pests and diseases. In California, omission of these processes may be especially problematic given the prevalence and economic importance of fruit and nut crops, which are sensitive to a variety of pests and diseases (Wilkinson et al., 2002). In addition, scaling the results of process-based crop growth models to the regional and global scales often of interest requires several non-trivial steps, as reviewed by Hansen and Jones (2000).

Adams et al. (2003) utilized an empirical approach to study climate change impacts on a wide range of California crops. Their models used *a-priori* decisions on predictor variables, with climate variations represented by average daytime maximum temperatures and rainfall for months between March and September. By ignoring daily minimum (night time) temperatures and non growing season months, it was implicitly assumed that these variables were less important for yield variations. The authors report high values for the proportion of yield variance explained (adjusted $R^2 > 0.5$) for many grain and fiber crops (e.g., wheat, rice, corn, cotton), but generally lower accuracies for fruits and vegetable crops.

Odekunle et al. (2007) uses GIS (Geographical Information System) technique to examine and map the spatio-temporal impact of rainwater variability on water availability for crop maize yields in the Guinea Savanna Ecological Zone of Nigeria. GIS makes it easy to work with spatial data, to see patterns, which could not be seen originally, and revealing hidden trends and distributions, thus gaining new insights. The statistical methods that were employed in his study include correlation of crop yield with annual rainfall total and Z- distribution anomalies. Balogun (1972) discussed three widely used methods of expressing rainfall variability and showed that use of the coefficient of variability is the most advisable when examining the spatial variability of rainfall. The coefficient of variability (CV) is used in this study and is defined as:

$$CV = \delta/\bar{x} \times 100\%.$$

Where:
CV = Coefficient of Variability
δ = Standard deviation
$\bar{x}$ = Mean

3.2 Description of Data Set

The climatological (rainfall) and crop yield (sorghum, *Sorghum bicolor*) data for the study area was obtained from Sokoto state agricultural development programme (SADP), for the period of (2000-2009).

For the purpose of collecting these datasets, the SADP divided Sokoto state into two parts i.e. northern and western. Of the many stations in the two parts, only fourteen have complete data coverages over the 2000-2009 periods for both rainfall and sorghum yield and these stations include Illela, Sabon Birni, Goronyo, Gidan Madi, Wurno, Isah and Kware from the northern part and Sokoto, Bodinga, Dange, Yabo, Sanyinna, Tambuwal and Margai from the western part. While the the rainfall data for the ten years were available for each of the fourteen stations, that for sorghum yield was also available for the same period but for northern and western parts, generalised. Though this generalization limited the chances of the study investigating the extent of spatial variations across the various stations, it nonetheless afforded the study an opportunity of assessing on broad basis the relationships between the two variable (rainfall and sorghum yield) over the two main parts (the northern and western) of the state.

Table 3.1: Description of data set

Type of data	period (years)
Rainfall	10
Sorghum yield	10

Source: Sokoto State Agricultural Development Programme.

3.3 Spatial Interpolation.

For the mapping of spatial pattern of trends from point data, Kriging interpolation method was used. Geostatistical analysis tool of ArcMap 9.1 (ESRI, 2004) was used for this purpose. Kriging is a stochastic interpolation method (Journel and Huijbregts, 1981; Isaaks and Srivastava, 1989), which is widely recognised as the standard approach for surface interpolation based on scalar measurements at different points. Studies show that Kriging gives better global predictions than other methods (Van Beers and Kleijnen, 2004). Kriging is an optimal surface interpolation method based on spatially dependent variance, which is generally expressed as a semivariogram. Surface interpolation using kriging depends on the selected semivariogram model and the semivariogram must be fitted with a mathematical function or model. Depending on the shape of semivariograms, different models have been used in the present study for their fitting.

Rainfall is a dynamic phenomenon, which changes over time and space. Complete analysis of rainfall events requires a study of both its spatial and temporal extents.

Hydrological investigation over a large area requires assimilation of information from many sites each with a unique geographic location (Shahid *et al.*, 2000, Shahid and Nath, 2002). GIS maintains the spatial location of sampling points, and provides tools to relate the sampling data contained through a relational database. Therefore, it can be used effectively for the analysis of spatially distributed hydro-meteorological data and modelling. In this research, GIS is used to show the spatial variation of rainfall.

3.4 DATA ANALYSIS

Statistically derived indices were used for this study combined with graphical methods. This is because statistical analysis has for long proved to be an integral part of geographical data analysis process. Statistics also enables facts to be more easily summarized and these allow one to arrive at conclusions more objectively. Among the major statistically-derived indices include being widely used in this regard are the mean, standard deviation and coefficient of variation. The mean of the monthly and annual rainfall was computed using this equation:

$$\bar{X} = \frac{\sum X}{n}$$

Where:

$\bar{X}$ = mean of the daily, monthly and annual rainfall
X = rainfall for a given period
n = number of cases or years in each station

These rainfall mean assumes a central tendency each period. Another statistical method used in this study is the standard deviation (δ) and is written mathematically as:

$$\delta = \frac{\sum (X - \bar{X})^2}{n}$$

Where;

δ = standard deviation
√ = square root
∑ = summation
X = rainfall for a given period
$\bar{X}$ = mean of any station
n = number of cases or years in each station

Correlation analysis was also used in order to evaluate the relationship between sorghum yield and rainfall of the growing season as well as sorghum yield and number of rainy days of the growing season. This relationship is typically expressed in the form:

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{[n\sum X^2 - (\sum X)^2 (n\sum Y^2 - (\sum Y^2))]}}$$

Where:

X = rainfall for a given period.
Y = sorghum yield for a given period.
n = number of cases.

A further regression analysis between sorghum yield and total rainfall was carried out using the Statistical Package for Social Science (SPSS) software.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the results of the various data analytical exercises conducted in the study, with particular emphasis on spatio-temporal distribution of rainfall and the impact of rainfall variability on sorghum yield. Relevant illustrations have used to facilitate the presentation.

4.1 Spatial Variability of Rainfall

Figure 4.1 shows the lines of equal annual average rainfall in Sokoto State. A close look at the figure reveals that there is a pattern of decreasing average annual rainfall as one moves from the western to the northern parts. This could be attributed to the impact of changing latitudes on spatial distribution of rainfall over the earth's surface. In the tropics, rainfall typically decrease in both amount and duration with increase in latitudes from the equator.

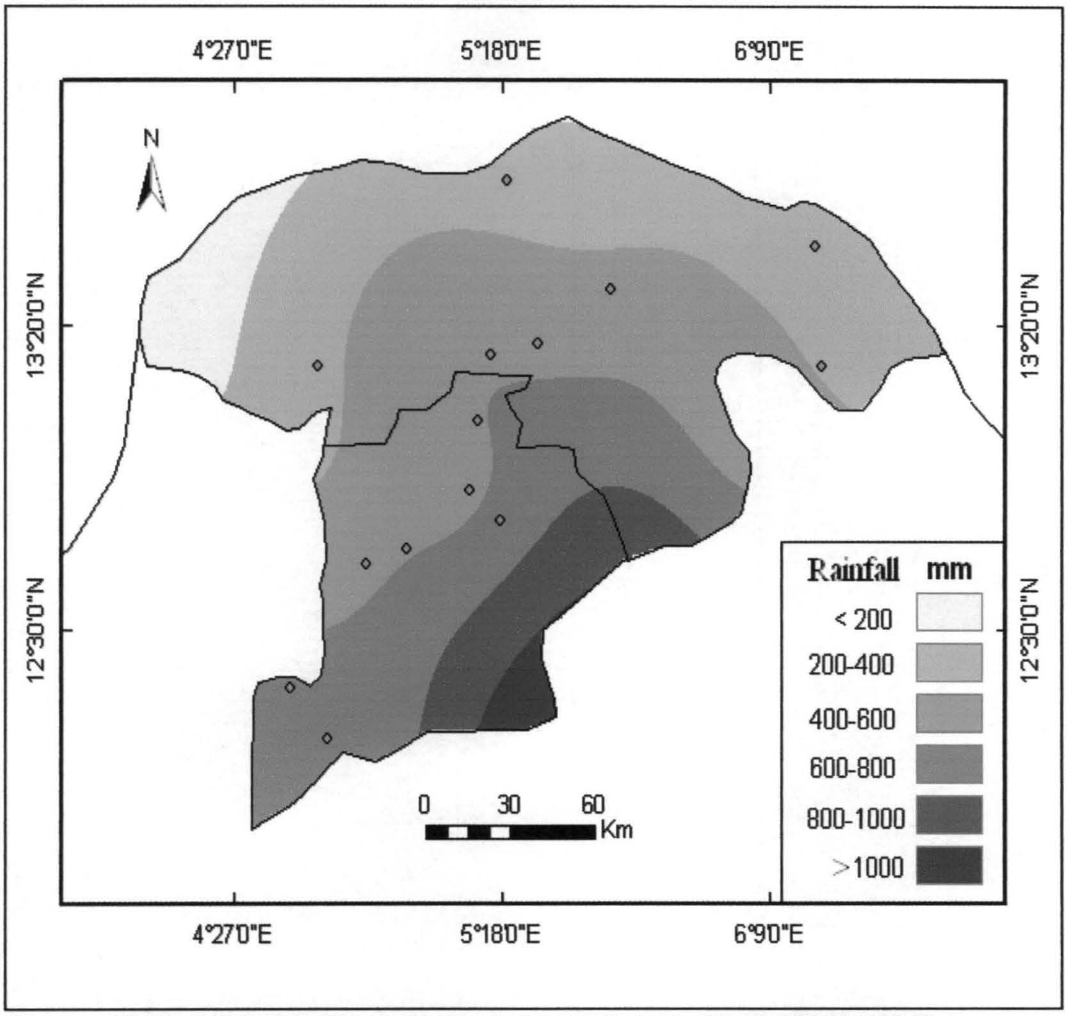


Figure 4.2: Spatial distribution of rainfall in Sokoto State (2000-2009)

Figure 4.2 shows the distribution of annual average rainfall in Sokoto State with over 1000mm in some western part and less than 200mm in some northern part.

Table 4.1: Five year running mean rainfall for Northern Sokoto State

Station	Running Mean Periods 2000-2004	2005-2009
Illela	450.6	433.8
S/ Birni	462.7	477.2
Goranyo	617.0	513.5
G/ Madi	479.4	478.3
Wurno	563.9	655.4
Isah	465.6	553.3
Kware	661.7	644.4

Source: Compiled by the author, 2010.

Table 4.1 shows five year running mean rainfall for the period 2000-2004 and 2005-2009 in seven stations of the northern part of the state.

Table 4.2: Five year running mean rainfall for Western Sokoto State

Station	Running Mean Periods 2000-2004	2005-2009
Sokoto	734.5	603.8
Bodinga	699.8	597.4
Dange	787.2	683.1
Yabo	710.9	612.9
Sanyinna	574	696.6
Tambuwal	753.5	681.7
Margai	673.6	776.7

Source: Compiled by the author, 2010.

Table 4.2 shows five year running mean rainfall for the period 2000-2004 and 2005-2009 in seven stations of the western part of the state.

Table 4.3: Some Descriptive Statistics for Annual Rainfall over Northern Sokoto State

Station	Mean	Std. Dev.	C.V (%)	Lat.	Long.	Elevation (m)
Illela	442.21	91.14	20.61	13.44	5.19	265
Sabon Birni	469.92	86.21	18.34	13.33	6.18	309
Goronyo	565.21	151.57	26.82	13.26	5.39	280
Gidan Madi	478.84	97.27	20.31	13.22	4.43	265
Wurno	609.67	162.14	26.60	13.17	5.25	304
Isa	509.43	74.49	14.62	13.13	6.19	326
Kware	653.07	56.31	8.62	13.12	5.16	266

Source: Compiled by the author, 2010

The results in table 4.3 shows the mean, standard deviation and coefficient of variation of annual rainfall in seven stations of northern part of the state.

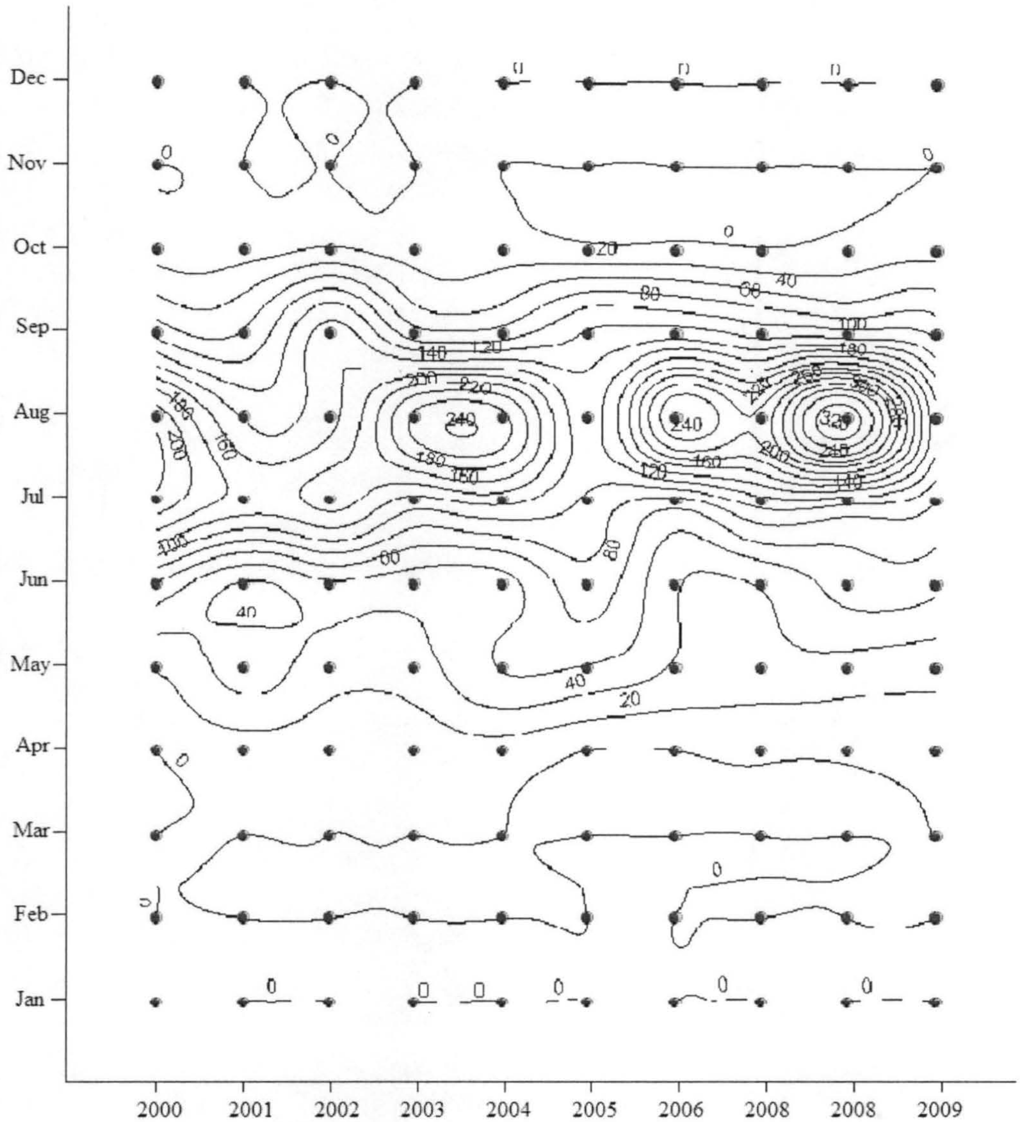
Table 4.4: Some Descriptive Statistics for Annual Rainfall over Western Sokoto State.

Station	Mean	Std. Dev.	C.V (%)	Lat.	Long.	Elevation (m)
Sokoto	669.15	105.26	15.73	13.04	5.14	284
Bodinga	648.62	141.69	21.85	12.53	5.1	304
Dange	735.12	229.03	31.16	12.5	5.2	310
Yabo	661.88	162.00	24.48	12.43	5	258
Sanyinna	635.32	171.87	27.05	12.41	4.52	208
Tambuwal	717.57	79.62	11.10	12.24	4.38	268
Margai	725.16	137.26	18.93	12.1	4.45	211

Source: Compiled by the author, 2010.

