RELATIONSHIP BETWEEN SEASONAL RAINFALL OVER NIGERIA NORTH OF LATITUDE 10°N AND SEA SURFACE TEMPERATURE

SUBMITTED

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The Postgraduate School

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In Partial Fulfillment of the Requirement for the Award of

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BY

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ABSTRACT

The rainfall distribution over this area as other areas of Nigeria is very important as most of the agricultural crops are rain fed and therefore depend mostly on rainfall. Where irrigation is practiced, it is not only expensive but only possible where dams are available or if the farmers live along the river banks. But both the dams and rivers depend on the amount of rain water collected. We can therefore understand the importance of rainfall distribution over a place with high evapotranspiration rate, where majority of the population are predominantly farmers.

The 1972 –73 drought which affected most parts of Nigeria especially the northern parts and the subsequent drought episodes had a devastating effect on food production and water supply both for human consumption and industrial use. There were widespread food shortages and livestock perished in their thousands. A few human lives were also lost, though not directly but due to malnutrition. There were therefore massive movement of the rural population to the urban areas and with no jobs and adequate accommodation, the government was confronted with the problems of crime and slums. To solve the water shortage problem the government embarked on building dams. The emphasis was on collecting as much water as possible for agricultural and industrial use. This continued until in 1988, when the Bagauda dam collapsed destroying farm lands, killing livestock and some human lives were also lost. Since then there have been occasional reports of this and other dams overflowing their banks causing a lot of damage. The floods experienced in Jigawa, Adamawa and Kano states in September 2001 claimed some lives and rendered many people homeless and properties worth millions of Naira were destroyed. One month after the devastating flood, the majority of people camped in primary school buildings could not be vacated for the students to resume their studies.

It is to avoid such disaster that this investigating was carried out to see whether there is a relationship between SST and seasonal rainfall with the view of formulating a predictive scheme in future. The results show that although the area generally had one rainfall peak there are years that we have double peaks. The seasonal rainfall showed wide variation from year to year and there are prospects of predicting it fairly accurately using SST.

DECLARATION

I declare that this work " Relationship between Seasonal Rainfall over Nigeria North of latitude 10^oN and Sea Surface Temperature" is my own work and has not been submitted at any institution before for whatsoever reason.

Information derived from published and unpublished works of others have been duly acknowledged.

D. D. ORKUMA

4/03/02

DATE

CERTIFICATION

This is to certify that this project is an original work under taken by Deve D. Orkuma and has been prepared in accordance with the regulations governing the preparation and presentation of projects in the Federal University of Technology Minna Postgraduate School.

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DEAN POSTGRADUATE SCHOOL

DEDICATION

To my wife

and children

Seember

Terlumun

Iveren

Sewuese

ACKNOWLEDGEMENT

I am very grateful to GOD the Father Almighty for his Mercy, Blessing and Protection for making it possible for me to complete this work.

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1.0 INTRODUCTION

1.1 THE GLOBAL TREND

There is overwhelming evidence of climatic change over the past decades in many parts of the world. Regions with normal rainfall, and thus adequate water supply are now having rainfall deficit. With the explosion of world population, the acreage under irrigated agriculture has therefore increased considerably around the world. It is estimated that the area of irrigated land in 1969 was about 20 times that of about 1800 (Shmueli, 1973). Furthermore, according to (FAO, 1977), it was predicted that the worldwide area of irrigated land will expand from 223 million hectares in 1975 to a value of about 273 million hectares by 1990.

If such an increase is extended to the end of this decade, then the area under irrigation will be much higher. Agriculture is the largest consumer of water, more than 80 per cent of the total water controlled by men (FAO, 1977). Changes in rainfall pattern can therefore adversely affect agricultural productions. With the quantity of water consumed by agriculture especially in the semi-arid regions, these regions have already depleted much of their surface and ground water resources. It is a fact that there exists a fundamental linkage between water resources management and economic development in many parts of the world. For example, water resources are very significant for agriculture and hydroelectric power generation. They also considerably affect other socio-economic activities such as transportation, tourism and the manufacturing of a variety of products including cement, textiles and chemicals upon which continued human existence largely depends (Ayoade and Oyebande 1978, Prasad 1982, Ayoade 1988). In particular, it is widely recognised that the economic and proper management of water resources which are subject to large spatio- development of much Africa is strongly dependent upon the characteristics temporal variations (Ledger 1969, Sutchiffe and Knott 1987).

A series of rainfall anomalies from the late sixties with serious consequences on man in different parts of the world have demonstrated the sensitivity of human welfare and a nation's economic development to climatic events. Drought episodes have shown the vulnerability of man to climate; the studies of which are the studies of the energy and water balance characteristics of the ocean-earth-atmosphere interactions. The energy and water balances in turn, govern the growth and climate adaptability of plants, the comfort and discomfort of man, the distribution of water resources and human settlements both in space and time. The space-time distribution of global water, food, ecological and many other natural resources are largely controlled by the space-time distribution of climate. Climatic anomalies and especially extreme events such as droughts, floods occurrence, and other anomalous climate variability have therefore been linked to low agricultural production, loss of life and property, famine, migrations and other socio-economic miseries. Drought, desertification, deforestation and flooding partly caused by climatic variations and changes, mainly resulting from human activities have currently reached hazardous levels as man indulges in activities that encourages environmental degradation.

1.2 THE ENSO PHENOMENA

ELNino is the term used to describe an extensive warming of the upper ocean in the tropical eastern pacific lasting up to a year or even more. The negative or cooling phase of El Nino is called La Nina. El-Nino events are linked with a change in atmospheric pressure known as the Southern Oscillation (SO). The characteristics of SO involves fluctuations in the walker circulation, the East- West cell exchanging air mass between the equatorial pacific and

Indonesia (Walker and Bliss, 1932). The strength of the Southern Oscillation has an effect on the pattern of SST and the atmospheric circulation over wide areas. In addition, these in turn affect precipitation and other climatic conditions in many different areas. Because the SO and El-Nino are so closely linked, they are often known collectively as the El-Nino/Southern Oscillation or ENSO. The system oscillates between warm to neutral (or cold) condition about every 3-4 years.

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During El-Nino episodes, the concentration of excess heat in the eastern tropical pacific ocean modifies the atmosphere immediately above it and the effects are carried around the globe by the modified circulation in the atmosphere, resulting in changes in normal weather patterns in many regions. SSTs in the Indian and Atlantic oceans are also modified, which in turn affects the climate over them and in adjacent continental regions. When the SOI is low, for example, the rains associated with El-Nino in Western South America are enhanced. The same index, however has been shown to correlate with a failure of monsoon rains over most parts of India and low rainfall in parts of Australia.

On the other hand, a high SOI tends to correlate with a better Indian monsoon, more reliable rains in Eastern Australia and more normal SSTs and rainfall in Western South America. The Southern Oscillation is thus a major phenomenon of the tropical world with widespread repercussions within the global system. ENSO has been linked to climatic anomalies throughout the world (Ropelewski and Halpert, 1987).

1.21 THE 1997-1998 ENSO IMPACTS

ENSO in 1997-1998 have the following impacts;

SOUTH AMERICA

* Guyana was severely affected by drought and gold mining was severely affected by water shortage,
* The coast of Ecuador and northern Peru recieved 350-775mm of rain during December 1997 and January 1998, compared to annual norms of 20-60mm;
* Torrential rains soaked Brazil, south-eastern Paraguay, most of Uruguay and adjacent parts of north-eastern Argentina.
* Rain on Colombia's Pacific coast increased the threat of landslides. While inland forest, fires destroyed about 150,000 hectares.
* Sea-level in the Colombia rose 20cm.

NORTH AMERICA

* Unusual jet-stream patterns over North America led to severe storms in the eastern north pacific and west coast of the USA; heavy precipitation (100 to 500 mm) pelted California.

ASIA AND THE PACIFIC

* In Indonesia and the Philippines, long-term dryness persisted over the region, despite scattered heavy rains,
* Tropical storms LES and KATRINA induced drenching rains in

northern Australia, with severe flooding in Katherine, Queensland.

* In Hong Kong, 1997 was the wettest year, with 3340 mm of rainfall.

AFRICA

* Unusually warm weather was reported in most of South Africa, Southern Mozambique and Central and Southern portions of Madagascar.
* Heavy rainfall across Central and Southern Mozambique, the Northern half of Zimbabwe and parts of Zambia, causing flash flood in places.
* Kenya was particularly hard hit by flooding, many villages were cut off, the main Nairobi-Mombasa road was made impassable and more than 1500 people died of Malaria, which was spread by flood waters.

SOURCE: WMO (1998)

From the documented impacts of 1982-83 and 1997-98, it can be seen that a large portion of the world's population is affected by the El-Nino phenomenon. In combination with its atmospheric partner, known as the Southern Oscillation, El-Nino affect temperature and rainfall patterns throughout the world in varying degrees. The social and economic impacts of this natural ocean-atmosphere interaction can be extensive and long-lasting. Rainfall is intricately linked to many aspects of society, including water availability and quality, agriculture, fisheries, energy, tourism, transportation and human health and safety.

While climate fluctuations with ENSO are inevitable, advance warning of the impending climatic conditions could mitigate the loss of human life and economic disruption associated with the more extreme events. Furthermore, by learning to incorporate climate information into decision-making frameworks, we can begin to exploit opportunities for improved water resources management and capitalise on advance warning information in climate-sensitive sectors as agriculture, fisheries, energy, and public health.