The results in table 4.4 shows the mean, standard deviation and coefficient of variation of annual rainfall in seven stations of western part of the state.

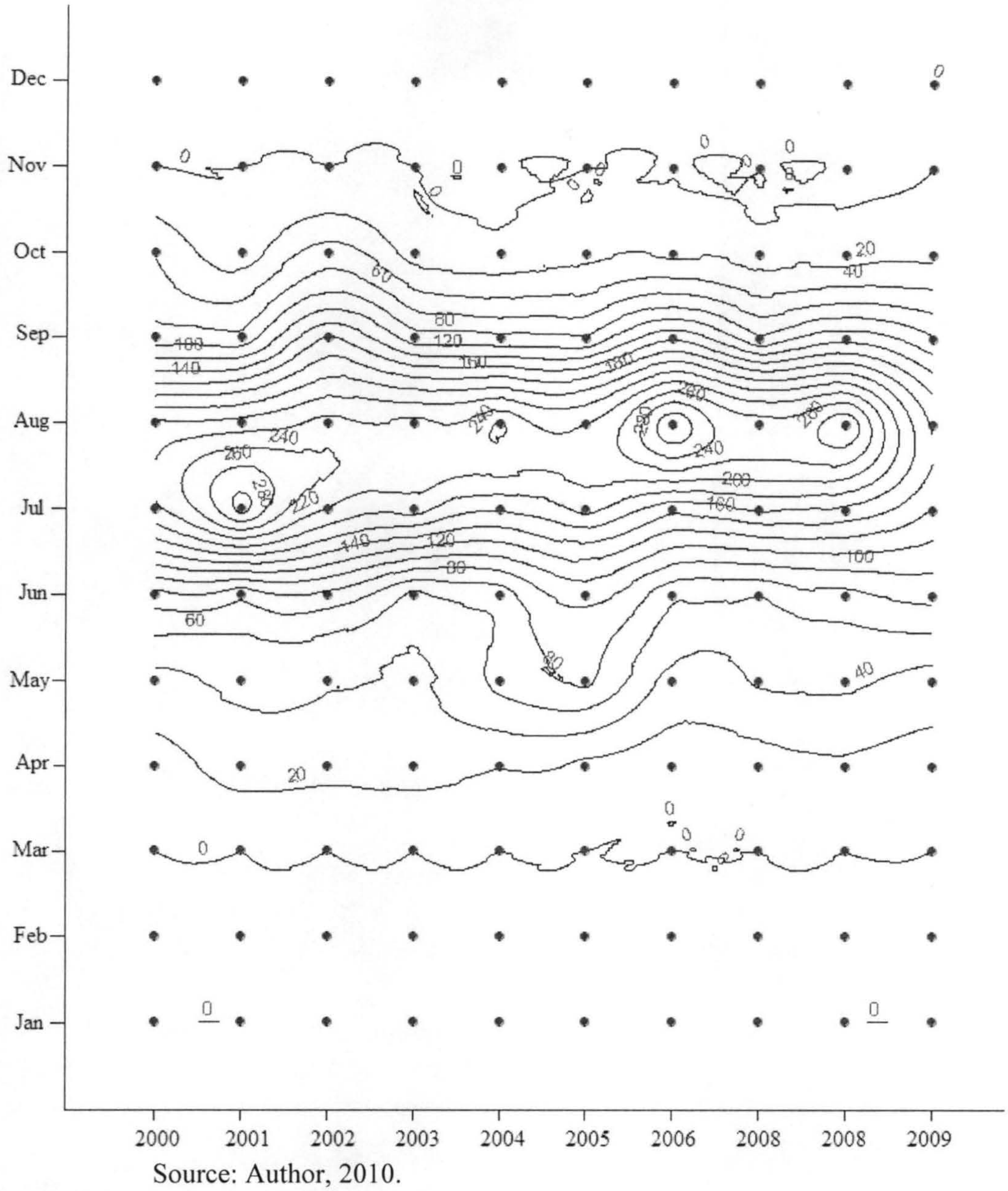
4.2 Temporal Variability of Rainfall



Source: Author, 2010.

Figure 4.3: Time-Time analysis for rainfall in Northern Sokoto State (2000-2009).

The rainfall interpolation of years against months for the period 2000-2009 in northern part of the State is shown in figure 4.3.

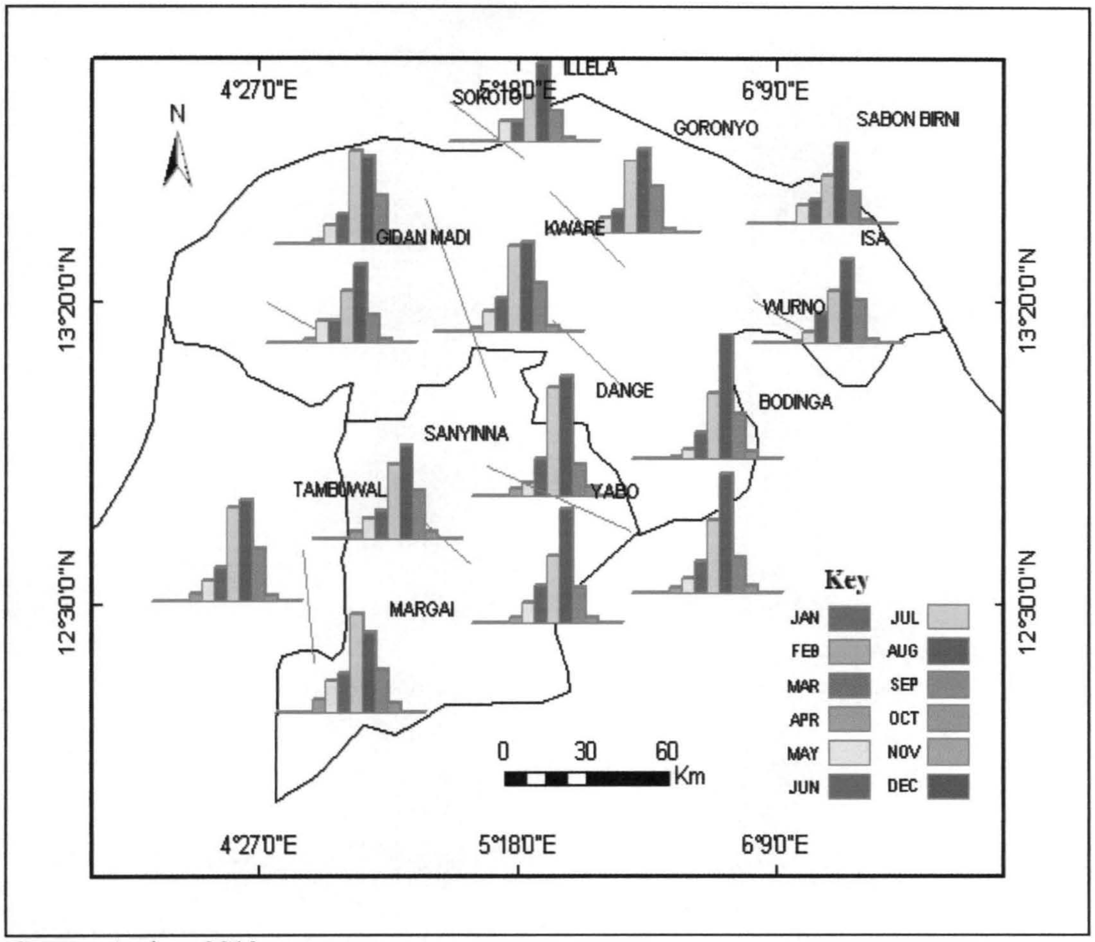


Source: Author, 2010.

Figure 4.4: Time-Time analysis for rainfall in Western Sokoto State (2000-2009)

The rainfall interpolation of years against months for the period 2000-2009 in western part of the State is shown in figure 4.4.

4.3 Monthly Variability of Rainfall



Source: Author, 2010.

Figure 4.5: Monthly distribution of rainfall in Sokoto State.

The monthly distribution of rainfall in the state is shown in figure 4.5 with histograms representing the amount of average rainfall received in each month.

4.4 Impact of Rainfall Variability on Sorghum Yield

The amount of rainfall and sorghum yield received in each year from 2000-2009 in northern part of the State is shown in table 4.5.

Table 4.5: Sorghum yield and rainfall over Northern Sokoto

Year	Yield (Kg/ha)	Rainfall (mm)
2000	3176	571.1
2001	2934	425.8
2002	3033	546
2003	3094	521.5
2004	3178	579.1
2005	3134	502.6
2006	3245	549.1
2007	3025	529.5
2008	3341	662.4
2009	3059	439.2

Source: Sokoto State Agricultural Development Programme.

The amount of rainfall and sorghum yield received in each year from 2000-2009 in western part of the State is shown in table 4.6.

Table 4.6: Sorghum yield and rainfall over Western Sokoto

Year	Yield (Kg/ha)	Rainfall (mm)
2000	3268	665
2001	3492	731.8
2002	3780	804.9
2003	3156	652.8
2004	3114	669.4
2005	3585	730.5
2006	3309	718.7
2007	3151	635.3
2008	3381	717.8
2009	3128	520.7

Source: Sokoto State Agricultural Development Programme.

In table 4.7 the results of the correlation between sorghum yield and annual total rainfall as well as the rainfall in the months of May to September for the two parts of the state is shown.

Table 4.7: Correlation of sorghum yield with growing season rainfall

Location	Total	May	June	July	August	September
Northern Sokoto	0.82**	-0.22	0.21	-0.23	0.86**	0.08
Western Sokoto	0.83**	0.23	0.76**	0.40*	-0.21	0.40*

Source: Author, 2010.

**Correlation is significant at ≤ 0.01
*Correlation is significant at ≤ 0.05

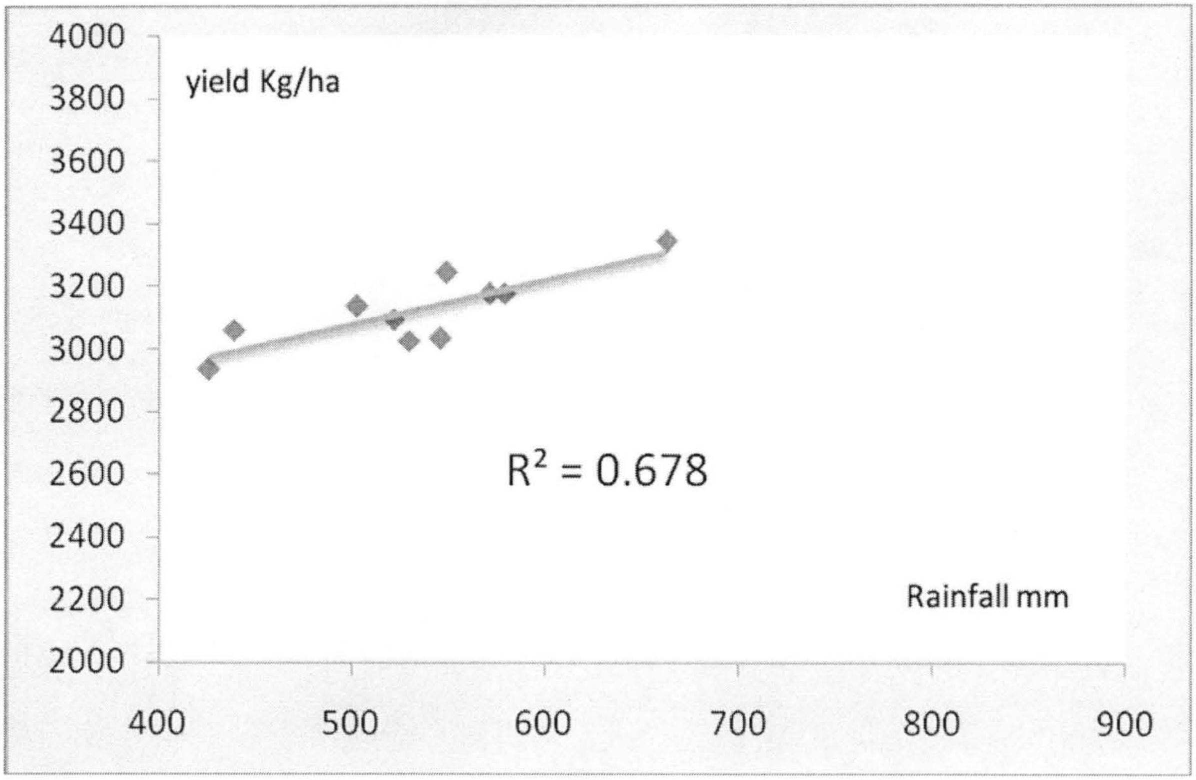


Figure 4.6: Relationship between sorghum yield and annual rainfall total in northern Sokoto state

Figure 4.6 shows the roughly linear relation between yield and rainfall, with a coefficient of determination amounting to 0.678.

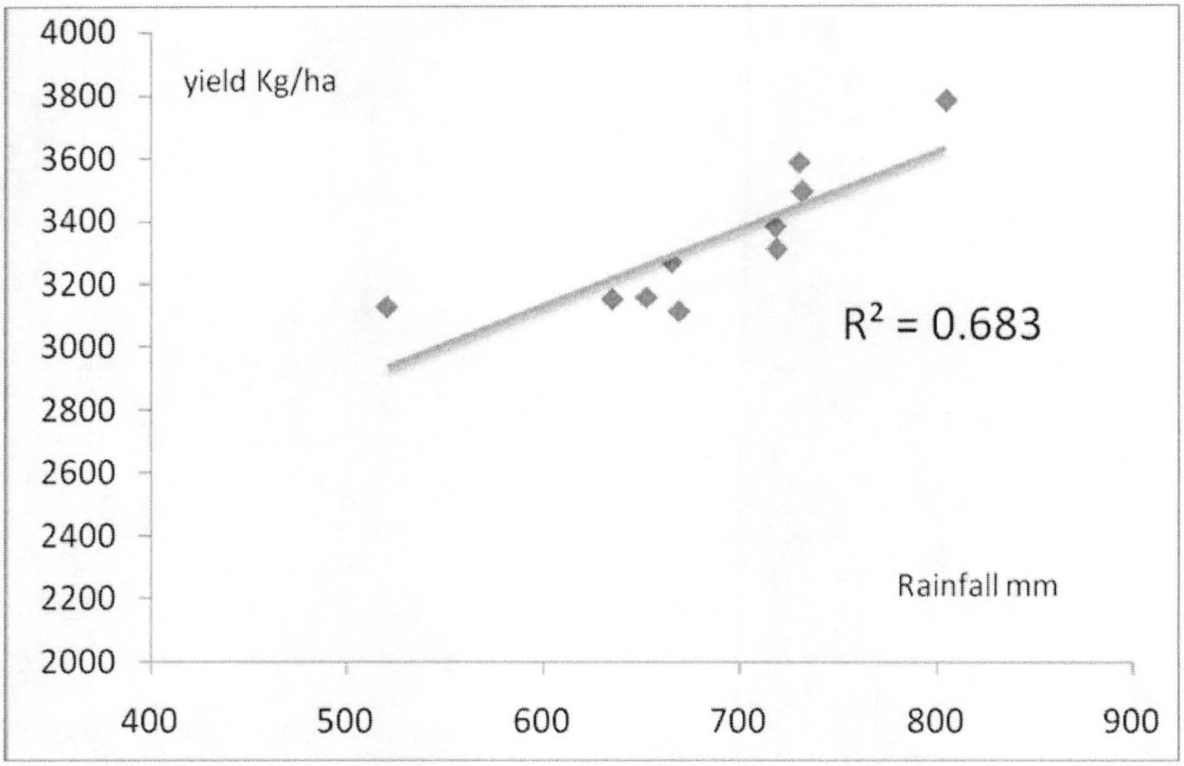


Figure 4.7: Relationship between sorghum yield and annual rainfall total in western Sokoto state.

Figure 4.7 shows the roughly linear relation between yield and rainfall, with a coefficient of determination amounting to 0.683.