1.3 THE NIGERIAN SITUATION

Nigeria gives a pride of place to agricultural production, hydropower generation and other waters resources projects in her social and economic development policy. Rainfall fluctuations had rendered, on many occasions, the economic forecast of planners of a failure. Over most parts of Nigeria, rainfall is the most important climatic parameter with the highest spatial and temporal variability. Flooding, soil erosion, drought and desertification have thrown the national economy into political and social convulsions. The seasonal patterns are generally associated with the seasonal characteristics of the Inter-Tropical Discontinuity (ITD) and other meso-scale features.

The reduced rainfall over the country in the areas north of latitude 10°N in the 1970's and 1980's especially the severe drought of 1972/73 and 1982/83 coupled with the high evaporation rates have tasked the ingenuity of water resources Managers in these areas. To ensure that adequate water is available for human, industrial and agricultural purposes they have embarked on the building of dams. Almost all fields of water resources management need meteorological data. Precipitation data for example are used for water availability studies, water supply, irrigation etc. The management of water projects like dams need information on the probability of extreme weather events, since there are occasions when these dams overflow their banks causing severe damage to property and washing away farmlands and sometimes causing deaths as happened at Kano in 1988. Because of the importance of drought over this area there is need to define what drought is.

Drought has been defined variously as follows:

(i) Meteorologically as situation when there is no precipitation for an extended period during which some precipitation should normally have been received depending on location and season;

(ii) In agricultural as a shortage of soil moisture available to crops which results in considerable yield reduction;

(iii) In hydrology as being responsible for depression of surface and underground water levels or diminution of stream flow; and

(iv) Socio-economically as water shortage adversely affecting the established economy, and therefore well being of a place.

1.4 AREA OF STUDY

The Study covers 10 Nigerian stations north of latitude 10°N (Fig. 1.1). All the ten stations have two distinct dry and wet seasons. The dry season covers a period of about seven (7) to eight (8) months from October to April/May, while the wet season is between four (4) and five (5) months from May to September. It can also be seen that rainfall has been erratic over the area and this has serious implications on water resources management. The annual rainfall varied from 236.7mm to 1537.3mm. Bauchi had lowest rainfall of 725.6mm and recorded the highest value of 1251.2mm. Gusau reported the least rainfall value of 708.9mm and the maximum value of 1507.1mm. Kano had low rainfall of 413.9mm and high value of 1087.4mm. Over Katsina the lowest rainfall recorded was 262.0mm and the highest value was 776.3mm. Potiskum reported the lowest rainfall amount of 408.5mm and the highest value of 968.1mm. Maiduguri had a low value of 263.5mm and a high value of 726.1mm. The minimum rainfall recorded over Nguru was 236.7mm while the maximum value was 601.7mm. For Sokoto the low and high values are 320.0mm and 850.5mm respectively. Yelwa reported the lowest rainfall of 596.1mm and the highest value of 1537.3mm. Zaria recorded a minimum of 685.6mm and a maximum of 1375.6mm. The unimodal rainfall pattern is exhibited but there were years when we have marked bimodal

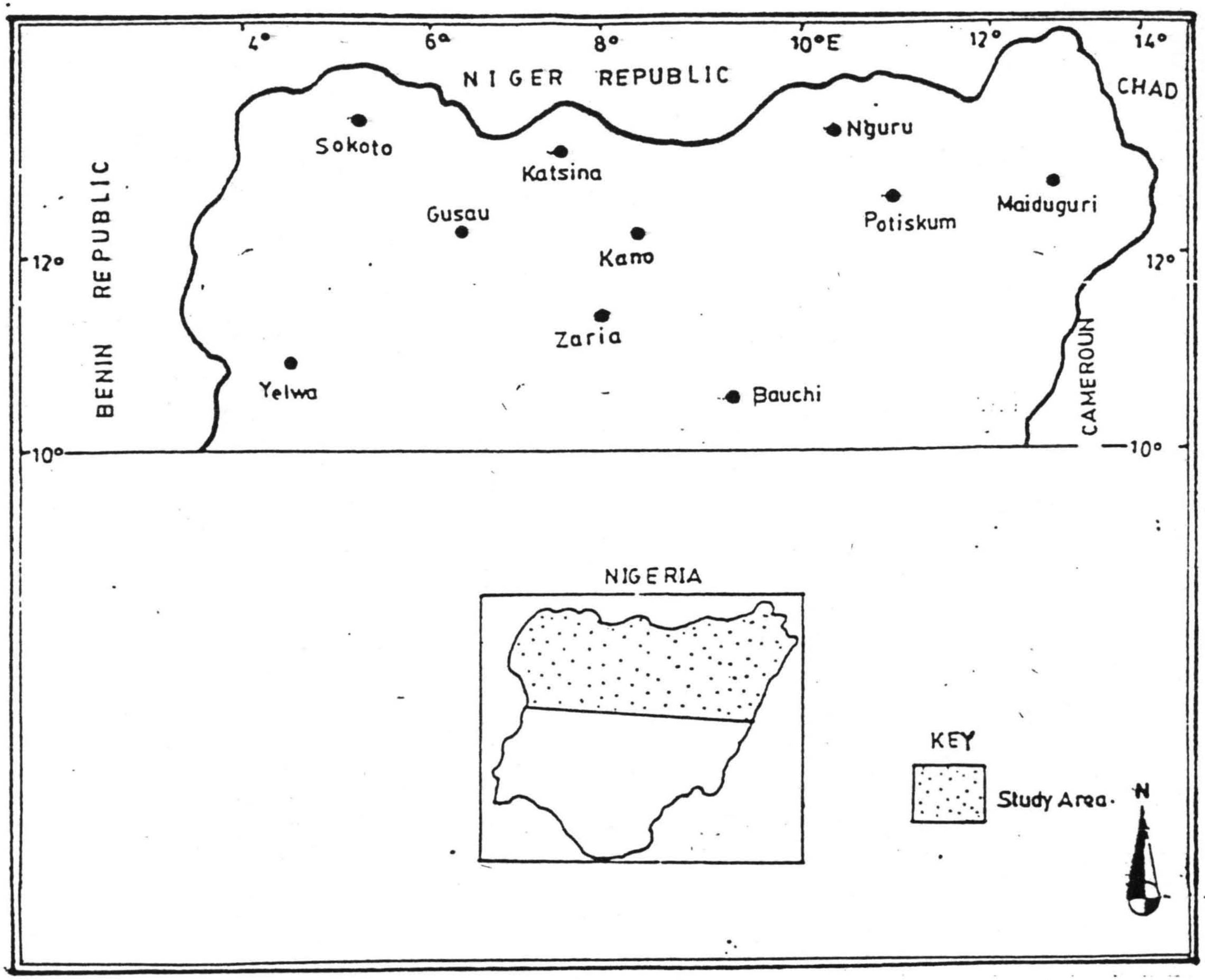

Fig. 1.1: MAP SHOWING STUDY AREA

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rainfall pattern. The dry season as can be seen lasts longer than the rainy season over this region of study where agricultural practices are the main stay of the economy.

1.5 PROBLEM STATEMENT

This area is seriously threatened by drought and desertification, which has seriously affected the water requirements of the people. Since most of these people here are farmers, their food production is dependent on the availability of enough precipitation, for although they have irrigation facilities in some places, these are limited and very expensive. The dams here also need enough precipitation for effective utilization. Since the early 1970s and 1980s these areas experienced severe water shortages that led to the displacement of many people. Some of these people lost their animals due to lack of pasture. Human lives were also lost though not directly but due to malnutrition.

To solve this problem of water shortage, the state governments especially that of Kano embarked on the building of dams to conserve water during the time of plenty, so that it can be used when necessary. But in 1988 and the subsequent years some of these dams have overflowed their banks causing damage to both lives and property. Again a lot of people were displaced and agricultural production was seriously affected as crops and animals were washed away. The question then is could some, if not all these disasters have been avoided?

1.6 JUSTIFICATION

The problem of drought is very grave and therefore it s understanding is very central to survival of the fragile economies of sub-Saharan African countries where the amount and spread of precipitation determine the success of all agricultural activities. Any precipitation deficit expose large areas to famine which if sustained could lead to migration which further disrupts the economy. Although there are other factors for effective agricultural production, the major variable is precipitation. The other variables which are equally important are fairly constant in a given situation. In a dry place, we cannot talk of precipitation spread, evaporation or evapotranspiration and plant water requirement. In dam management, adequate precipitation will not only minimize evaporation but will provide water to the dams, both directly and through catchment area and underground reserve. It is therefore to answer the question whether these disasters could have been avoided or minimized that this work is embarked on. Earlier studies made use mostly of ENSO but here other areas of the global oceans are also investigated.

1.7 AIM

The aim of the study is to investigate if there has been precipitation fluctuation and to establish the relationship between SST and seasonal rainfall.

1.8 OBJECTIVES OF THE STUDY

The objectives are to:

(i) Review the precipitation pattern to see whether there is variability over the years.

(ii) To find the relationship between SST and seasonal rainfall with the intention of formulating a prediction scheme for seasonal rainfall in future.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ENSO, SST AND RAINFALL VARIABILITY

Among the number of studies on the space-time characteristics of various meteorological parameters, the oldest in record are studies of global temperature and precipitation data. Also closely related are the studies on the links between ENSO and large scale precipitation patterns. Sir Gilbert Walker in 1920s was the first to provide the clue to the link between these climatic effects on distant parts of the globe and Walker's circulation cell with a major component of El Nino. He noticed that when pressure rises in the East Pacific, it falls in the West and vice versa. He further observed that monsoon seasons with low index conditions were often marked by drought in Australia, Indonesia, India, and parts of Africa. He also claimed that during low-index, winters tend to be usually mild in Western Canada.