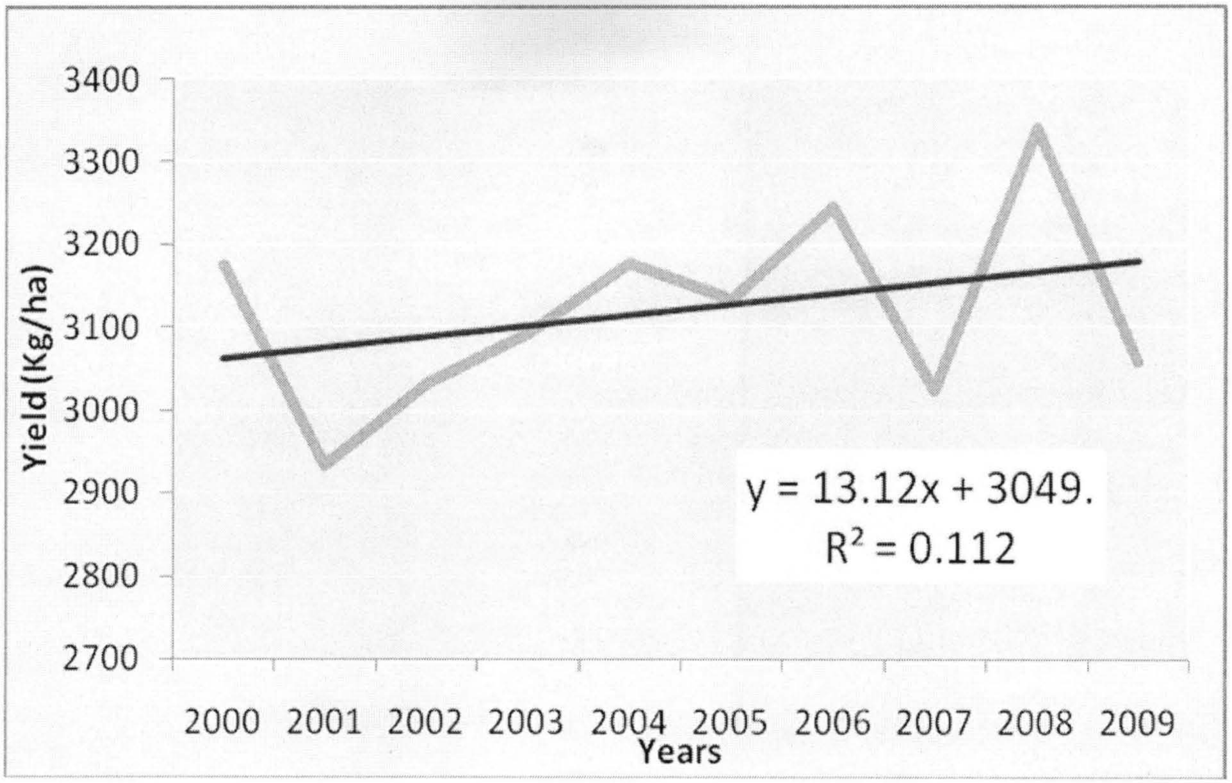


Figure 4.8: Trends of sorghum yield in northern Sokoto state.

The trends in Figure 4.8 accounts for 11% of the inter-annual yield variability in northern part of the study area.

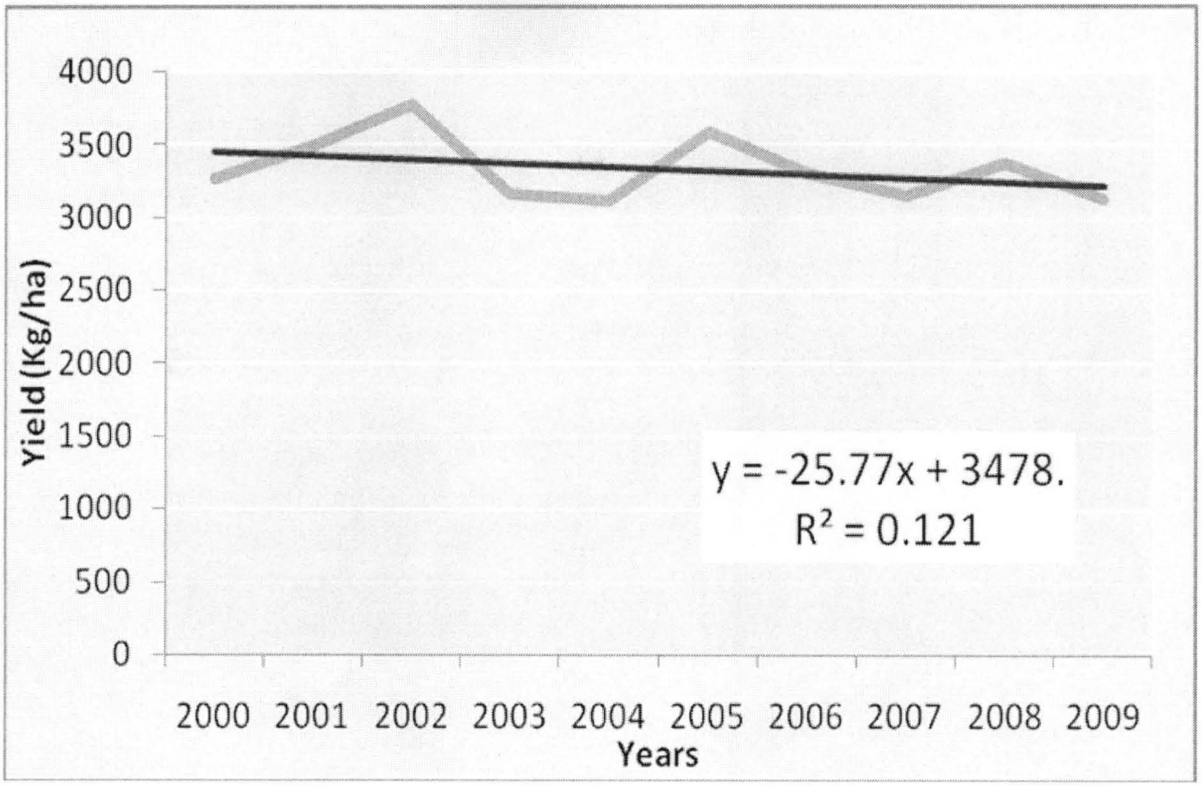


Figure 4.9: Trends of sorghum yield in western Sokoto state.

The trends in Figure 4.9 accounts for 12% of the inter-annual yield variability in northern part of the study area.

4.5 Sorghum Yield and Number of Rainy Days

The number of rainy days and sorghum yield received in each year from 2000-2009 in northern part of the State is shown in table 4.8.

Table 4.8: Sorghum Yield and Number of Rainy Days in northern Sokoto

Year	Yield (Kg/ha)	Number of rainy days
2000	3176	32
2001	2934	30
2002	3034	34
2003	3094	35
2004	3178	38
2005	3034	32
2006	3245	34
2007	3025	35
2008	3341	34
2009	3059	35

Source: Sokoto State Agricultural Development Progrmme.

The number of rainy days and sorghum yield received in each year from 2000-2009 in western part of the State is shown in table 4.9.

Table 4.9: Sorghum Yield and Number of Rainy Days in Western Sokoto

Year	Yield (Kg/ha)	Number of rainy days
2000	3268	40
2001	3492	40
2002	3780	43
2003	3156	41
2004	3114	39
2005	3585	43
2006	3309	40
2007	3151	37
2008	3381	34
2009	3128	34

Source: Sokoto State Agricultural Development Progrmme

The results in table 4.10 shows the mean, standard deviation and coefficient of variation of rainy days in seven stations of northern part of the state.

Table 4.10: Descriptive statistics for number of rainy days in Northern Sokoto State.

Station	Mean	Std. Deviation	Coef. Variation	Lat.	Long.	Elevation (m)
Illela	29.40	4.81	16.36	13.44	5.19	265
Sabon Birni	30.30	6.09	20.10	13.33	6.18	309
Goronyo	32.70	3.77	11.53	13.26	5.39	280
Gidan Madi	31.20	5.69	18.24	13.22	4.43	265
Wurno	33.40	4.17	12.49	13.17	5.25	304
Isa	39.70	5.21	13.12	13.13	6.19	326
Kware	39.60	3.20	8.08	13.12	5.16	266

Source: Author, 2010.

The results in table 4.11 shows the mean, standard deviation and coefficient of variation of rainy day in seven stations of western part of the state.

Table 4.11: Descriptive statistics for number of rainy days in western Sokoto State

Station	Mean	Std. Deviation	Coef. Variation	Lat.	Long.	Elevation (m)
Sokoto	46.30	6.53	14.10	13.04	5.14	284
Bodinga	34.80	5.45	15.66	12.53	5.1	304
Dange	35.30	4.06	11.50	12.5	5.2	310
Yabo	35.30	4.64	13.14	12.43	5	258
Sanyinna	36.30	4.72	13.00	12.41	4.52	208
Tambuwal	37.80	6.66	17.62	12.24	4.38	268
Margai	48.90	4.95	10.12	12.1	4.45	211

Source: Author, 2010.

In table 4.12 the results of the correlation between sorghum yield and annual rainy days as well as the rainy days in the months of May to September for the two parts of the state is shown.

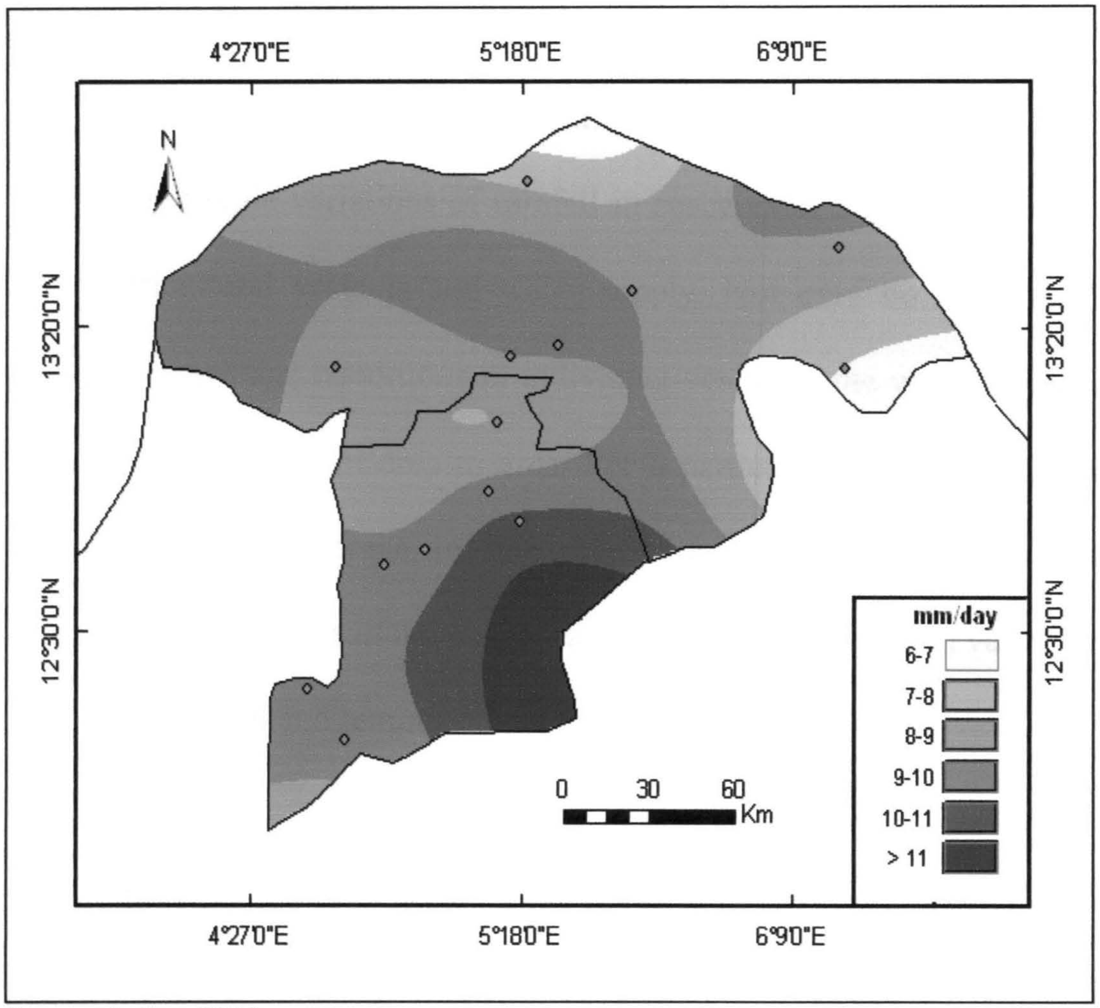
Table 4.12: Correlation of sorghum yield with growing season number of rainy days

Location	Total	May	June	July	August	September
Northern Sokoto	0.47**	-0.05	-0.18	0.06	0.61**	0.25
Western Sokoto	0.44*	0.02	0.77**	0.25	-0.49	0.34

Source: Author, 2010.

**Correlation is significant at [illegible] ≤0.01
*Correlation is significant at [illegible] ≤0.05

4.6 Intensity of Rainfall



Source: Author, 2010.

Figure 4.10: Intensity of rainfall in Sokoto State.

In figure 4.10 the intensity of rainfall in mm/day over Sokoto state is shown, the map shows areas of high and low intensities.

5.1.2 Temporal Variations of Rainfall

Figure 1a-g and 2a-g shows the annual rainfall total received from northern and western Sokoto for the period (2000-2009). There is a clear variations from year to year, for example if a year experiences high amount of rainfall this invariably implies that rainfall for the next year might decrease or increase for example Bodinga in the northern part of the state recorded 47mm in 2007 but increases up to 668.3mm the following year (2008). The western part of the state also follow the same pattern, for example Illela has annual total rainfall of 618.5mm, but the following year it decreases to 312.9mm. This fluctuation in the annual rainfall is experienced in all other stations across northern and western parts of the state. These suggest that severe shortfall in soil moisture of one year may be aggravated by problems of lower precipitation in the previous year.

Analysis of the five year running means rainfall for all the stations in northern and western part of the state revealed that periods with rainfall above or below the long term means vary. For example Sokoto in the southern part has a long term mean of 669.15mm have one five year period with rainfall above and one five year period with rainfall below the long term mean (see table 4.1). Illela in the northern part of the state has a long term mean of 442,21mm has one five year period with rainfall above and one five year period with rainfall below the long term mean (see table 4.2). Likewise for all other stations there is re-occurrence of below average rainfall which often leads to the occurrence of drought.

Variations in rainfall over years in northern part of the study area is shown in figure 4.3, the iso-lines show that July and august recorded the wettest months over the study period . it has also been observed that in 2008 up to 320mm of rainfall was recorded in the month of August. High inter annual- variability of rainfall has also been noted. The western part of the state also experienced similar variations (figure 4.4) the iso lines show that the months of July and august recorded the highest amount of rainfall with year 2001 recording up to 280mm in

July while in the year 2008 280mm was recorded in the month of August.

5.1.3 Monthly variability of Rainfall

Rainfall in Sokoto is highly variable from one month to another, rainy season usually starts in may in the western part and June in the northern part and ends in October. The rest of the months are dry. The months of July to September are months of heavy rainfall, that is months of appreciable rainfall. In the northern part of the state the mean for these months are 140mm in July, 204mm in August and 89.9mm in September while in the western part of the state is 204mm in July, 241mm in August and 97mm in September (figure 4.5).

5.1.4 Variation in the Onset and Cessation of Rainfall

Kowal and Knabe (1972) defined the start of the rainfall as the 1st 10days in the season, in which the amount of rainfall is equal to or greater than 25.4mm but with two subsequent decades of precipitation greater than half evapotranspiration. Hence, date of onset of rainfall in the northern part of the state is early June around Illela and Isah, while in the southern part of the state is in the middle of May. The duration of the rainy season is four month in the northern part and five months in the western part of the state.

Cessation date of the rainy season marks the beginning of the equator ward retreat of the summers monsoon in west Africa. Kowal and Knabe (1972) also define the end of the rain as the last ten days of the rainy season with at least 12.7mm of rainfall and evapotranspiration in the previous ten day period. According to Ayoade (1998) quoted by Buba (1995) that while the ITD penetrated gradually northwards at the onset of the rainy season, it retreats at twice the speed with which it penetrated at the end of the rains. It is the early retreat of the rains from mean-state or premature cessation that affects the normal cropping season. However, from this study, it is observe that the normal mean state cessation of rainfall in both northern and western parts of the state is in the month of September. The reason for having the same cessation period for both the northern and western parts of the state is the speed of the ITD when retreating, which is twice the speed with which it penetrated.

5.1.5 Impact of Rainfall Variability on Sorghum Yield

The simplest possible parametric method to estimate crop yields is to regress them against rainfall, particularly in areas where water is the dominant limiting factor to agricultural production (Palm, 1997). Figure 4.6 shows the roughly linear relation between yield and rainfall in northern part of the study area, with a coefficient of determination amounting to 0.678, i.e. about 68% of the variability of sorghum yields can be assigned to rainfall. Coefficient of determination of 0.683 was obtained in the western part of the state figure 4.7, which means that 68% of the variability of Sorghum yield is attributed to rainfall. In Figure 4.8 trends accounts for 11% of the inter annual yield variability in northern part of the study area and 12% (figure 4.9) for western part, which is in line with the fact that the state is semi-arid.

Table 4.5 and figure 3 show variation in annual sorghum yields and as responses from rainfall variability for the period 2000-2008 over northern Sokoto state. Generally, the table shows that sorghum yields behave in a similar manner, i.e. increase in rainfall results to increase in yield. The highest production of sorghum during these periods (2000-2008) was in year 2008 with a yield of 3341 kg/ha followed by 2000 with 3176kg/mm. Apart from these two years, fluctuation in the yields of sorghum had been taking place from year to year. The lowest yield recorded was in 2001 with the total yield of 3025kg/ha. The behaviour of rainfall and sorghum yield in western part of the state is similar to that of the northern part, except that there is higher amount of rainfall and yield in the western part. Table 4.6 and figure 4 shows that the year with highest annual rainfall of 804.9mm (2002) has the highest yield of 3780kg/ha. In 2004 however, when rainfall was low 669.4mm, yield was 3114kg/ha.

The relationship between sorghum and rainfall has been analysed using correlation. Table 4.7 shows the result of the relationship, it is very clear that the disaggregates of the rainfall, specifically, June, July, August and September, show significant correlations with the variation in sorghum yield.

5.1.6 Sorghum Yield and Number of Rainy Days

The growth period of sorghum crop is approximately 120 days. The period between the start (onset) and end (cessation) of (LRS). This is important agronomically as the annual total rainfall. The highest number of rainy days over northern Sokoto state during the study period was 38days in 2004, that year, sorghum yield was 3178kg/ha, in 2001 the total number of rainy days was 30. The corresponding yield that year was also low (table 4.8).

The western part of the state recorded up to 34 days in 2002 when the corresponding yield was 3780 kg/ha. The least number of rainy days was in 2008 when the number of rainy days was 34. The corresponding yield was 3381 kg/ha (table). The reason for this failure was attributed to decreases in the number of rainy days and the uneven distribution of rainfall throughout the year (2008) (table 4.9). Thus, satisfactory production of sorghum can be obtained when the pattern of crop water requirements matches the pattern of rainy days and availability of water. It can be observed from table 4.10 and 10.11 that the number of rainy day vary from one location to another. This can be said to be a function of the latitudinal location of the places in question, which not only affect the number of rainy days, but the timing of onset and cessation, length of the rainy season as well as the amount of rainfall received.

The relationship between sorghum and number of rainy days has been analysed in this study using correlation. Table 4.12 shows the result of the relationship.

5.1.7 Intensity of Rainfall

Rainfall intensity is the precipitation amount divided by storm duration in days hours or minutes. Precipitation intensity varies with time interval used. Average intensities for short periods are generally much greater than those for longer time intervals. The mean intensity generally increases as the total amount of precipitation increases except at high elevations. Figure 4.4 shows the distribution of rainfall intensity in Sokoto state, the map shows that areas of high intensity greater than 11mm per day are found in western part while intensity of 6-7mm are found in the northern part of the state.

The monthly intensity of rainfall are shown in figure 5a-5g and 6a-6g generally, higher intensities of 15-34mm per day are recorded in the months of July and August in the western part of the state and 13-26mm per day in the northern part.

5.2 Summary of the Major Findings

This study has tried to compare the rainfall variations and sorghum yield between northern and western Sokoto state. In order to achieve the aim and associated objectives of the study certain methodologies were carefully employed ranging from data collection, analysis of the data, map production using GIS and review of relevant literature.

The result obtained from the analysis shows that higher amount of rainfall is recorded in western than in the northern part of the state as such rainfall variations is higher in northern part of the state. This is evident in the number of rainy days, duration of rainfall, onset and cessation as well as amount and intensity. The yield of sorghum also follows the same pattern as it decreases from western to the northern part. A correlation between growing season rainfall and sorghum yield as well as number of rainy days and sorghum yield shows a positive correlation in both northern and western parts of the state.

5.3 Conclusion

From the analysis of rainfall variations on sorghum yield, it can be concluded that the amount of sorghum yield varies from western to northern parts of the state and that there is a fluctuation in the amount of yield recorded from year to year as a result of spatiotemporal distribution, nature, variability and reliability of rainfall.

Generally, rainfall influence crops growth and yield. The variability of rainfall between different places in each year, between different year in each place and between short periods within each season affects sorghum yield. Thus rainfall pattern define the nature of the primary adaptive challenge faced by farmers. Which is how to use constrained labour and capital resource most efficiently in response to an erratic and unpredictable supply of the most important of productivity; water.

5.4 Recommendations

For the sake of improvement on the effect of rainfall variations on sorghum yield in Sokoto state the following recommendations are been made.

- The use of kriging interpolation in assessing rainfall variability.
- There is need for more research and investment in crop production as a means of increasing productivity.
- Genetically drought resistant variety of sorghum should be used in northern part of the state.

- Government should pay more attention to the meteorological stations for proper data utilization, thereby predicting the possible outcome of rainfall onset, cessation and disasters.

REFERENCES

Adams R. M, Wu J., and Houston L. (2003) Climate Change and California, Appendix IX: The effects of climate change on yields and water use of major California crops, California Energy Commission, Public Interest Energy Research (PIER), Sacramento, CA.

Adams W. M. (1992) Wasting the Rains: *River People and Planning in Africa,* Carthscan, London pp 55-56.

Adejuwon J.O. (2004) Crop yield Response to Climate Variability in the Sudano- Sahelian Ecological Zones of Nigeria in southwestern Nigeria. In *AIACC Report of Workshop for Africa and Indian Ocean Island.* Dakar, Senegal, pp. 15-16.

Adejuwon J.O. (2005) Food Crop Production in Nigeria: Present effects of Climate Variability. *Climate Research, inter-Research, Germany.*

Adejuwon J.O., Odekunle T.O. (2004) Variability and Intensity of the "little Dry Season" in southwestern Nigeria. *In AIACC Report of Workshop for Africa and Indian Ocean Island.* Dakar, Senegal, pp 8-9.

Adejuwon J.O., Odekunle T.O. (2006) Variability and the Severity of the "little Dry Season" in southwestern Nigeria. *Am. Meteorogical Soc.* 483-493.

Adejuwon, S. A. (1988) An assessment of the pattern of rainfall fluctuations between 1922-1985 in Nigeria. PhD Thesis, Unpublished. Ile-Ife: Obafemi Awolowo University.

Anuforom, A. C. (2004) "Rainfall Variability and Its Impact on Yield of Millet and Yam in Nigeria". Presented at the 30th *International Post Graduate Course at the WMO Regional Training Center*, Bet-Dagan, Israel.

Balogun, C. (1972) 'The variability of rainfall in Nigeria', *Nigerian J. Science, 6,* 89.

Barry, R. G. and Chorely, R. J. (2003) *Atmosphere Weather and Climate.* Routledge 8th edition, London.

Bello N.J. (1997) Investigating the spatial pattern of the characteristics of the onset and cessation of the rains in Nigeria. *Geo. Journal* 43: 113–123.

Buba, L. F. (1992) Rainfall variability in Kano region. Paper presented at National Geographic Association Conference Usman Danfodiyo University Sokoto.

Buba, L. F. (1999) Climate change and sustainable Agriculture in semi-arid zone of north-eastern Nigeria. Unpublished.

Bunting, A. H., Dannett, M. D., Elston, J. and Milford, J. R. (1976) Rainfall Trends in the West African Sahel. *O. J. R. Meteorol. Soc., 102, pp. 59-64.*

Cane, M. A., Eshel. G., Buckland. R. W. (1994) Forecasting Zimbabwean maize yield using eastern equatorial pacific sea surface temperature. *Nature* 370: 204-205.

Conway, D. (2000) The Climate and Hydrology of the Upper Blue Nile, Ethiopia. *Geographical Journal 166, 49-62.*

Davis G. (1982) *Atlas of Sokoto State.* Ibadan: Caxton Press (West Africa) Limited.

Diouf, M., Nonguierma, A., Royer, A., Some´ , B., (2000) Lutte contre la se´cheresse au Sahel: re´ sultats, acquis et perspectives au Centre re´gional AGRHYMET [Drought control in the Sahel: results, experiences and future prospects for the AGRHYMET Regional Centre]. Se´cheresse 11 (4), 257–266.

ESRI. (2004) *ArcMap 9.1*. Environmental Systems Research Institute: Redlands, California.

Faniran A, Ojo O. (1980) *Man's Physical Environment*. An Intermediate Physical Geography. Heinemann: London.

Fasona M.J., Omojola A.S. (2005) Climate Change, Human Security and Communal Clashes in Nigeria. *Paper prepared for Human Security and Climate Change Conference* in Asker, Oslo, June 21 to 23 2005.

Fontaine, B., Janicot, S. (1996) Sea surface temperature fields associated with West African rainfall anomaly types. *Journal of Climate* 9: 2935–2940.

Fontaine, B., Philippon, N., Camberlin, P. (1999) An improvement of June–September rainfall forecasting in the Sahel based upon region April–May moist static energy content (1968–1997). *Geophys. Res.* Lett. 26, 2041–2044.

Goldreich, Y. (1995) Temporal variations of rainfall in Israel. *Clim. Res.*, 5, 167-179.

Gommes R. (2006) Non-Parametric Crop Yield Forecasting, a Didactic Case Study for Zimbabwe. *Paper presented at the EU/JRC meeting on Remote Sensing Support to Crop Yield Forecast and Area Estimates 30 Nov. - 1 Dec., Stresa, Italy.*

Gommes, R., H.P. Das, L. Mariani, A. Challinor, B. Tychon, R. Balaghi and M.A.A. Dawod, (2007) *WMO Guide to Agrometeorological Practices*, Chapter 5, Agrometeorological Forecasting. 70 pp. Current version downloadable from http://www.agrometeorology.org/fileadmin/insam/repository/gamp_chapt5.pdf. (11/02/2010. 5:30pm)

Graef F. and Haigis J. (2001) Spatial and temporal rainfall variability in the Sahel and its effects on farmers' management strategies. *Journal of Arid Environments* 48: 221–231.

Graef, F. Weller U., Stahr, K. (1999) Land evaluation in SW-Niger with SOTER-an analysis on regional and village scale. In : *Proceedings of the Regional Workshop: farmers and scientists in a changing environment: Assessing Research in West Africa.* University of hongheim Benin, 22-26. Margrave Verlag, Germany. pp. 223-236.

Grove, A.T. (1972) Climatic change in Africa in the last 20,000 years, Les Problemes de Developement du Sahara Septentrional Ouarghla Colloquium vol. 2, Algiers.

Hansen JW, and Jones, JW (2000) Scaling-up crop models for climate variability applications. Agricultural Systems 65(1): 43–72

Hare F.K. (1985) Climate variability and change: pp. 37-66, in (Kates RM, Ausubel JH, Berberian M Eds) Climate Impact Assessment: Studies of the interaction of Climate and Society. Chichester, Wiley Press.

Hastenrath, S.L., Kutzbach, J.E. (1983) Paleoclimatic estimates from water and energy budgets of East African lakes. *Quat. Res.* 19, 141–153.

Hulme, M. (1992): Rainfall Changes in Africa 1931-1960 to 1961-1990. *International Journal of Climatology, 12: 685-699.*

IPCC (2000) "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories". *The Intergovernmental Panel on Climate Change (IPCC) Working Group I,* National GHG Inventories programme, IGES, Hayama, Kanagawa, Japanhe Regional Impacts of Climate Change: An Assessment of Vulnerability.

IPCC (2001) Changes around the Antarctic PeninsulaAvailable at http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622 (15/02/2010. 12:45pm)

IPCC (2004a) Climate Change 2003: Impacts Adaptations and Vulnerability http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622 (15/02/2010. 12:45pm)

IPCC (2004b) Climate Change 2003: Synthesis Report. Available at http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622 (15/02/2010. 12:45pm)

Isaaks HE, Srivastava RM. (1989) *An Introduction to Applied Geostatisitics*. Oxford University Press: New York.

Jackson, I.J. (1985) Tropical rainfall variability as an environmental factor: some considerations. *Singapore J. Trop. Geogr.*, 6: 23-34.

Jackson, I.J. (1986) Relationships between rain days mean daily intensity and monthly rainfall in the tropics. *J. Climatol.*, 6: 117-134.

Jackson, I.J. (1988) Daily rainfall over Northern Australia: deviations from the world pattern. *J. Climatol.,* 8: 463-474.

Jackson, I.J. (1989) *Climate, Water and Agriculture in the Tropics*, second edition. Longman, Harlow.

Janicot, S., Sultan, B. (2001) Intra-seasonal modulation of convection in the West African monsoon. *Geophys. Res.* Lett. 28: 523–526.

Jensen, J.R. (1990) Decrease in point annual rainfall in northern Nigeria, 1905–1983 (89). *Paper presented at the First Biennial Hydrology Symposium ''Hydrology for National Development''.* IHD Programme of Nigeria, Maiduguri.

Journel AG, Huijbregts CJ. (1981). *Mining Geostatistics*. Academic Press: New York.

Kidson, J. W. (1977) African rainfall and its relation to upper air circulation. *Quart. J. Roy. Meteor. Soc.,* **103:** 441–456.

Kowal J. M and Kassam, A. H. (1978) Agricultural Ecology of Savanna: A study of West Africa. Clarendon Press Oxford, London.

Kowal J. M., Knabe D. T. (1972) Agroclimatological Atlas of the Northern States of Nigeria with explanatory notes. Ahmadu Bello University Press, Zaria.

L'Hoˆ te, Y., Mahe´ , G., (1996) Carte des pre´cipitations moyennes annuelles de l'Afrique de l'ouest et centrale. Pe´riode 1951–1989 [A Map of Average Annual Precipitations Over West and Central Africa for the 1951–1989 Period] ORSTOM, Montpellier, France.

Lebel, T., Lebarbe´ , L. (1997) Rainfall climatology of the HAPEXSAHEL region during the years 1950–1990. *Journal of Hydrology* 188–189, 43–73.

Mabbutt, J.A. (1989) Impacts of carbon dioxide warming on climate and man in the semi-arid tropics. *Climat. Change,* 15: 191-221.

Mamman, A. B., Kwabe S. A. (1993) Sokoto and Kebbi States, in R.K. Udo and A.B. Mamman (eds) Nigeria: *Giant in the Tropics,* Lagos: Gabumo Publishing Co. Ltd. pp. 245-255.

NEST (2003) *"Climate Change in Nigeria"*: A Communication Guide.

Nicholson S. E. (1983) " Sub-Saharan Rainfall in the years 1976-80: Evidence of continued draught." Mon. Weather Rev., 111, 1614-1654.

Nicholson S.E, Some B, Kone B. (2000) A note on recent rainfall conditions in West Africa, including the rainy season of the 1997 ENSO year. *Journal of Climate* **13**: 2628–2640.

Nicholson S.E. (1989) Rainfall variability in Southern Africa and its relationship to ENSO and the Atlantic and Indian Oceans. *Preprints of the Third International Conference on Southern Hemisphere Meteorology and Oceanography.* American Meteorological Society: Buenos Aires, Argentina; 366–367.