Wright (1984) investigating the relationship between indices of the Southern Oscillation, found that the fields of SST, rainfall and pressure in their core regions are strongly coupled, and their fluctuations take place simultaneously to within a month. Ropelewski and Halpert (1986) studied the North American precipitations and temperature patterns associated with the ENSO. A combination of time series analysis and stochastic methods were used for the data analysis. According to them, the warm phase of the Southern Oscillation was linked to rainfall distribution over some parts of North America.

It was found out that above normal precipitation was associated with ENSO in 18 out of 22 cases (81%) in the season starting with October of the ENSO year to March of the following year for an area of North America that include south-eastern United States and Northern Mexico. Above normal precipitation was also observed in the Great Basin area of the Western United States in 9 out of 11 cases (81%) for April through October.

The analysis also showed that there was no high latitude precipitation signal. It was also found out that in Alaska and Canada positive temperature anomalies in 17 out of 21 ENSO episodes (81%) were experienced in December of the ENSO year through March of the following year near the Gulf of Mexico. Negative anomalies of temperature were also found in 20 out of 25 cases (80%) in between October of the ENSO year through to March the following year.

Kiladis (1991) studying the teleconnection between ENSO events and climate anomalies in distant regions, noted that many of the teleconnections identified by Sir Gilbert Walker in the early decades of the twentieth century has been reconfirmed in the 1980s. He discussed several regions of prominent teleconnection: North east Brazil, the Peruvian Coastal area, Ethiopian Highlands, Southern Africa, Indonesia, South Asia etc. He also showed that the teleconnections associated with cold events tend to be opposite to those associated with warm event. The warm phase ENSO episode between 1470-1989 was investigated by Shaowu (1991). Using sets of proxy data of unusual weather occurrence over the globe, such as the Australia drought, Peruvian floods etc., one hundred and fifteen El-Nino events were found exhibiting a mean interval of 4.5 year for the period 1470-1989. Although there was no close relationship between the frequency of El-Nino events and global warming, it was however noted that strong volcanic eruptions in the lower latitudes were followed in most cases by an El-Nino event.

In investigating both the North American precipitation and temperature patterns, and global and regional scale precipitation patterns associated with the ENSO, Ropelewski and Halpert (1986, 1987) showed that:

(i) Normal precipitation was associated with ENSO in most cases during the seasons and

(ii) In most of these regions, the season of ENSO related precipitation was found to be in phase with the normal annual precipitation cycle.

Nicholson (1995) worked on ENSO signals in the tropical Atlantic and Western Indian ocean using a harmonic analysis method pioneered by Ropelewski and Halpert (1986). Monthly SST data from Co-operative Ocean Atmospheric Data (COAD data set) were analysed for an Atlantic Indian Ocean domain extending from 40^0N - 40^0S. It was found out that large areas, mostly north of the tropical Atlantic and tropical Indian Ocean consistently exhibit inter-annual SST variations. The Atlantic, especially south of the equator showed an apparent response to ENSO but was less consistent. The area was found to be an area were ENSO composite warming begins during the early ENSO year, when cold anomalies prevail over most of the Atlantic. It was further observed that the Atlantic ocean as a whole reaches its peak warming around October, November, and December of the ENSO year, and maximum cooling one-year earlier. In the Indian ocean the timing was discovered to be more uniform with the identified sectors generally exhibiting peak cooling and warming during January, February and March of the ENSO year and the following year respectively.

The influence of global SST on Africa rainfall has been extensively investigated. Using observational and numerical modelling studies Palmer (1986), Folland et al (1986) have for example, shown clear statistical and physical relationships between world-wide patterns of SST anomalies and rainfall in sub-Saharan Africa. Rainfall trends in Africa between 1901 and 1985 have been shown by Lough (1986), Folland et al (1986), Hasternrath (1984), and Lamb (1982, 1985) to be directly influenced by contrasting patterns of SST anomalies on a global scale. The persistent dryness in the Sahel since 1968 has been linked with the enhanced warmth in South Atlantic, Eastern South Pacific and Indian Oceans and the cooler than normal SST. In the North Atlantic, Mediterranean and North Pacific.

Using observational and numerical studies Palmer (1986), Folland et al (1986) have for example, shown clear statistical and physical relationships between world-wide patterns of SST anomalies, and rainfall in sub-Saharan Africa. Rainfall trends in Africa between 1901 and 1985 have been shown by Lough (1986), Folland et al (1986), Hasternrath (1984), and Lamb (1982, 1985) to be directly influenced by contrasting patterns of SST anomalies on a global scale. For instance, the persistent dryness in the Sahel since 1968 has been linked with the enhanced warmth in South Atlantic, Eastern South Pacific and Indian Oceans and the cooler than normal SST in the North Atlantic, Mediterranean and North Pacific.

The annual movement of rainfall across the African continent has been well documented in many studies among which are those by Nicholson (1981), and Hsu and Wallace (1976). Ogallo, Janowiak and Halpert (1988) using the correlation of the global surface temperature anomalies within 30^0N and 30^0S and the time series of the major Rotated Principal Component Analysis (RPCA) modes of the seasonal rainfall over East Africa, observed significant instantaneous (zero lag) and time lagged correlation between SST anomalies over portions of the global oceans and some of the principal seasonal rainfall modes in East Africa.

Munthali and Ogallo (1988) worked on the spatial and temporal characteristics of rainfall over Malawi. The temporal characteristics investigated included the frequency, probability, persistence and recurrence of the extreme rainfall events, while the spatial components were regional coherence and teleconnections with El-Nino. Monthly rainfall records for the period 1897-1983 for 42 stations were used. It was established that the pattern of the rainfall anomalies index during the El-Nino for low southern oscillation years indicated that during 65% of the El-Nino years below normal rainfall were recorded over many parts of Malawi. The probability of obtaining above normal rainfall during the cold episode (high southern oscillation index) was relatively small (0.55).

It was also observed hat during 73% of the high southern oscillation indexes normal or above normal rainfall conditions were observed over many parts of Malawi. It was also noted that some of the observed rainfall anomalies could however not be associated with El-Nino or the Southern Oscillation.

In his study of teleconnections between seasonal rainfall over East Africa and global SST anomalies (Ogallo 1988a), revealed that the spatial patterns of the significant correlation between seasonal rainfall and SST anomalies indicated a see-saw pattern between the eastern pacific ocean and the Indonesian region which coincides with positive rainfall anomalies over the coastal regions of East Africa, and indicated a relationship between rainfall variability in East Africa and the ENSO. The method used in this study was Principal Component Analysis (PCA). Ogallo (1988b) worked on the relationship between seasonal rainfall in East Africa and the Southern Oscillation using correlation analysis methods. His results were that during the month of July-September, significant positive zero lag correlation in the range of 0.5 were observed over some western parts of East Africa. Low zero lag correlation were however obtained over most of the regions with the January-May and annual rainfall records. The computed lagged correlation values displayed characteristics similar to those observed from the zero lag correlation. It was however noted that although there were some relationships between the Southern Oscillation indices and seasonal rainfall over parts of East Africa, some of the extremes wet and dry episodes were not related to the Southern Oscillation.

In recent years, a great deal of study has been provoked by the recent long-term persistence characteristic in the Sahelian rainfall pattern which indicates the long-term decreasing trend from the 1950s to the 1980s. A major effort has been to relate this dramatic decline in the rainfall to some global parameters like the Sea Surface Temperature (SST) anomaly patterns on the Atlantic or global scale (Folland et al, 1986, Parker et al, 1988, Wolter, 1989, Wolterand Hasternrath, 1989,1990). The prolonged Sahelian drought of

1968-1973 has been examined in various studies (Bunting, 1975, Druyan, 1988 and WMO, 1993). This drought, although more severe and persistent than any other drought in the history of the Sahel, has been found to be within expected climate variability and may occur 3-4 times each century. The drought, coupled with ENSO events, over grazing and other human-induced environmental degrading factors have been blamed for the expansion of desert-like conditions over the Sahel and the Eastern African region (Drought 1993, WMO 1993).

The Drought Monitoring Centre (DMC) Nairobi, carried out various studies/analysis on the general conditions which precedes an ENSO by a few months, which are;

- 850 hpa westerly wind anomalies in Pacific ocean
- the SOI i.e. the difference in pressure between Tahiti and Darwin becomes strongly negative.
- positive SST anomalies in eastern pacific that persist beyond the normal winter time annual warming.
- enhanced convective activity in central equatorial Pacific ocean.
- falling sea-level in the western pacific ocean and rising level in the eastern Pacific.

And that the idealised ENSO cycle is basically a 24 months period starting with July preceding the event designate July (-) through June after the event, designated June (+). The year in which maximum SST anomaly is observed is referred to as the El-Nino year and designated (o).

The amount and seasonal distribution of the rainfall received at any location varies significantly during the years, resulting in droughts or abundance of rainfall. It has been noted that some of these anomalies coincide with the El-Nino years. There is a significant relationship between Sahel rainfall, the global SST and tropical circulation patterns as has been reported by Lamb (1978) and Lough (1986), among many others. Awosika et al (1995) having studied the land-ocean-atmosphere interaction over the Gulf of Guinea shelf of the eastern tropical Atlantic, noted that the Gulf of Guinea coastal and marine processes are controlled by land-ocean-atmosphere interactions. It was also shown that upwelling phenomenon in the gulf is mainly linked to zonal wind outside the gulf. The energy from these winds is transmitted to the gulf via equatorial waves.