Nicholson, S. E. and Palao, I (1993) A reevaluation of rainfall variability in the Sahel. Part I. Characteristics of rainfall fluctuations. *International Journal of Climatology, 13, 371-389.*

Nicholson, S.E. (1981a) Rainfall and atmospheric circulation during drought periods and wetter years in Africa. Mon. *Weather Rev.* 109, 137–154.

Nicholson, S.E. (1981b) *The historical climatology of Africa.* In: Wigley, T.M.L., Ingram, M.J., Farmer, G. (Eds.), Climate and History (Cambridge). pp. 249–270.

Nicholson, S.E., Some′, B., Kone′, B. (2000) An analysis of recent rain conditions in West Africa, including the rainy seasons of the 1997 El Nin˜ o and 1998 La Nin˜ a years. *Journal of Climate.* 13. 2628–2640.

Obasi, G.O.P (2003a) *Statement at the International Symposium on Climate Change (ISCC)* Beijing, China, 31 March 2003.

Obasi, G.O.P (2003b) "Regional conference on climate change and food Sustainability" in the 21st century: *Keynote Address*, Lagos, Nigeria, 11, November 2003.

Obioha, E.E. (2009) Climate variability, environment change and food security nexus in Nigeria. *Journal of human ecology* 26 (2): 107-121.

Odekunle T.O., Orinmoogunje I. O.O. and Ayanlade A. (2007) Application of GIS to assess rainfall variability impacts on crop yield in Guinean Savanna part of Nigeria. *African Journal of Biotechnology,* Vol. 6, pp. 2100-2113

Oladipo E. O. (1993) Is the climate of Nigeria becoming more arid? *Paper presented at the 36th Annual conference of the Nigerian Geographical Association, Federal University of Technology, Minna. Pp:13.*

Orlandini, F., D. Lanari, L. Pieroni, B. Romano and M. Fornaciari, (2004) Instrumental test to estimate a model of forecast yield: a non-parametric application to the pollen index in south Italy. *Ann. Appl. Biol.*, 145:81-90.

Osagie O.I. (2002) Cereal Output to Plunge Next Year, in: AgroBusiness. THISDAY Online.

Osman M., Sauerborn P. (2002) A preliminary assessment of characteristics and long-term variability of rainfall in Ethiopia — basis for sustainable land use and resource management. In *Conference in International Agricultural Research, Deutscher Tropentag 2002*, Witzenhausen, 9–11 October.

Owen, R., Crossley, R., Johnson, T., Tweddle, D., Kornfield, I., Davison, S., Eccles, D., Engstrom, D. (1990) Major low levels of Lake Malawi and their implications for speciation rates in cichlid fishes. *Proc. R. Soc.* London. pp. 519–553.

Paturel J.E., Servat E., Kouame´ B, Lube`s H., Ouedraogo M., Masson J.M. (1997) Climatic variability in humid Africa along the Gulf of Guinea Part II: an integrated regional approach. *Journal of Hydrology* 191, 16–36.

Philips J. G., Cane M. A., Rosenzweig C. (1998) ENSO, seasonal rainfall patterns and simulated maize yield variability in Zimbabwe. *Journal of Agric. and forest met.* 90: 39-50.

Reilly JM, Graham J, and Hrubovcak J (2001) Agriculture: the potential consequences of climate variability and change for the United States, Cambridge University Press, New York, NY

Salako F. K. (2006) Rainfall temporal variability and erosivity in subhumid and humid zones of southern nigeria. *Land Degrad. Develop.* 17: 541–555.

Seleshi Y., Demar′ee, G.R. (1995) Rainfall variability in the Ethiopian and Eritrean highlands and its links with the southern oscillation index. *Journal of Biogeography* **22**: 945–952.

Servat E, Paturel J.E, Lube`s H, Kouame′ B, Ouedraogo M, Masson JM. (1997) Climatic variability in humid Africa along the Gulf of Guinea Part I: detailed analysis of the phenomenon in Co^te d'Ivoire. *Journal of Hydrology* 191: 1–15.

Shahid S., Nath S. K. (2002) GIS integration of remote sensing and vertical electrical sounding data for hydrogeological exploration. *Journal of Spatial Hydrology* **2**(1): 1–12.

Shahid S., Nath S. K., Roy J. (2000) Ground water potential modelling in a soft rock area using GIS. *International Journal of Remote Sensing* **21**: 1919–1924.

Shanko D., Camberlin P. (1998) The effects of the southwest Indian Ocean tropical cyclones on Ethiopian drought. *International Journal of Climatology* **18**: 1373–1388.

Shaw, P. (1985) The desiccation of Lake Ngami: an historical perspective. *Geogr. J.* 151, 318–326.

Singh, K. K. and Singh S.V. (1996) Space-time variation and regionalization of seasonal and monthly summer monsoon rainfall of the sub-Himalayan region and Gangetic plains of India. *Journal of climate research,* vol. 6: 251-262.

Sivakumar, M. V. K., Virmani, S. M. and Reddy, S. J., (1979) Rainfall Climatology of West Africa: Niger Informations Bulletin 5, ICRISAT, Pantacheru, India, 66pp.

Sivakumar, M.V.K., Virmani, S.M. and Reddy, S.J. (1979) Rainfall climatology of West Africa: Niger. Information Bulletin 5, ICRISAT, Patancheru, India, 66 pp.

Tessema Z., Lamb P.J. (2003) Interannual variability of *Keremt* growing season over drought-prone part of Ethiopia. CLIVAR, Contribution to Exchange No. 27, September 2003. http//www.clivar.org-publications-exchanges-selected.htm.url.

Thomson, A. M., Rosenberg, N. J., Izaurralde, R. C., and Brown R. A. (2005) Climate change impacts for the conterminous USA: An integrated assessment: Part 2: Models and validation. *Climatic Change, 69(1): 27–41*

Traore´ , S.B., Reyniers, F.-N., Vaksmann, M., Kouressy, M., Yattara, K., Yorote, A., Sidibe´ , A., Kone´ , B., (2000) Adaptation a` la se´cheresse des e´cotypes locaux de sorgho du Mali [Drought adaptation of local sorghum ecotypes in Mali]. Se´cheresse 11 (4), 227–237.

van Beers WCM, Kleijnen JPC. (2004) *Kriging Interpolation in Simulation: A Survey*. In *Proceedings of the 2004 Winter Simulation Conference*, Ingalls RG, Rossetti MD, Smith JS, Peters BA (eds).Washington, DC, 5–8 December 2004.

Vinnikov, K. Ya., Groisman, P. Ya., Lugina, K. M. (1990) Empirical data on contemporary global climate changes (temperature and precipitation). *J. Climate,* 3: 662-677.

Westra, S. and Sharma, S. (2005) An Exploratory Study Of Seasonal Rainfall Variability In Australia Using Independent Component Analysis. *Journal of Climate, 10* (5), 1004-1020, 1997.

Wilkinson R, Clarke K, Reichman J, and Dozier J (2002) Preparing for a changing climate: the potential consequences of climate variability and change for California, California Regional Assessment Group for the U.S. Global Change Research Program

WMO (2000) Strategic Plan for the Enhancement of National Meteorological Services in Regional Association II (Asia) (2001–2004).

Appendix

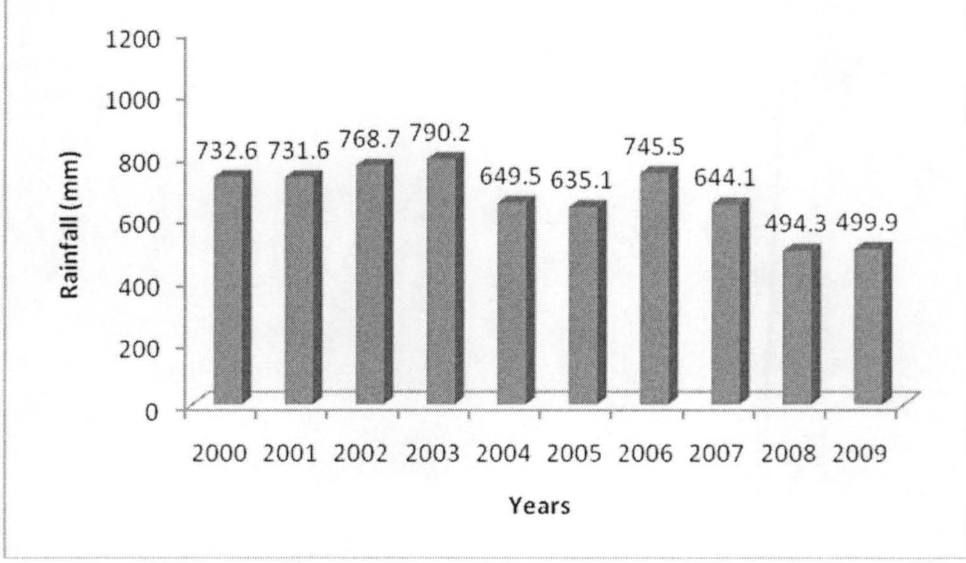


Figure 1a: Annual rainfall for Sokoto (2000-2009)

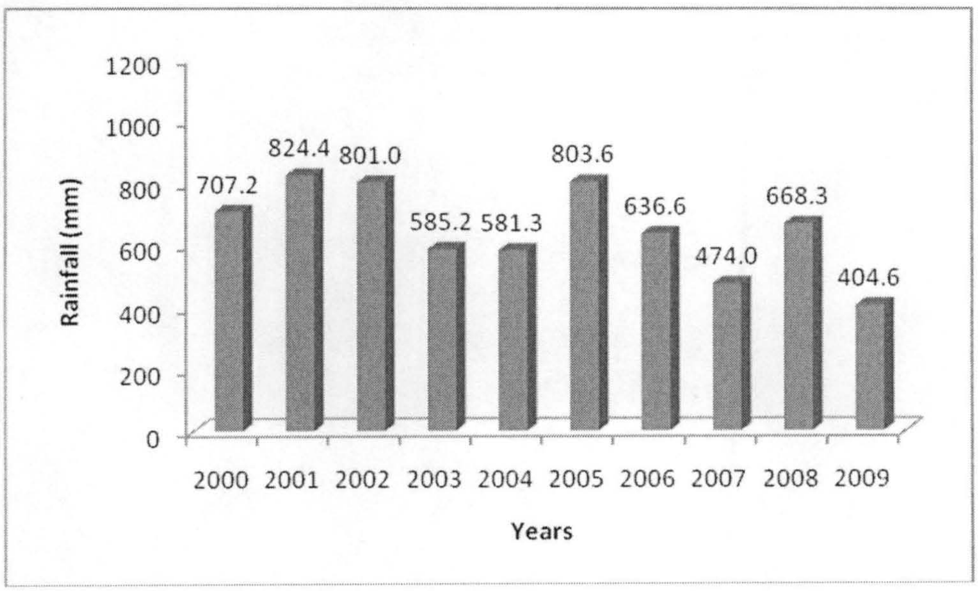


Figure 1b: Annual rainfall for Bodinga (2000-2009)

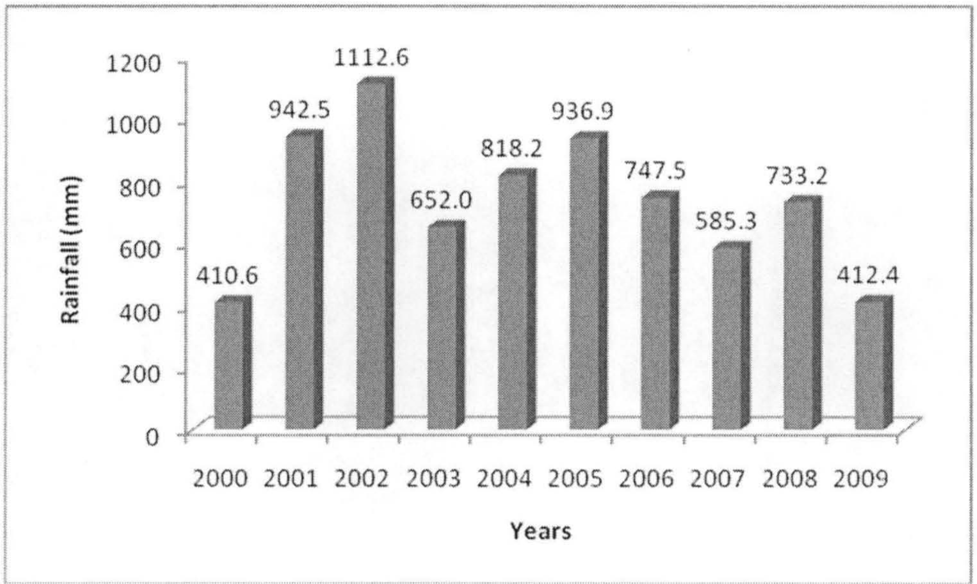


Figure 1c: Annual rainfall for Dange (2000-2009)

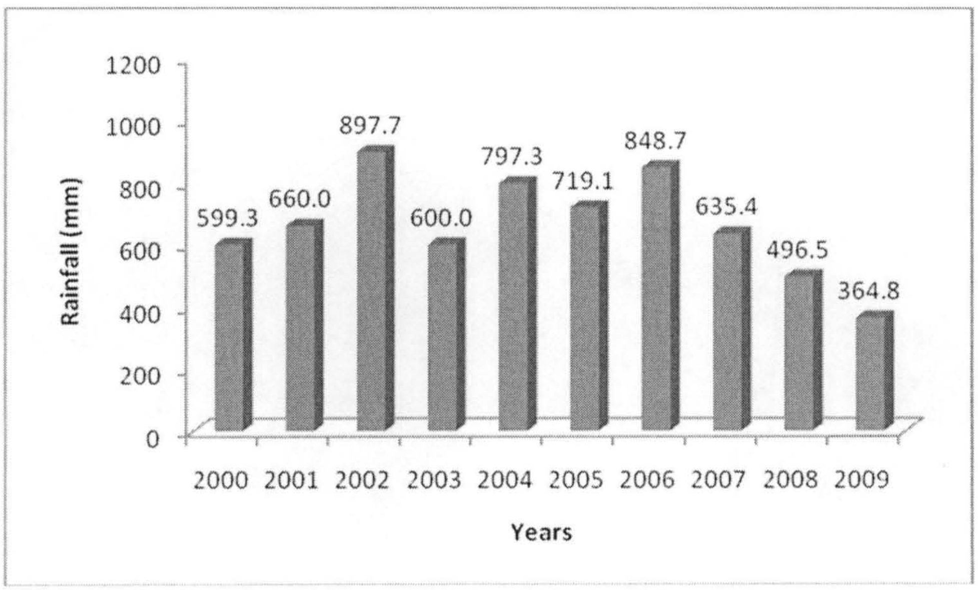


Figure 1d: Annual rainfall for Yabo (2000-2009)

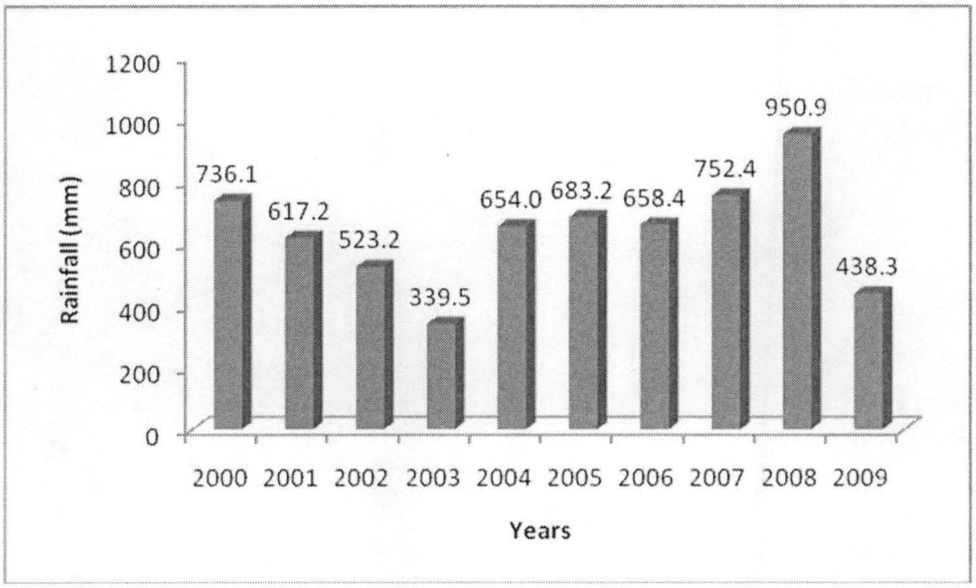


Figure 1e: Annual rainfall for Sanyinna (2000-2009)