After studying the rainfall pattern in Ghana associated with the southern oscillation, Sonekan (1997) showed a low degree of relationship between urban rainfall in Ghana and ENSO. Results from other analyses however indicated anomalies during the warm and cold ENSO phases. His concluded that the SOI only might not be the best predictor for seasonal rainfall over Ghana and that other potential predictors must be investigated.

2.2 RAINFALL VARIABILITY

The most widely studied hydroclimatic variables in the tropics is rainfall. This may not in part be unconnected with the fact that of all the climatic variables, data on rainfall are the most readily available and for relatively long period. Another possible reason for the relatively high attention paid to rainfall variations in tropical Africa is that climatic and hydroclimatic variations can virtually be considered equal to rainfall variations in the region (Oguntoyinbo and Odingo 1979). It is therefore not surprising that more studies abound on rainfall variations than on any other climatic or hydroclimatic variable in Tropical Africa. Many studies use time series analysis to examine African rainfall data. Bunting et al (1976) studied long-term rainfall records from selected stations in West Africa. They concluded that no trends or periodicities could be found in the data, extending over 50 years or more, to indicate that a systematic pattern of below-normal rainfall had been established in recent years.

Ogallo (1979) analysing annual rainfall series for 69 stations in Africa with varying lengths of record, concluded that although oscillatory characteristics were observed, no significant trends or periodicities were evident. However, for seven stations in West Africa, which are located to the south of the Sahel zone, his results indicated an increasing rainfall tendency in some years prior to 1974 (the period of below-normal rainfall in the Sahelian region). Walker and Rowntree (1977) found evidence of drought persistence from year to year in the more arid northern Sahel (15^0N-18^0N) as compared to the southern zone (12^0N-15^0N).

Nicholson (1979) using an expanded database, examined long-term rainfall series for the semi-arid region of sub-Sahara Africa (between 12^0N and 20^0N) and found evidence to support a tendency toward persistence in the sub-tropical rainfall series. He discussed periods of severe drought (1912-1914, 1940's, 1968-1973) in the 75-year rainfall series for the entire region where average annual rainfall varies between 500 and 1200mm. The studies showed that the succession of recent drought years in the Sahel is not unprecedented.

Aspliden and Adefolalu (1976) worked on the climatic patterns of the West African sub-tropics by analysing mean monthly radiosonde soundings below the 100hpa level for eight West African upper air stations during the period 1960-1970. These stations were grouped in southern and northern zones, because of the large climatic variations within this region. Four stations were located along the latitude of 5^0N and the others around 13^0N-14^0N. The southern zone represents the general monsoon belt within the sub-humid tropical zone with a mean annual rainfall of 1600-2000m. The northern zone is typical of the semiarid climatic region of the Sahel with a mean annual rainfall of 700mm. In each zone, the spatial characteristics were homogeneous over their longitudinal extent.

Some scientists believe that the Sahelian droughts of West Africa have persisted since 1969 and would even persist into the next century, thus indicating climatic change to drought condition (Lamb (1985), Winstanley (1973). Others with contrasting views have argued that although variations have occurred in the amount of rainfall recieved over West Africa, especially since the early 1970s, these variation have been localised over parts of the region. Hence, based on this, there is no convincing evidence as at present to conclude that the climate of the region is becoming wetter or drier (Ojo, 1983). Ojo (1983 and 1987) in his studies of climatic variation on West Africa, observed that a lot of variations have occurred between the different climatic zones and even within the same climatic zone of the sub-region. Consequently, it is difficult to conclude that the climate of West Africa is progressively becoming drier or moister.

In his study of recent trends in aspects of hydroclimatic characteristics in West Africa, Ojo (1983b) noted that the year to year spatial analysis of the distribution of rainfall in West Africa shows that although 1931, 1939, and 1954-1955 were relatively wetter years than the average conditions, many locations within the sub-region had negative deviations. He further noted that during 1932, 1942, 1944 and 1971-1973, when conditions were relatively drier, many parts of West Africa had relatively positive deviations and thus there were no readily observable climatic trends in the sub-region both in time and space. It may however be noted that the focus of most of these studies centres essentially on the analysis of the characteristics of rainfall variations rather than on the probable causes of the variations. Nonetheless, the studies contributed substantially to the understanding of the spatio-temporal characteristics of the recent hydroclimatic variations that have occurred in different parts of Africa and West Africa. Some scholars have also attempted to examine the probable causes of recent climatic variations and climate change in different parts of the world.

2.3 SIGNIFICANCE OF ITD

Oyebande and Oguntoyinbo (1970), using correlation and regression models, examined the mean annual rainfall patterns in south-western Nigeria in relation to four locational factors namely relief, latitude, longitude and continentality. They noted that the correlation and regression analyses lent statistical support to the relationships between meteorological elements and rainfall patterns in south-western Nigeria. They observed that latitude (the ITD factor) is of great significance throughout the year as it influences the rainfall patterns both during the monsoonal and squall line periods. It was further observed that relief and to a lesser extent, longitudes are important factors of rainfall for most of the year. The study however noted the relative influence of some local factors such as land and sea breezes especially along the coastal areas and some topographic influences, other than relief. Olaniran (1987), investigated the distributional pattern of rainfall occurrence in storms of different sizes in Nigeria and related the patterns obtained to three factor viz. Inter-Tropical Discontinuity (ITD), Disturbance lines and Altitude. He noted that the distribution of annual rainfall in Nigeria shows a strong latitudinal variation and an altitudinal control. In general, five weather zones A, B, C, D and E are usually recognised in West Africa. Along the coastal area, these five weather zones could be experienced during a year. Inland as many as six or even seven may be experienced in a particular location (Ojo, 1997). Previously the existence of four weather zones, aligned east-west in parallel with the ITD was recognised by Hamilton and Archbold in 1945. Each of the zones is characterised by specific weather conditions, which can be identified in the rainfall and temperature refines. A lot of variations however occur within each zone, and the weather conditions over a particular area depend on the characteristics associated with the prevailing weather zone.

2.4 SUBTROPICAL HIGH PRESSURE CELLS

The Subtropical high pressure cells and the Easterly waves are significant features of the synoptic systems in West Africa. The subtropical high pressure cells are two zonally placed high pressure cells between latitude 25^0 and 30^0 in the Northern and Southern hemispheres respectively. In the northern winter one of these high pressure cells has its centre over Western Europe and the other with axis extending over parts of Northeast Mauritania, Algeria, Mali and Niger. These two cells are separated by a sub-polar low pressure belt whose cells are located over the coast of Spain to the west and around Malta to the east. The associated trough so induced, injects cold dry continental air mass deep into the country. The Saharan anticyclone or Libyan high when fully established in winter (which coincides with our dry season) after the passage of the mid-latitude troughs creates a tight pressure gradient (>10hpa) between Sebha and Abeche. In addition, the associated strong winds arise and transport dust haze from the source region to the northern parts of the country. The relaxation of the high pressure gradient normally leads to dust clearance. In general the presence of the high-pressure cells over an area in summer is an indication of stable weather conditions.

2.5 EASTERLY WAVES

The Easterly waves are formed in East/Central Africa (long 25^0-35^0E) south of the African Easterly Jet core (AEJ), where the mean zonal flow is batropically unstable (Burpee, 1972). The wave structure shows a surface convergence zone, a cyclonic vortex at 850hpa and a distinct wave pattern at 700hp. Wave intensity tends to decrease upwards thereafter (Omotosho 1984, 1999). They have phase speed of 7-8m/s, a wavelength of about 2000-3000m and a 4-day meridional oscillation. Thunderstorms/rain occurs to the southeast/southwest of a typically developed easterly wave.

The West African squall line which is a line of disturbed weather about 300-1000km long lies roughly north/south and moves generally from east to west over the West African region, with a speed of about 30 knots and which is accompanied by heavy bank of connective clouds, strong gust of winds, precipitation, thunder and lightning (Balogun, 1974). Largely, the West African squall lines are dependent on or controlled by the summer time monsoon oscillations. They are absent when the monsoon retreats from most parts of West Africa. (November-March), suppressed if the monsoon is too deep (giving way to monsoon rain) over coastal regions in June/July and very violent when the monsoon depth is about 12km, especially north of 11^0N.

2.6 CLIMLAB

CLIMLAB combines the power of computational engine octave for numerical and matrix calculations. It has the graphical ability of GrADS to produce different kinds of plots and two dimensional contours with graphical references. The soft ware is designed to create data sets, calculate standardized anomalies, de-trend time series draw different kind of statistical plots, create simple statistical prediction models and perform so many other function.

CHAPTER THREE

3.0 METHODOLOGY

3.1 DATA

3.1.1 RAINFALL

The monthly rainfall data used in this study was obtained from the Department of Meteorological Services Oshodi-Lagos for a period of 25 years from 1971 to 1995. It covers ten (10) stations namely; Bauchi, Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum, Sokoto, Yelwa and Zaria.

S/NO	STATION	COORDINATES
1	BAUCHI	LAT I0^{O} 17^{IN} LONG 09^{O}49^{IE}
2	GUSAU	LAT 12^{O} 10^{IN} LONG 06^{O}42^{IE}
3	KANO	LAT 12^{O} 03^{IN} LONG 08^{O}32^{IE}
4	KATSINA	LAT 13^{O} 01 LONG 07^{O} 41^{IE}
5	MAIDUGURI	LAT 11^{O} 51^{IN} LONG 13^{O}05^{IE}
6	NGURU	LAT 12^{O} 53^{IN} LONG 10^{O} 28^{IE}
7	POTISKUM	LAT II^{O} 42^{IN} LONG 11^{O}02^{IE}
8	SOKOTO	LAT 12^{O} 53^{IN} LONG 10^{O} 28^{IE}
9	YELWA	LAT 10^{O}53^{IN} LONG 04^{O}45^{IE}
10	ZARIA	LAT II^{O} 04^{IN} LONG 07^{O}45^{IE}

3.1.2 SST

The SST data were obtained from the International Research Institute for climate prediction.

3.2 METHOD OF ANALYSIS

3.2.1 MISSING DATA

The few rainfall missing data which was less than 2% of the data set was replaced by the averaging technique.

3.2.2 MONTHLY RAINFALL

These were plotted for each of the stations and an interesting rainfall pattern for some of the years was revealed.

3.2.3 ANNUAL RAINFALL

The annual rainfall was obtained by summing the monthly rainfall. This was the plotted to see the trend. The standardized rainfall was also plotted.

3.2.4 SEASONAL RAINFALL

The seasonal rainfall totals for each of the stations were calculated from the monthly rainfall for a 3-month period with overlapping starting with May- June-July (MJJ), June-July-August (JJA), July-August-September (JAS).

3.2.5 NINO REGIONS AND SEASONAL RAINFALL

The relationship between the Nino regions and the seasonal rainfall were carried using the CLIMLAB menu option "correlation with the Nino region". This option allows the user to compute correlation coefficients between the seasonal rainfall and the SST values in the Nino region. The region is specified by its latitude and longitude. The months to be averaged are also specified together with the period of years. The file containing the seasonal rainfall data is entered in the Browse window and we click "OK" to start the computations (Fig. 3.1). The program will compute the average sea surface temperature for those months in the region selected for each year. These are then correlated with the seasonal rainfall and displaced on a correlation map.

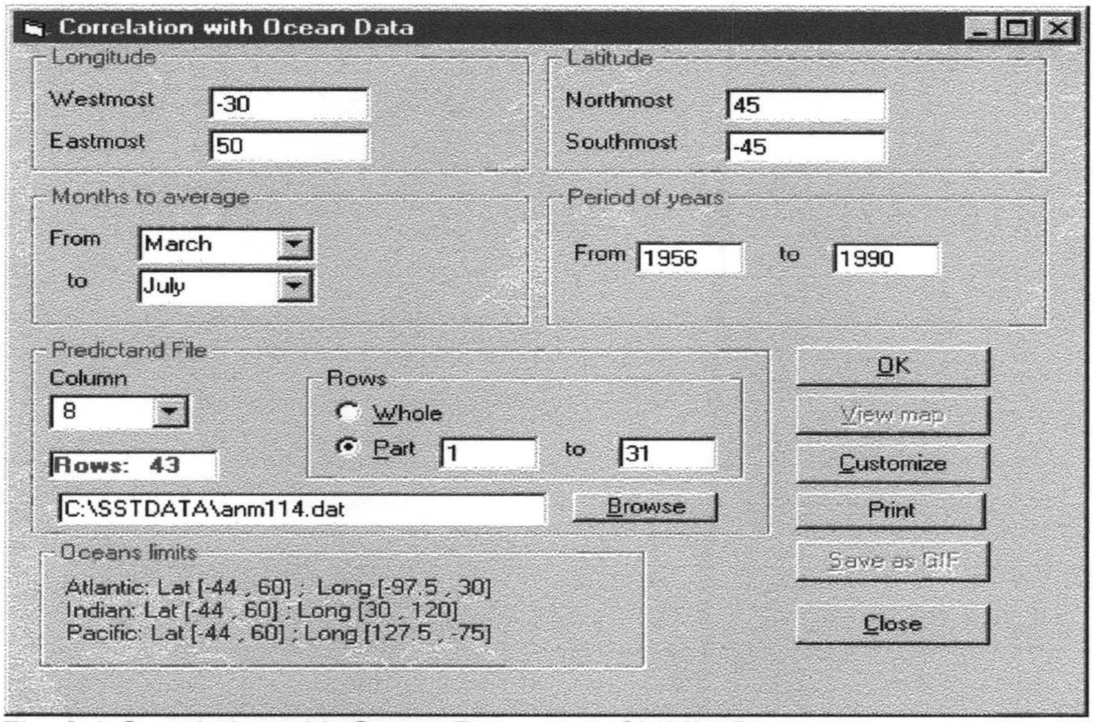

Fig. 3.1 Correlation with Ocean Data using CLIMLAB

3.2.6 GLOBAL OCEANS AND SEASONAL RAINFALL

Investigation of the global ocean SSTs for a relationship with the seasonal rainfall was done using the CLIMLAB menu option "correlation with the oceans". The process above was then followed using different locations. Distinct areas of high correlation with the SST were then extracted and averaged over a two or three month period.

3.3 STANDARDIZATION OF VALUES

After detrending the time series it was then standardized to remove some minor distortions in the data set. The formula used to standardized is

$$\mathbf{Xn} = (\mathbf{X} - \bar{\mathbf{X}})/\sigma$$

where

Xn = Normalized value

X = Monthly value

$\bar{\mathbf{X}}$ = Mean monthly value for a period N

σ = Standard deviation

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 RAINFALL VARIATION

There was a wide variation in rainfall over the area both in time and in space during the period.

4.1.1 ANNUAL RAINFALL

The annual rainfall over the area varied from 1537.3mm over Yelwa in 1994 (Fig. 4.11a) to 236.7mm in 1983 at Nguru (Fig. 4.11b). Except for 1983 when Yelwa recorded rain amount of 596.1mm, the rainfall reported for all the other years was more than 700.0mm. Nguru also reported low rainfall of 240.5mm in 1986, 247.6mm in 1972, 250.2mm in 1987 and 259.3mm in 1973. Other values were above 300.0mm with the highest amount of 601.7mm recorded in 1974.

Bauchi as shown in Fig. 4.12a, recorded the highest rainfall of 1251.2mm in 1981 and the least value of 725.6mm in 1985. Generally the rain recorded over the station was more than 750.0mm. Gusau as can be seen in Fig. 4.12b, reported rainfall of 708.9mm in 1982 which was the least amount for the period. The maximum value for the period was 1507.1mm recorded in 1994. Generally rainfall over this station was high when compared to the other areas.

Fig. 4.13a shows that Kano recorded low rainfall of 413.9mm in 1973 and high value of 1087.4mm in 1991. For the other years, the rainfall was generally more than 500.0mm. The highest rainfall over Katsina as shown in Fig. 4.13b was 776.3mm recorded in 1979 and the least amount of 262.0mm was recorded in 1993.