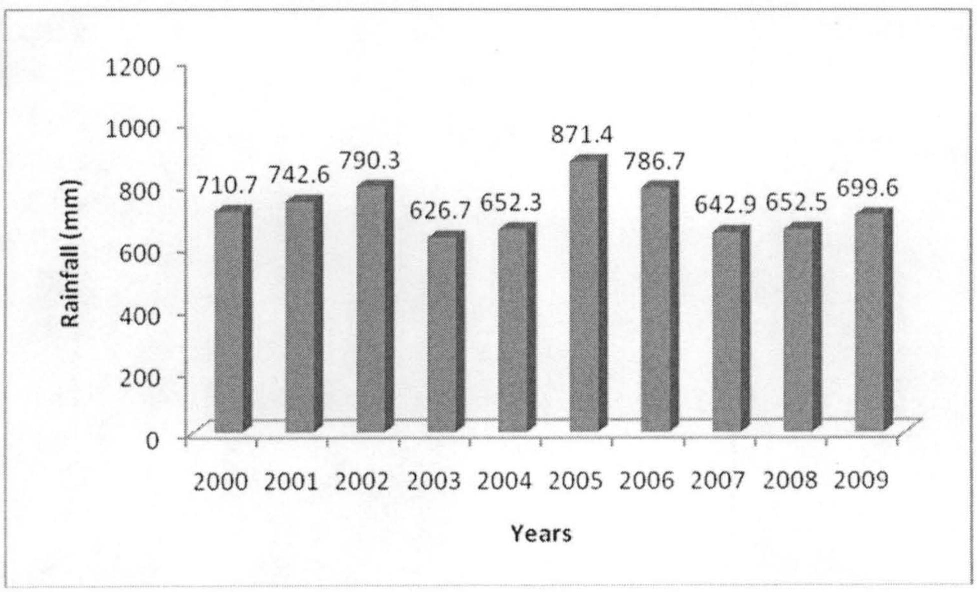


Figure 1f: Annual rainfall for Tambuwal (2000-2009)

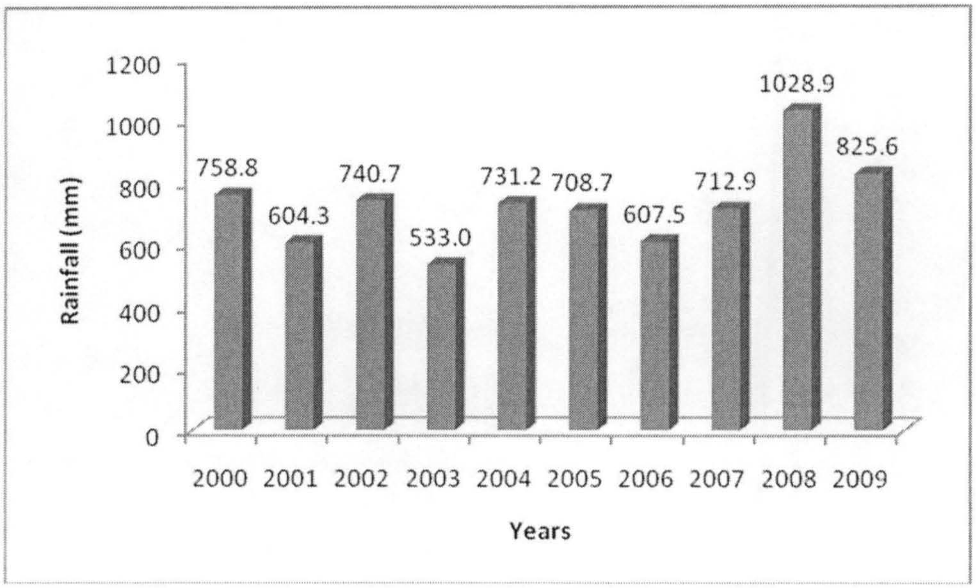


Figure 1g: Annual rainfall for Margai (2000-2009)

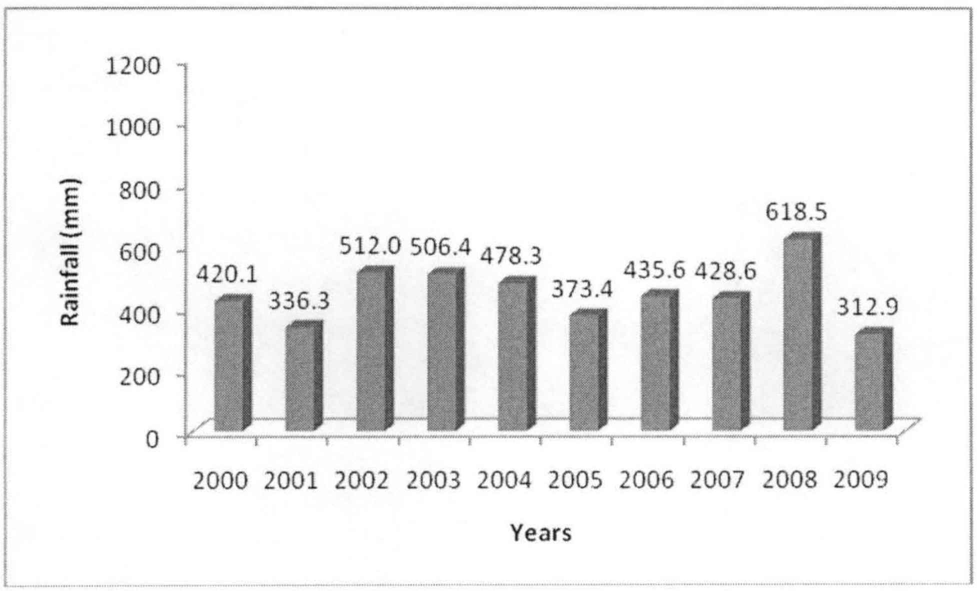


Figure 2a: Annual rainfall for Illela (2000-2009)

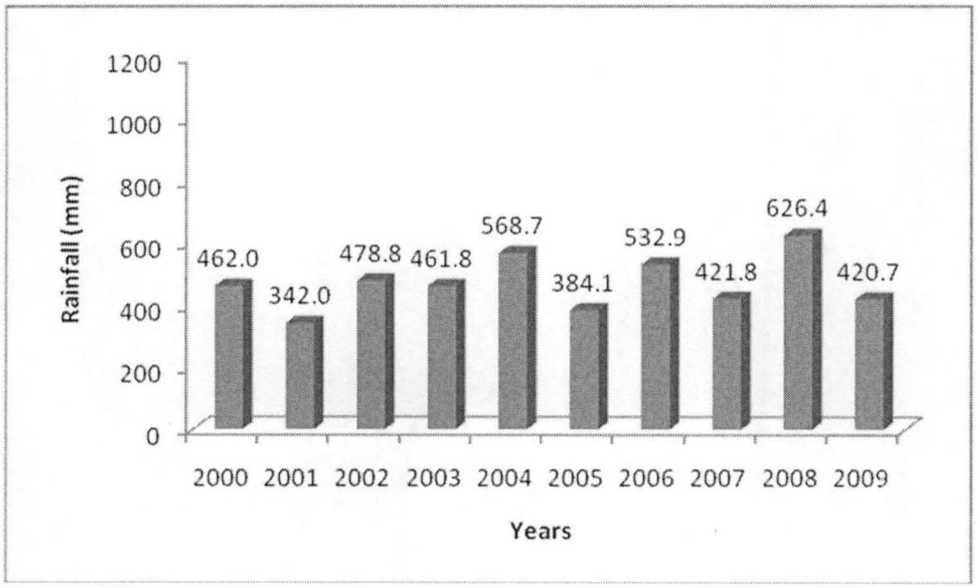


Figure 2b: Annual rainfall for Sabon Birni (2000-2009)

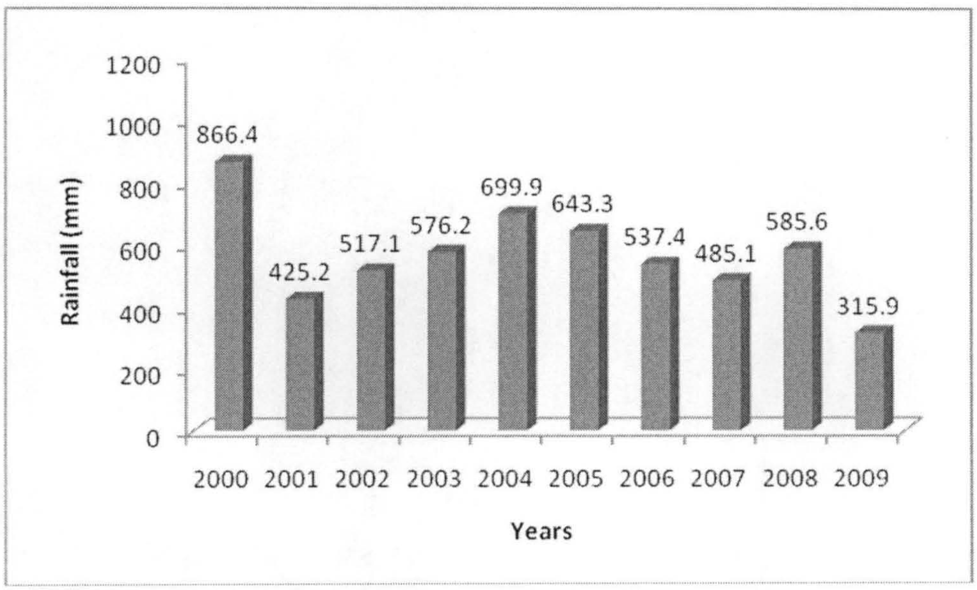


Figure 2c: Annual rainfall for Goronyo (2000-2009)

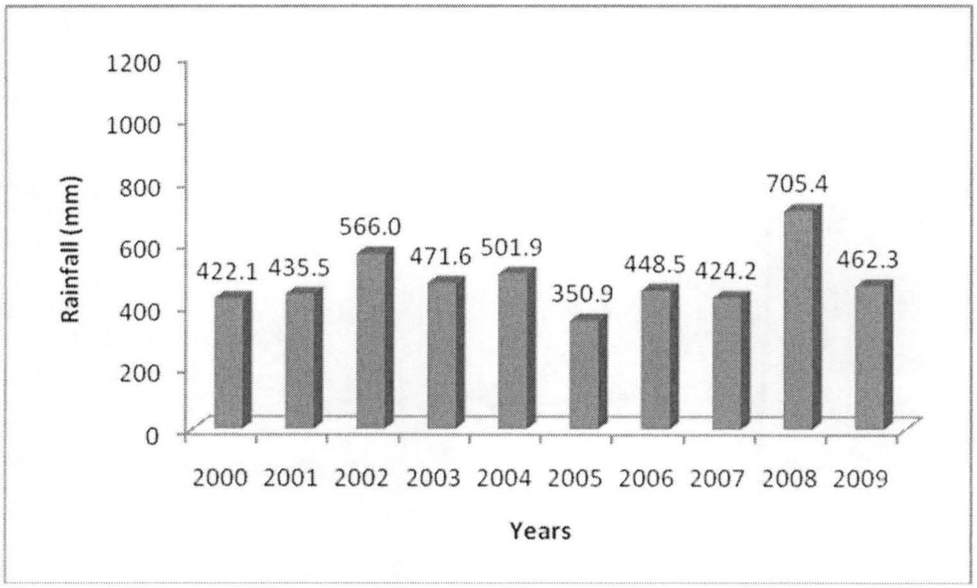
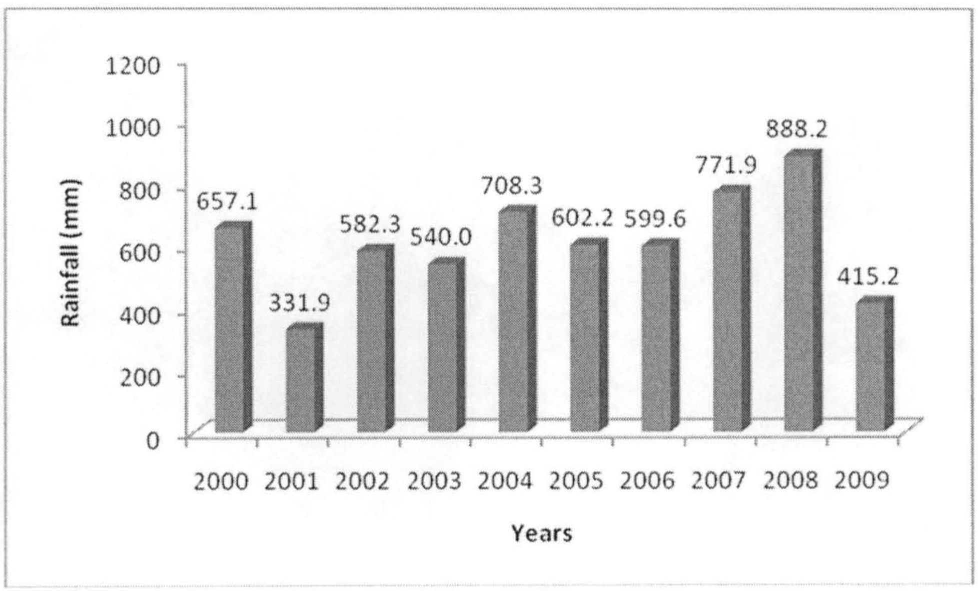


Figure 2d: Annual rainfall for Gidan Madi (2000-2009)



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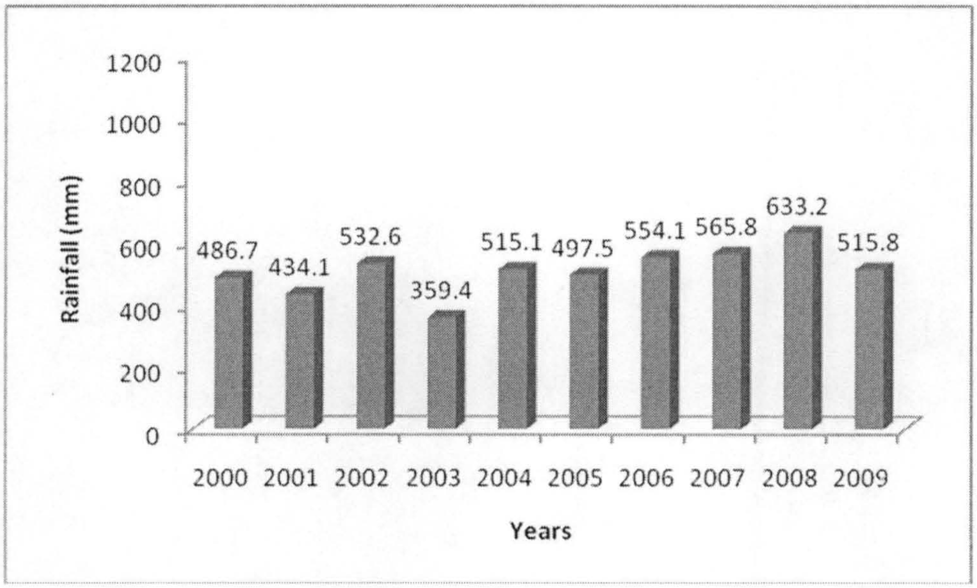

Figure 2f: Annual rainfall for Isah (2000-2009)