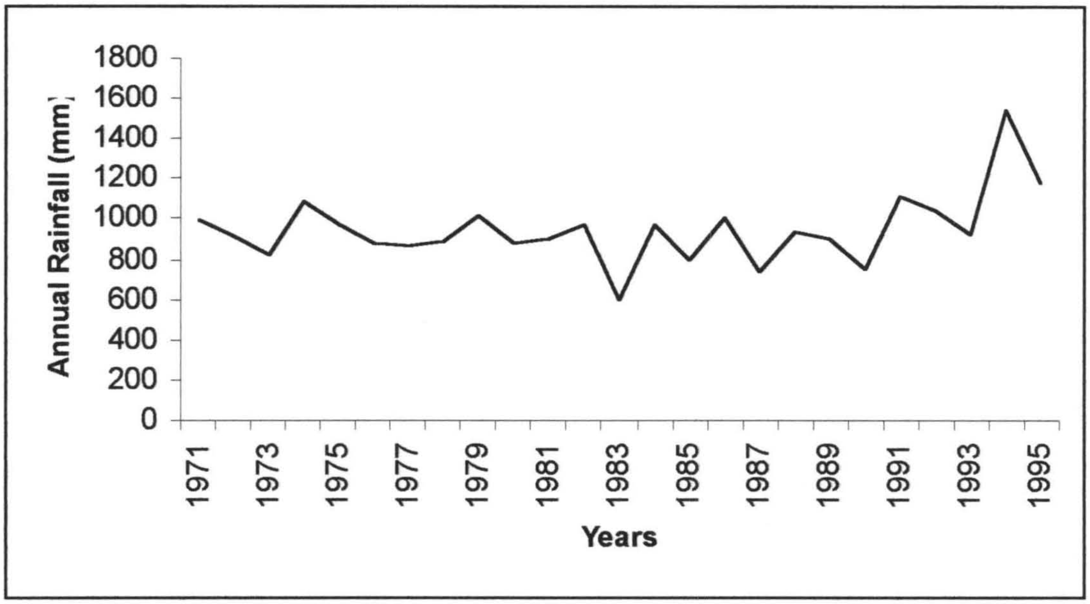

Fig. 4.11a Annual Rainfall (mm) for Yelwa

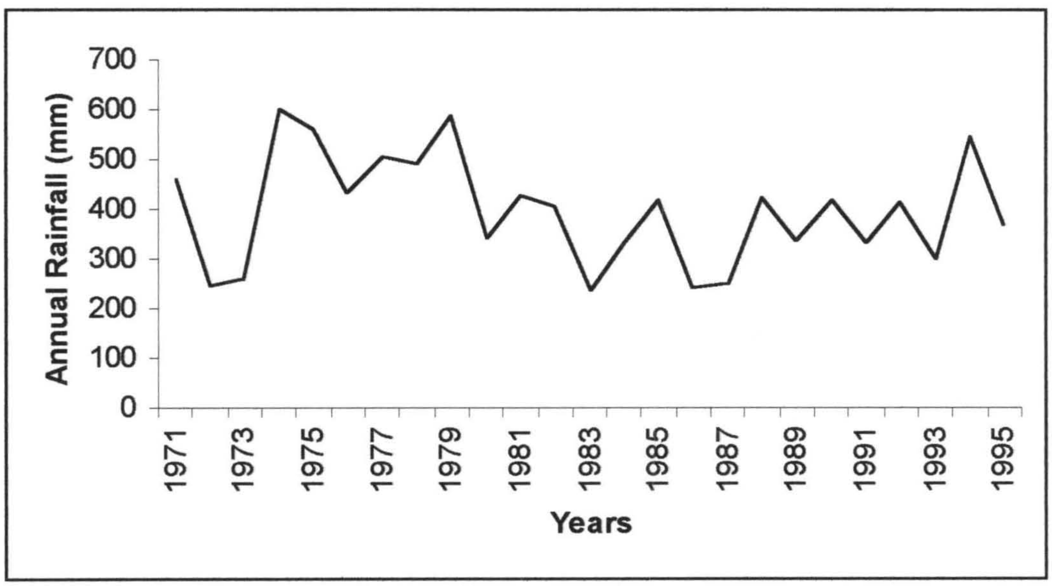

Fig. 4.11b Annual Rainfall (mm) for Nguru

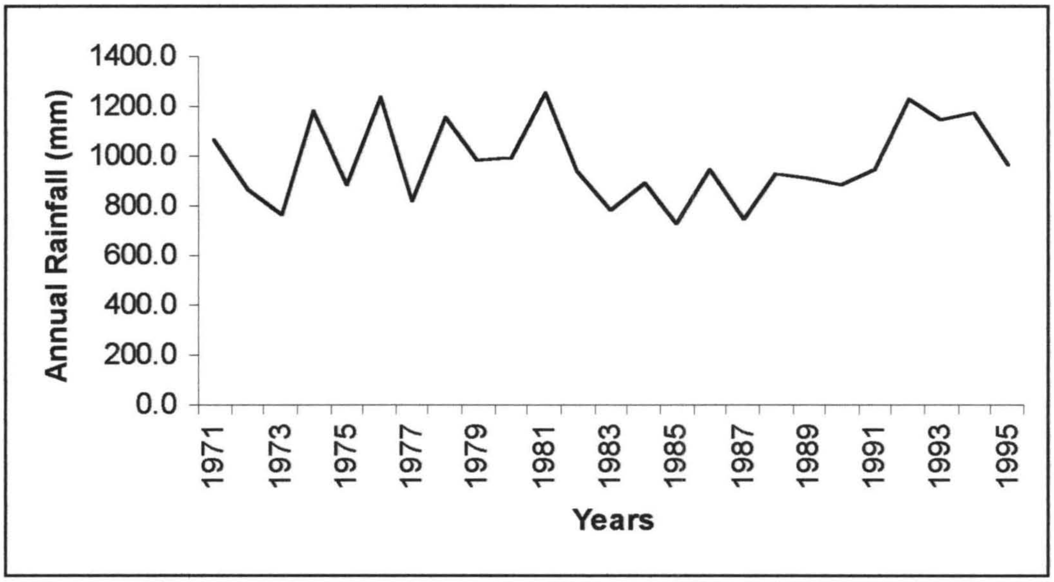

Fig. 4.12a Annual Rainfall (mm) for Bauchi

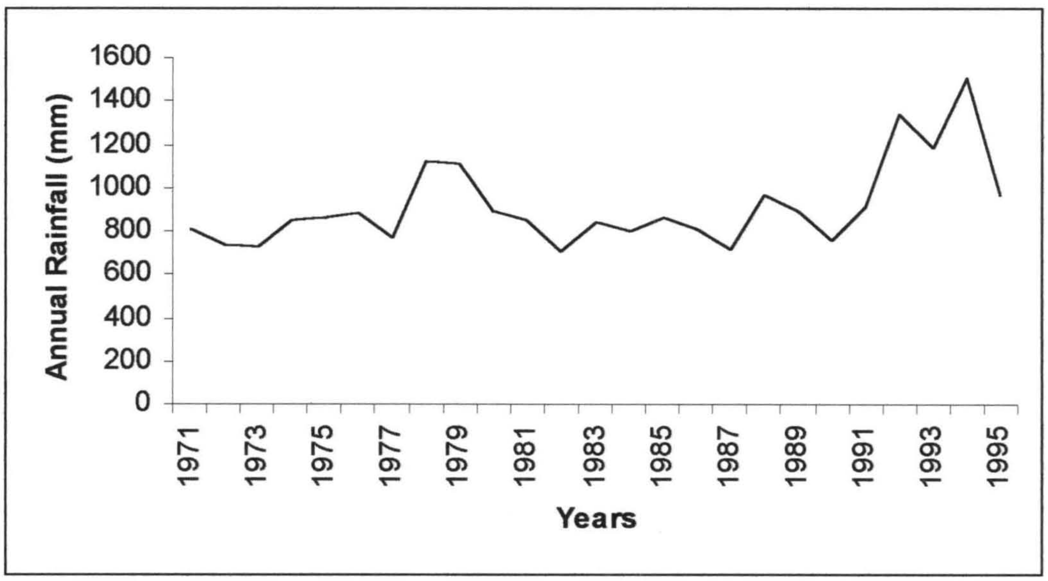

Fig. 4.12b Annual Rainfall (mm) for Gusau

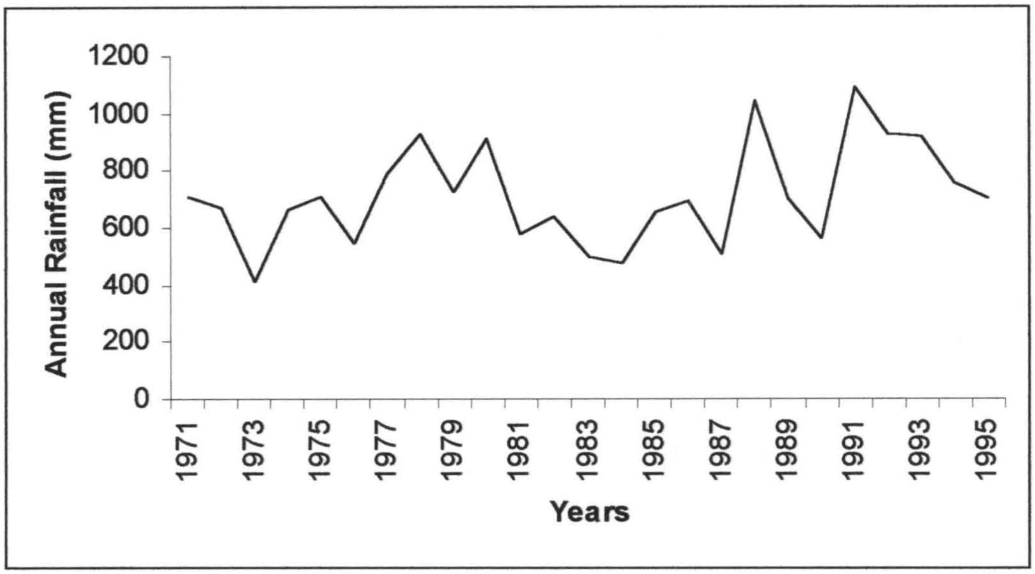

Fig. 4.13a Annual Rainfall (mm) for Kano

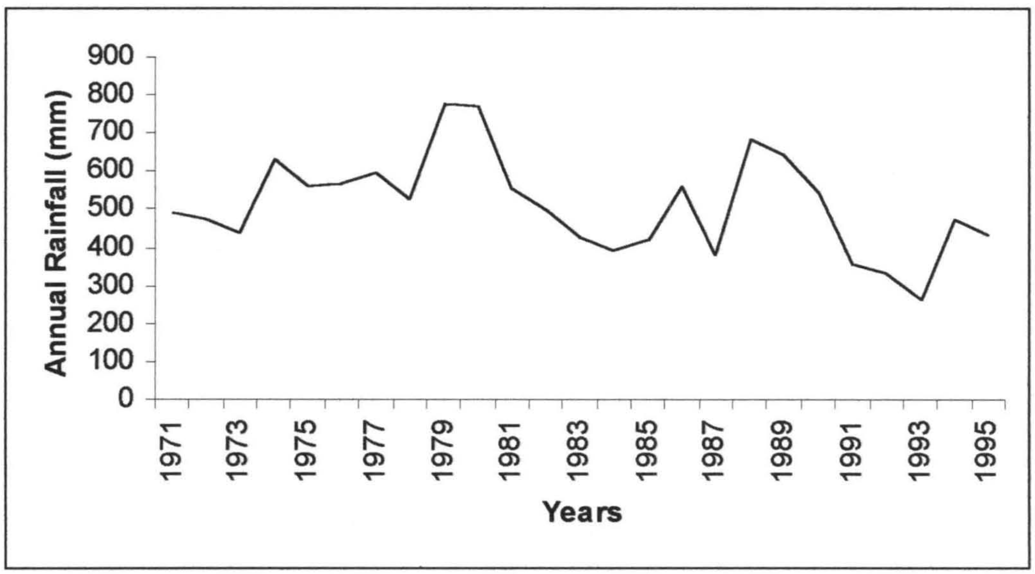

Fig. 4.13b Annual Rainfall (mm) for Katsina

Over Potiskum, the annual rainfall for the period was generally more than 450.0mm, with the highest rain amount of 968.1mm reported in 1988 and the lowest value of 408.5mm recorded in 1990 (Fig. 4.14a). Maiduguri as indicated in Fig. 4.14b, had 263.5mm of rainfall in 1983 and 726.1mm in 1978. For the other years, the rainfall was generally greater than 350.0mm.

In 1976 and 1987 Sokoto recorded rainfall of 850.5mm and 320.0mm respectlvely. For the rest of the period the rainfall was generally above 400.0mm as can be seen in . Fig. 4.15a. From Fig. 4.15b it is obvious that the highest rainfall of 1375.6mm was recorded for Zaria in 1978 and a minimum of 685.6mm was recorded in 1983. Between the two extremes, the rainfall was over 750.0mm.

4.1.2 MONTHLY RINFALL

There were wide variations of rainfall from month to month over these stations during the period of study. While for most of the years we have one rainfall peak, there were few years that two rainfall peaks were reported.

4.1.2.1 UNIMODAL PEAK RAINFALL

The rainfall pattern generally showed on peak usually in August during most of the time of study. Maximum rainfall was however occasionally recorded in July.

4.1.2.2 BIMODAL PEAK RAINFALL

There were years during the period of study when rainfall over the stations exhibited two maxima. While some double maxima were significant, others were less significant. In this study, emphasis will be on the significant ones. Bauchi as seen in Fig. 4.120 had the bimodal rainfall pattern in 1984, 1986, 1987 and 1991. Gusau in 1972, 1978, 1980 and 1994 had two rainfall maxima as indicated in Fig. 4.121. From Fig. 4.122, Kano had two rainfall peaks in i1972, 1977, 1984 and 1993.