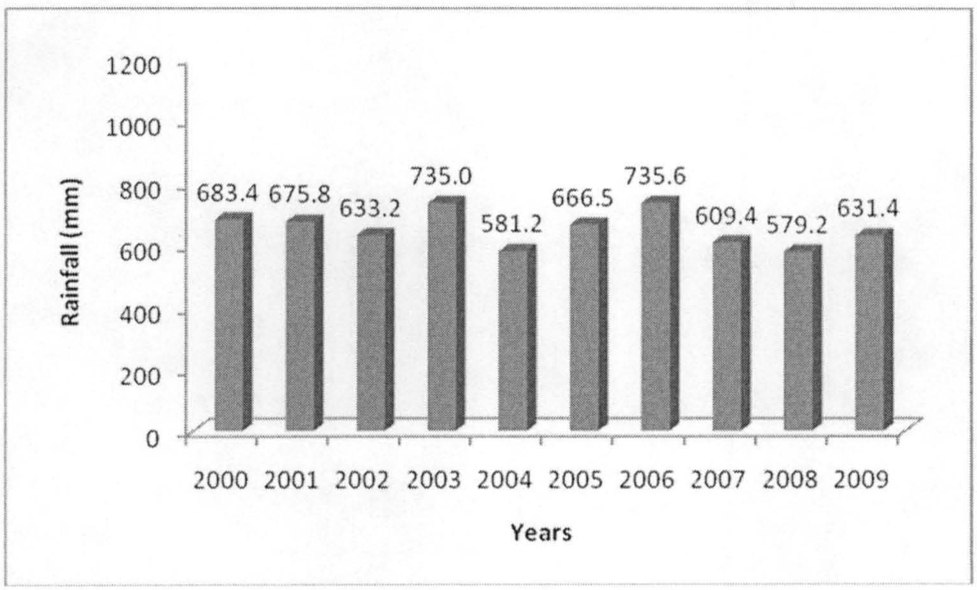

Figure 2g: Annual rainfall for Kware (2000-2009)

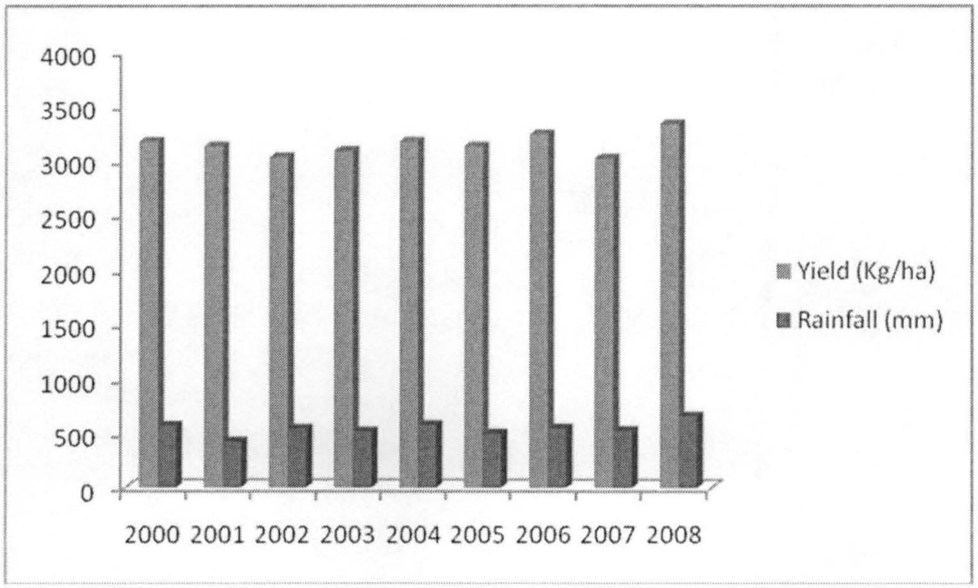

Figure 3: Rainfall and sorghum yield in Northern Sokoto State (2000-2008)

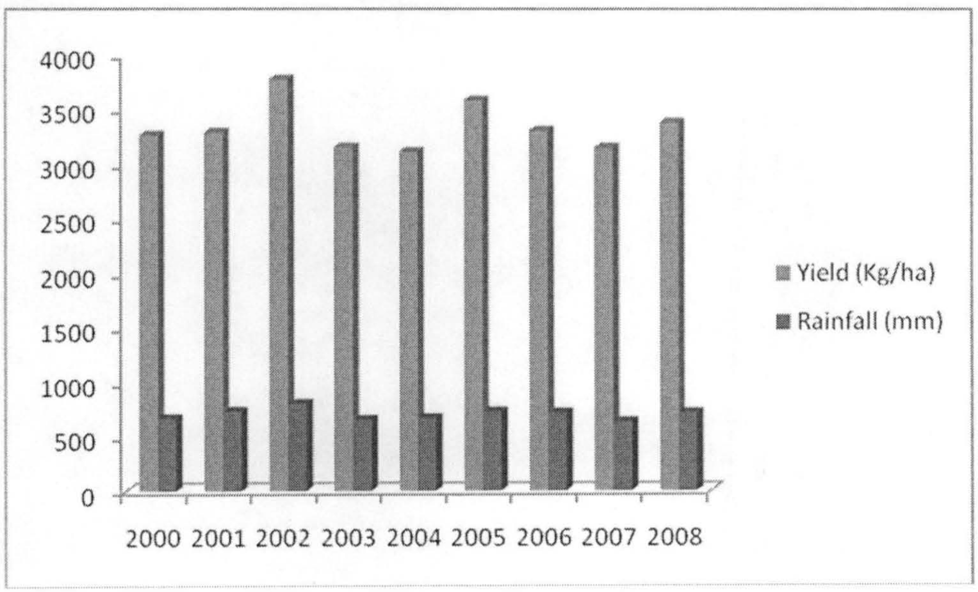

Figure 4: Rainfall and sorghum yield in western Sokoto State(2000-2008)

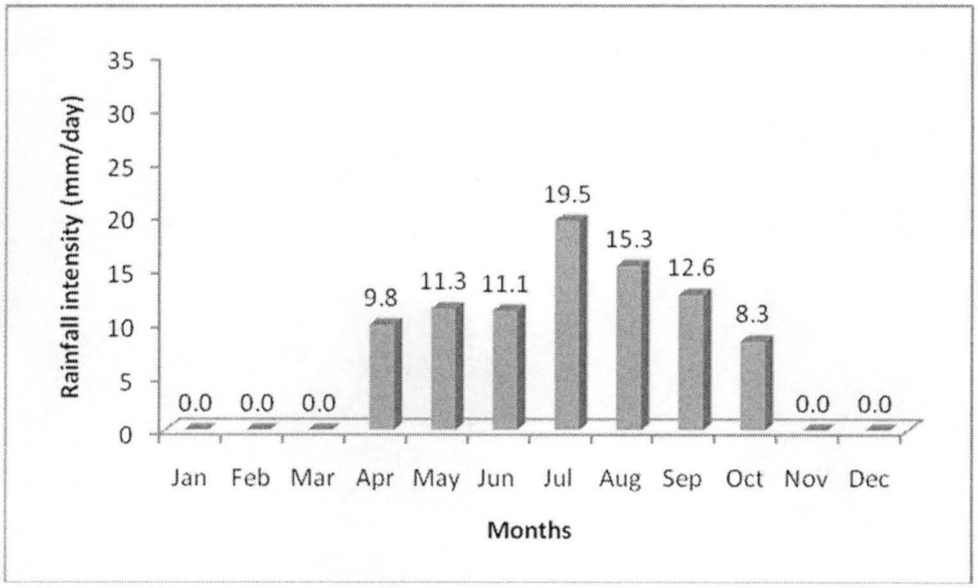

Figure 5a: Mean monthly Rainfall intensity of Sokoto (2000-2009)

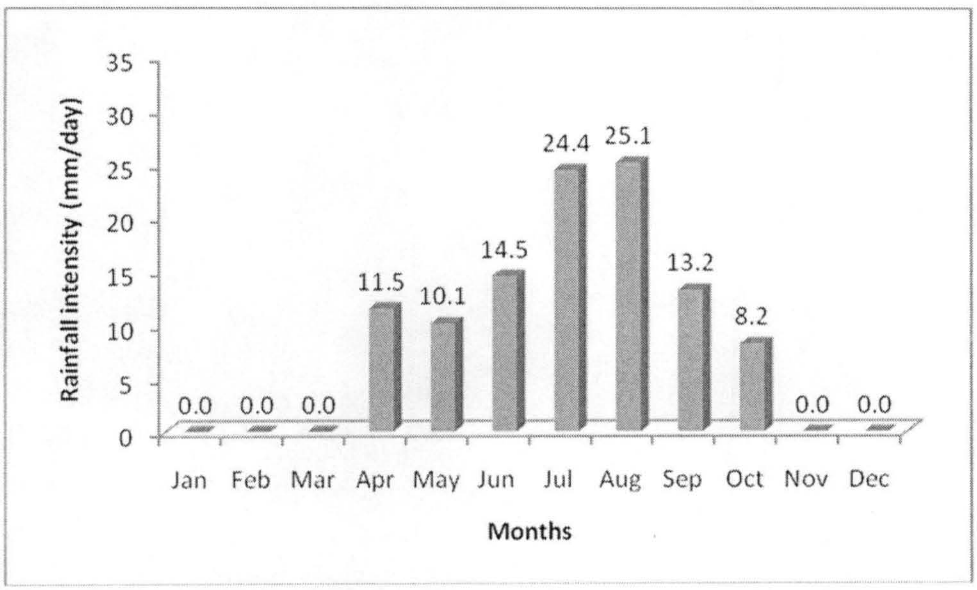

Figure 5b: Mean monthly Rainfall intensity of Bodinga (2000-2009)

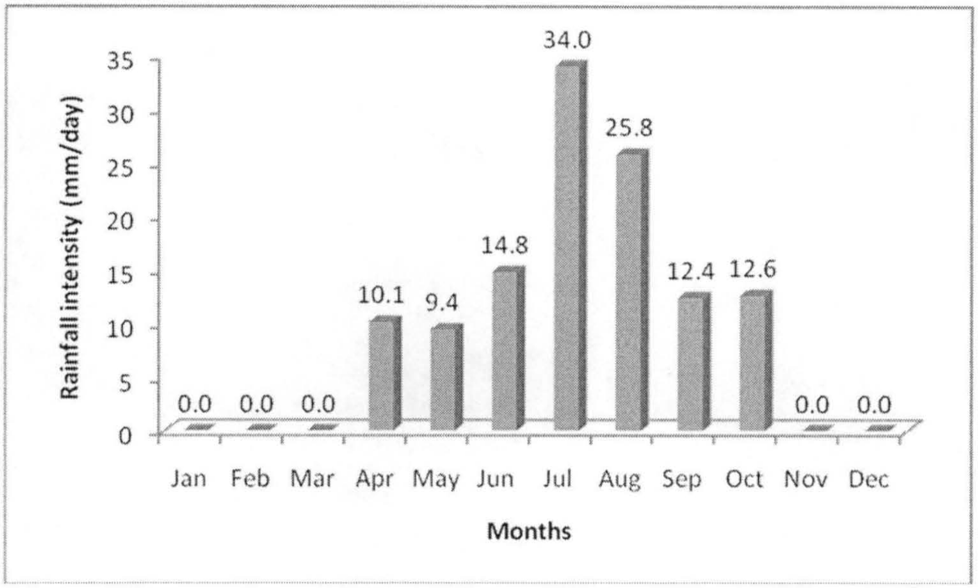

Figure 5c: Mean monthly rainfall intensity of Dange (2000-2009)

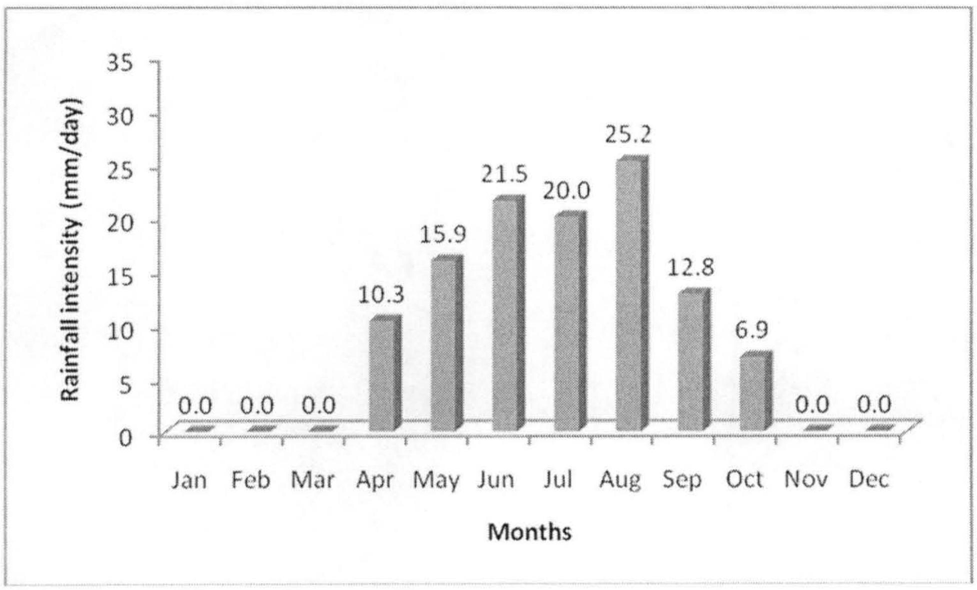

Figure 5d: Mean monthly rainfall intensity of Yabo (2000-2009)

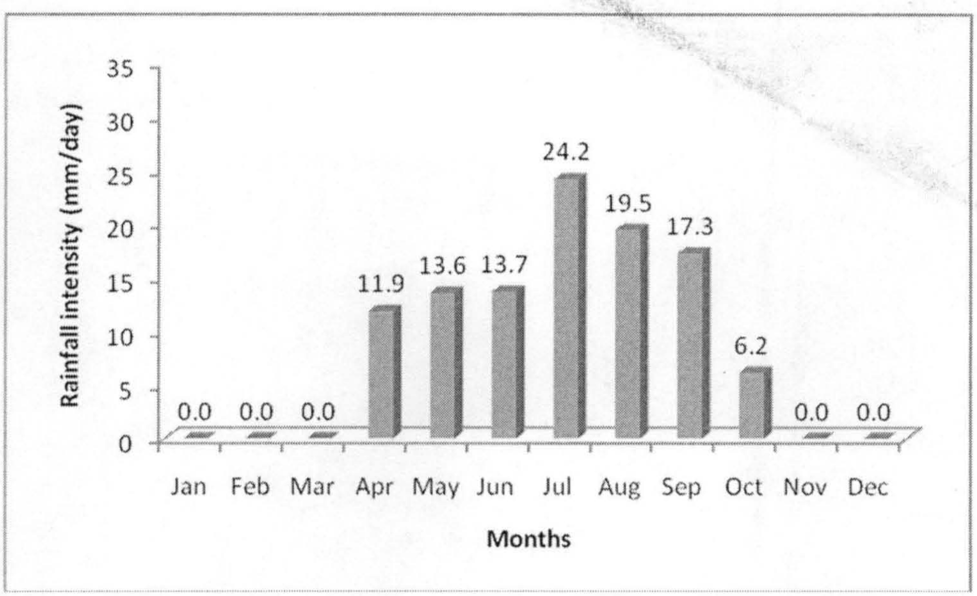

Figure 5e: Mean monthly rainfall intensity of Sanyinna (2000-2009)

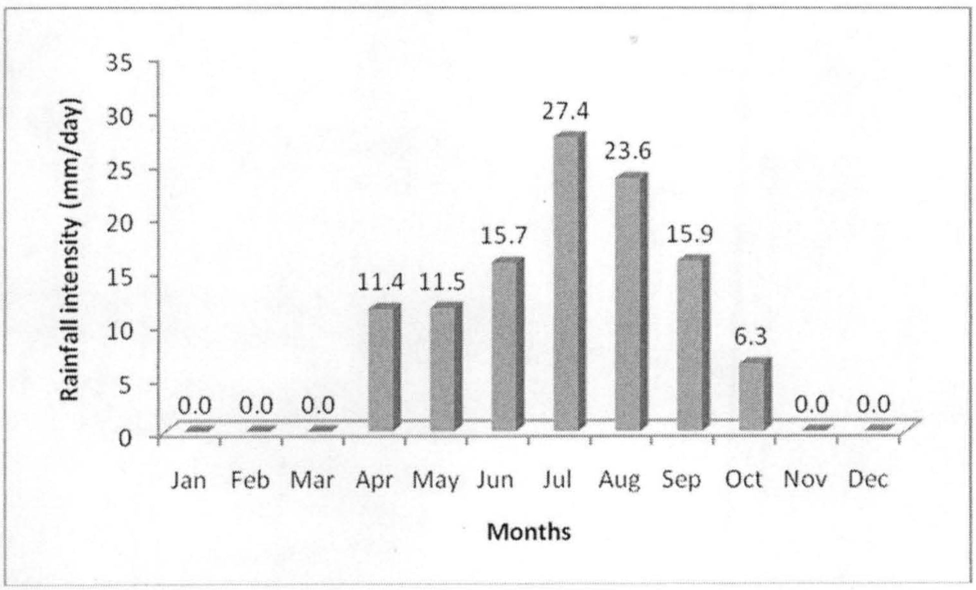

Figure 5f: Mean monthly rainfall intensity of Tambuwal (2000-2009)

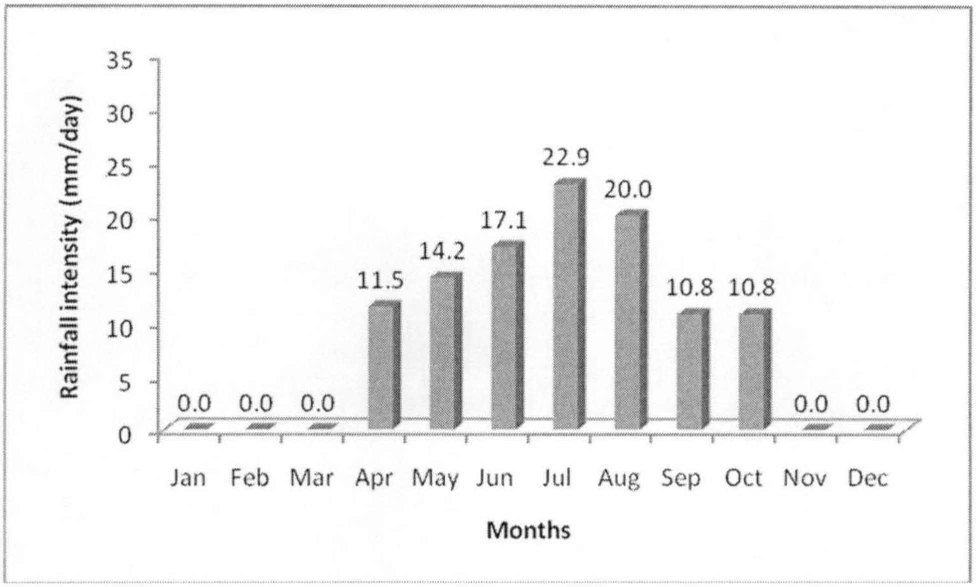

Figure 5g: Mean monthly rainfall intensity of Margai (2000-2009)

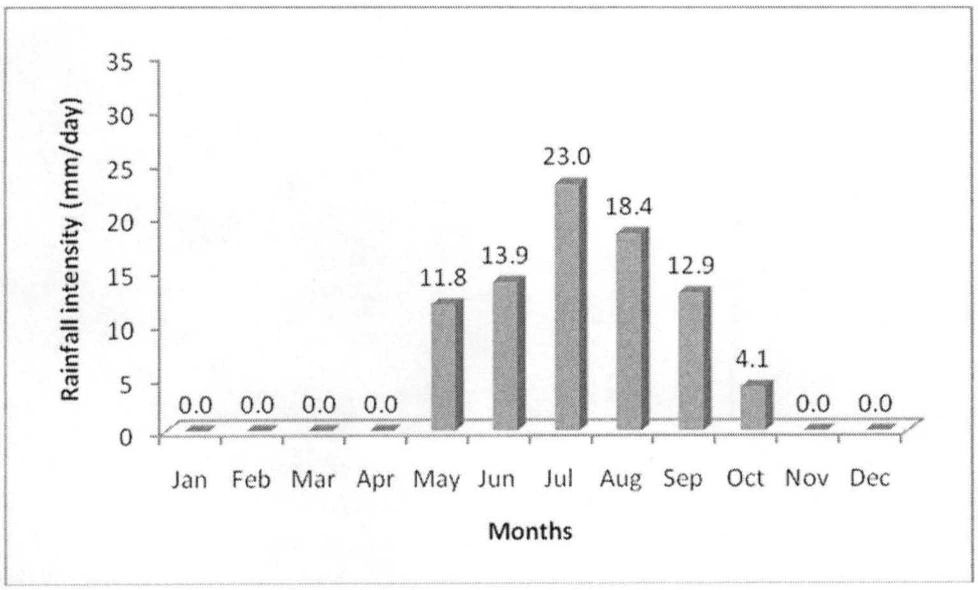

Figure 6a: Mean monthly rainfall intensity of Illela (2000-2009)

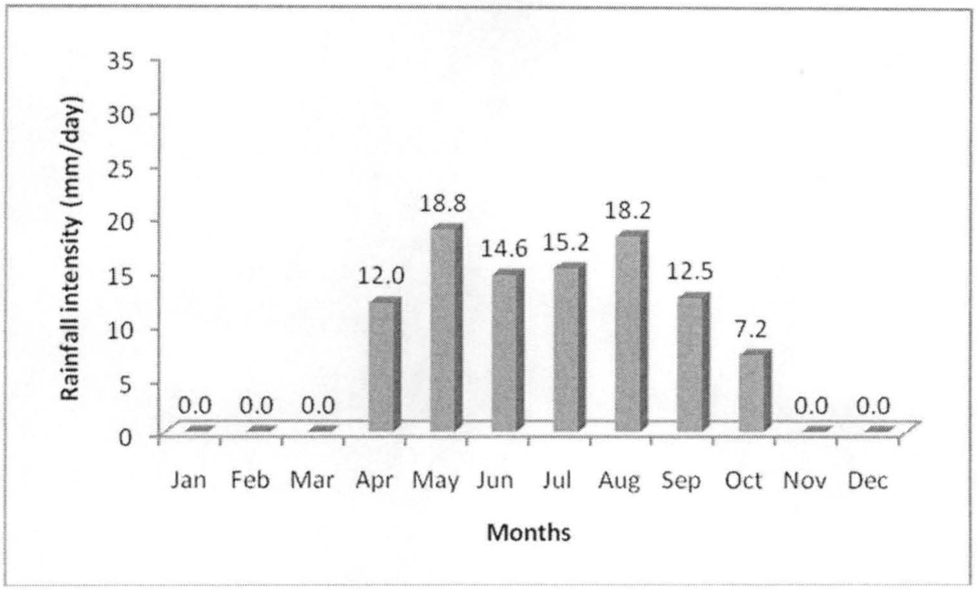

Figure 6b: Mean monthly rainfall intensity of Sabon Birni (2000-2009)

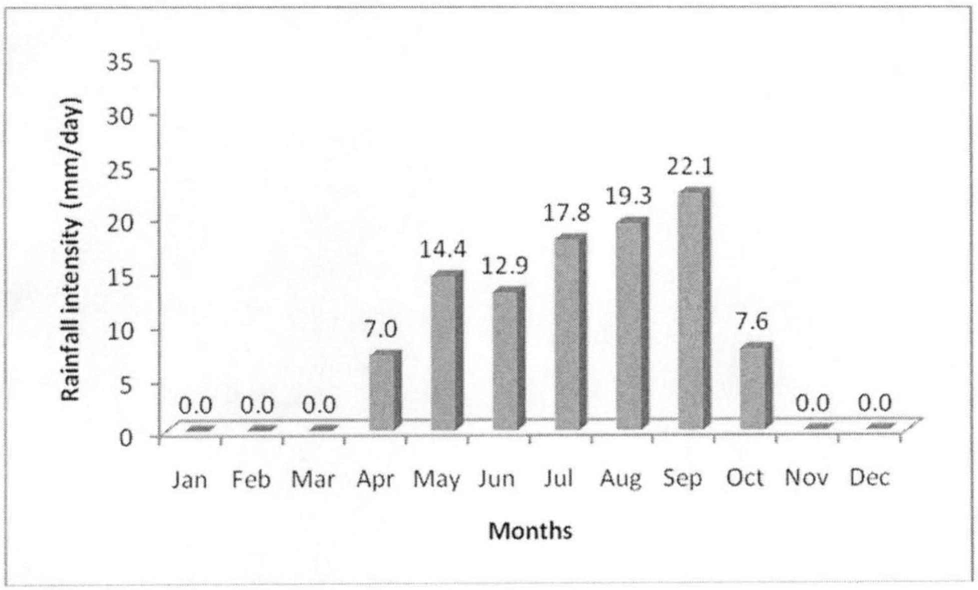

Figure 6c: Mean monthly rainfall intensity of Goronyo (2000-2009)

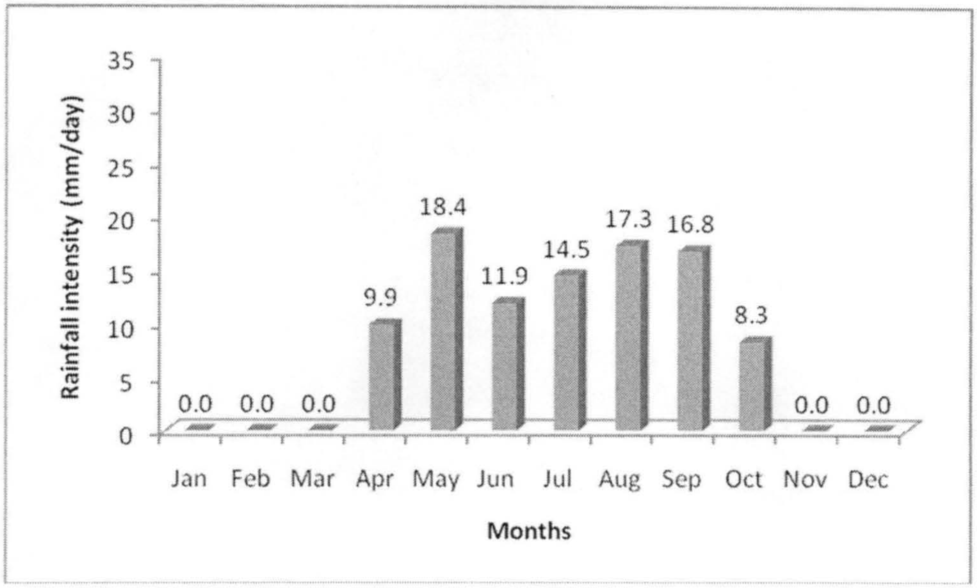

Figure 6d: Mean monthly rainfall intensity of Gidan Madi (2000-2009)

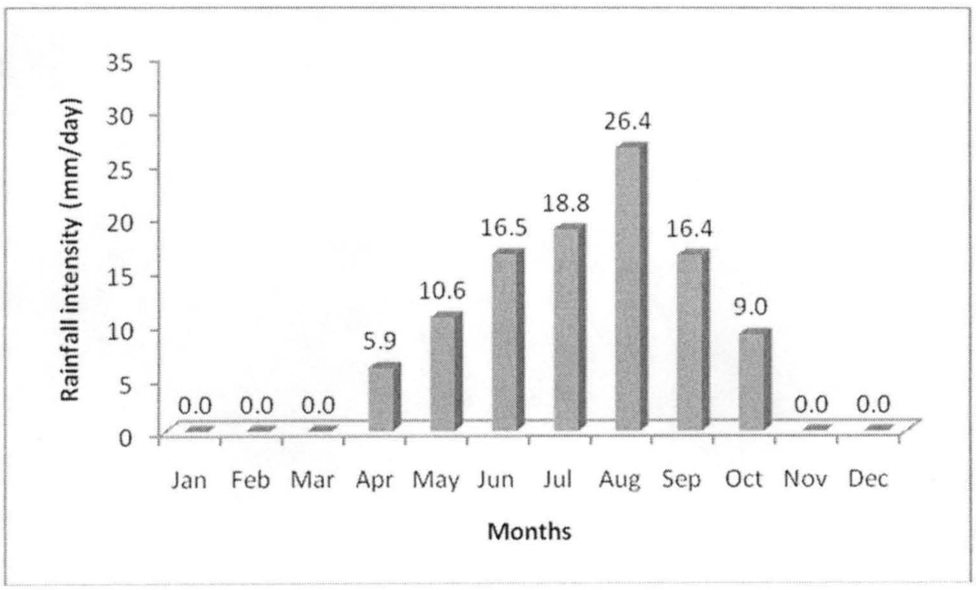

Figure 6e: Mean monthly rainfall intensity of Wurno (2000-2009)

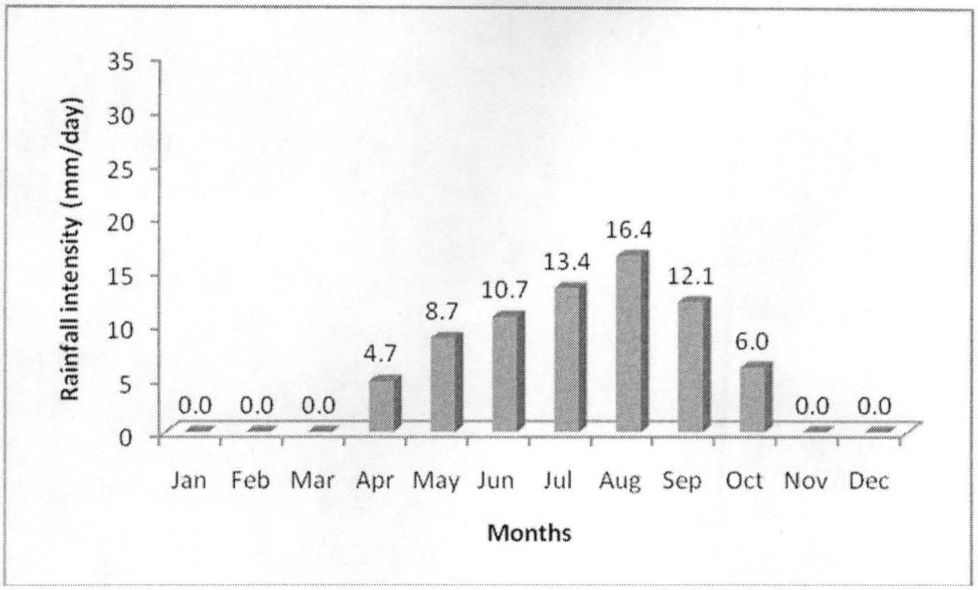

Figure 6f: Mean monthly rainfall intensity of Isah (2000-2009)

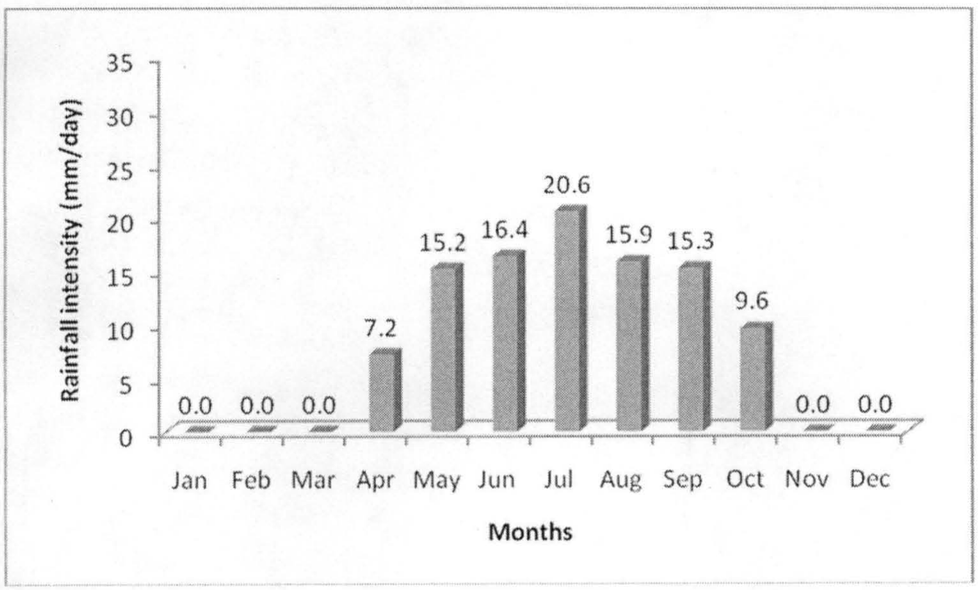

Figure 6g: Mean monthly rainfall intensity of Kware (2000-2009)