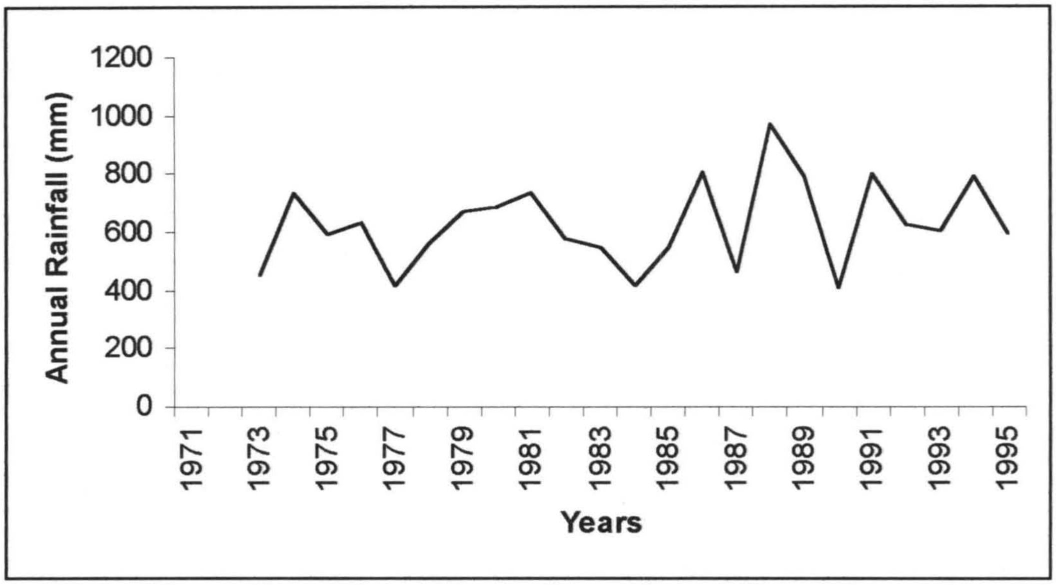

Fig. 4.14a Annual Rainfall (mm) for Potiskum

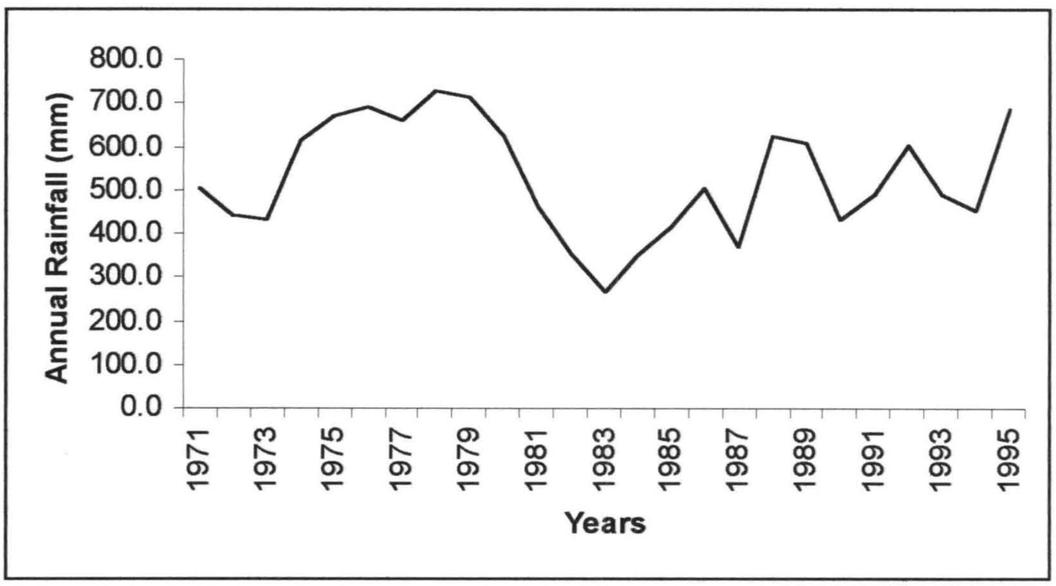

Fig. 4.14b Annual Rainfall (mm) for Maiduguri

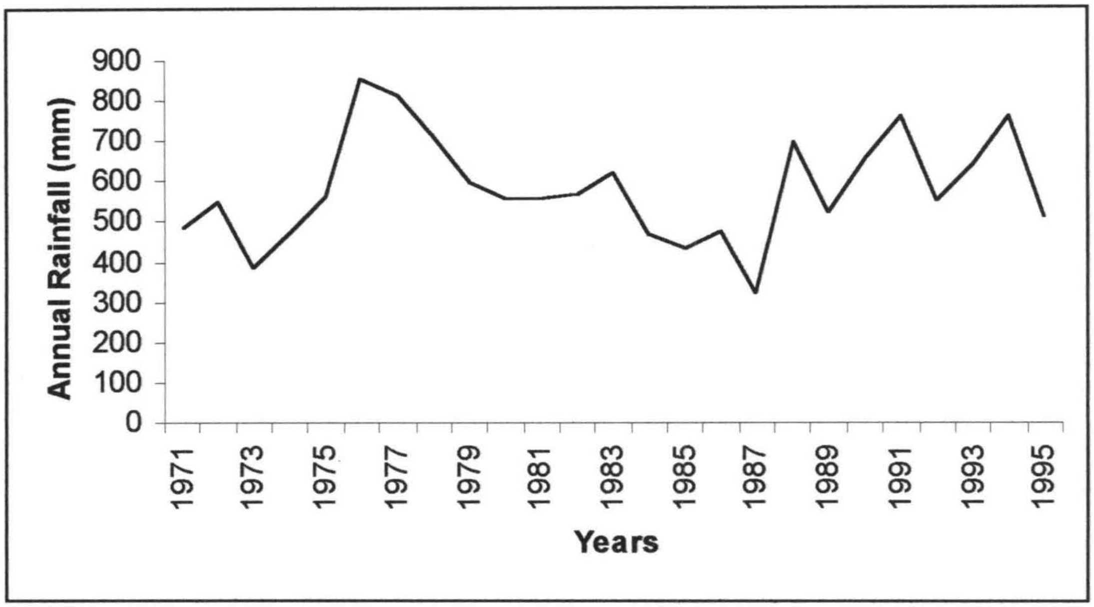

Fig..4.15a Annual Rainfall (mm) for Sokoto

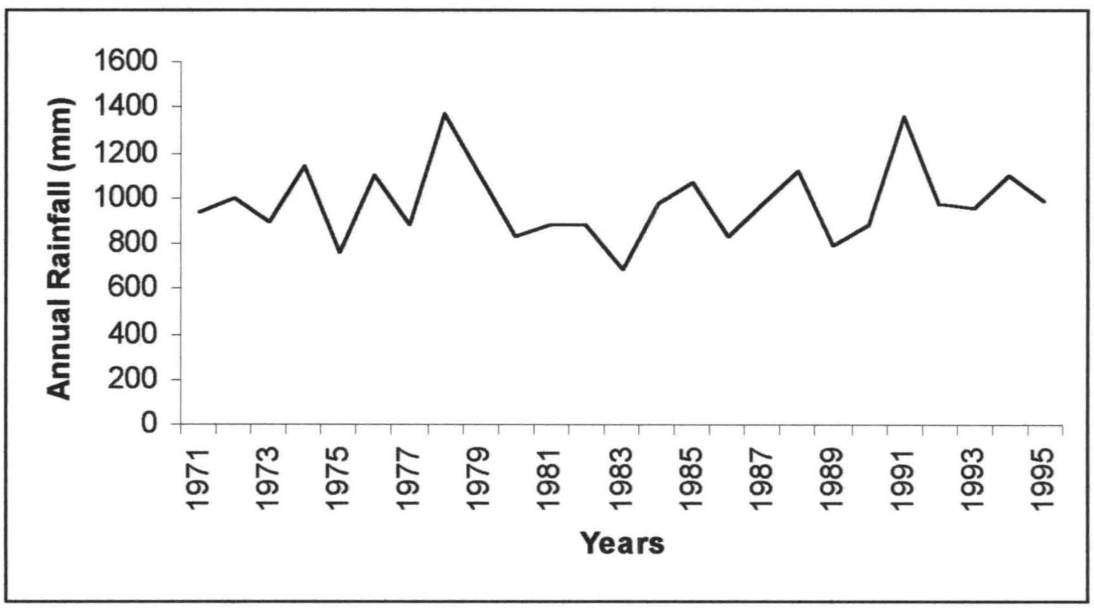

Fig.4.15b Annual Rainfall (mm) for Zaria

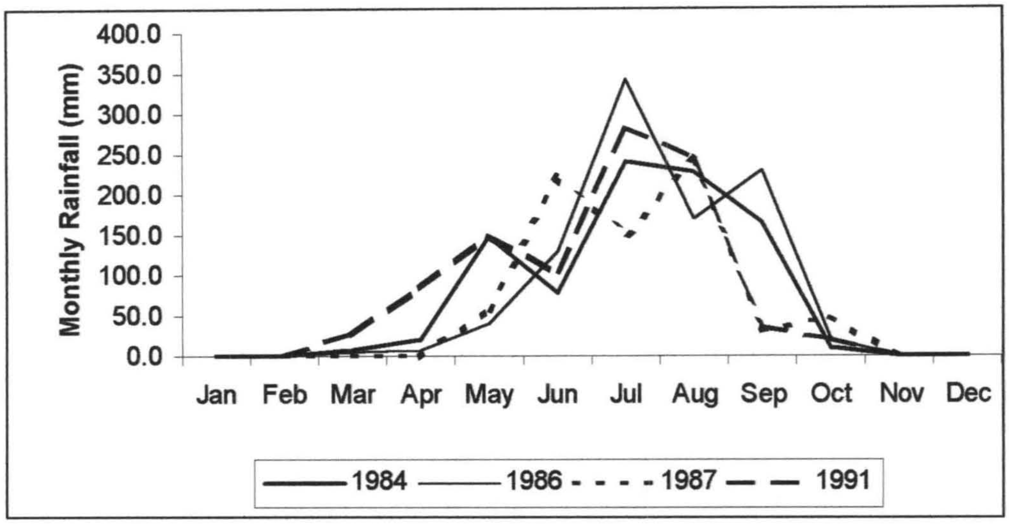

Fig. 4.120 Bauchi Monthly Rainfall

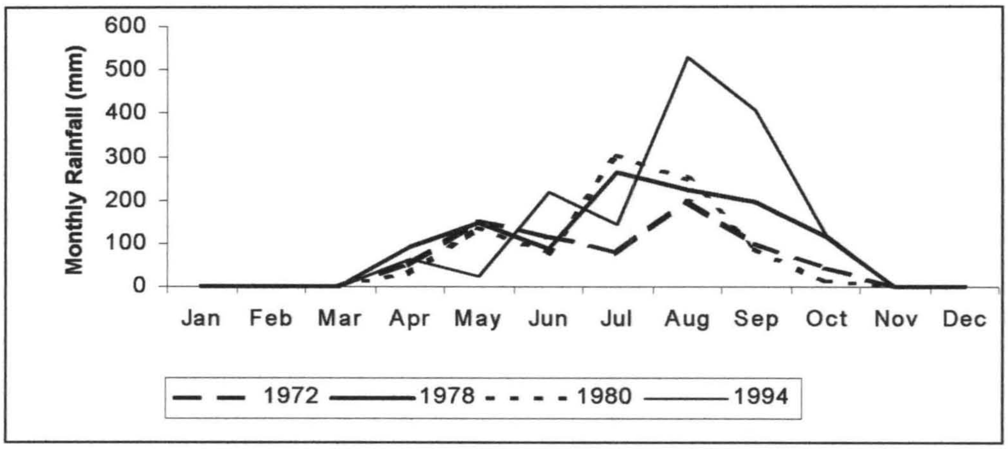

Fig. 4.121 Gusau Monthly Rainfall

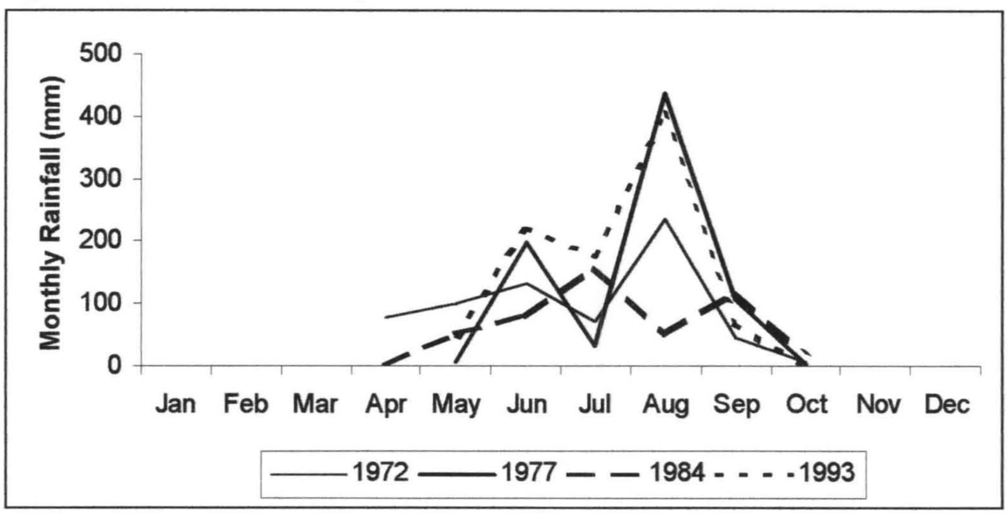

Fig. 4.122 Kano Monthly Rainfall

Apart from the year 1984 when the maxima occurred in July and September, the peaks for the other years were recorded in June and August.

As shown in Fig. 4.123, Katsina had double rainfall peaks in 1988 and 1991. Maiduguri exhibited two rainfall maxima in 1972 and 1977 (Fig. 4.124). Nguru as indicated in Fig. 4.125, recorded the bimodal rainfall pattern in 1971, 1972, 1988 and 1992.

Potiskum had its own double rainfall peaks in 1991 and 1992 as can be seen in Fig. 4.126. In Fig. 4.127 it can be seen that Sokoto reported bimodal rainfall in 1980 and 1992. Yelwa exhibited two rainfall peaks for the years indicated in Fig. 4.128a and b. For the years 1972, 1976, 1991 and 1992 Zaria had two rainfall peaks as can be seen in Fig. 4.129.

4.1.3 DURATION OF RAINFALL

Although there were years that the rainfall started as early as January, over some of the stations, the general trend was that the rainy season started over these areas in April and runs through October with rare occasions when there is rain in November and December. Even when there is rain in November and December the amount is insignificant. There are also years that the rain started in May and ceased in September. Rainfall was also reported in some stations from April to September and May to October.

4.1.4 RAINFALL ANOMALIES

The plotted standardized rainfall anomalies exhibited a mixture of above normal, normal and below normal rainfall. The anomalies for these stations are depicted in Figures 4.1 40 to 4.149. Bauchi as shown in Fig. 4.140 had below normal rainfall in 1972, 1973, 1975, 1977, and from 1982 to 1991 and 1995. The rest of the years for the period have above normal rainfall. From Fig. 4.141 it can be seen that except for the years 1978, 1979, 1988 and from 1992 to 1995 when Gusau had surplus rainfall, the rest of the period was dry. During the period Kano had more dry years than wet years (Fig. 4.142).

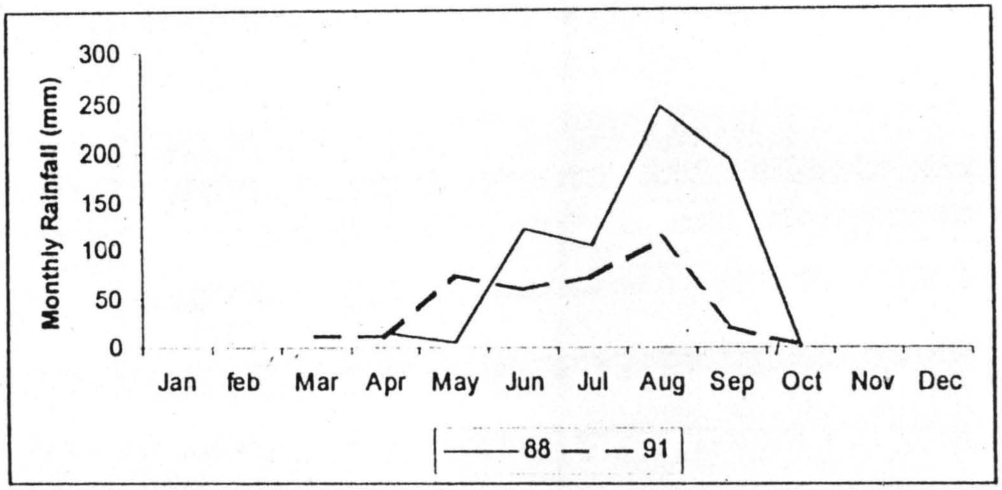

Fig. 4.123 Katsina Monthly Rainfall

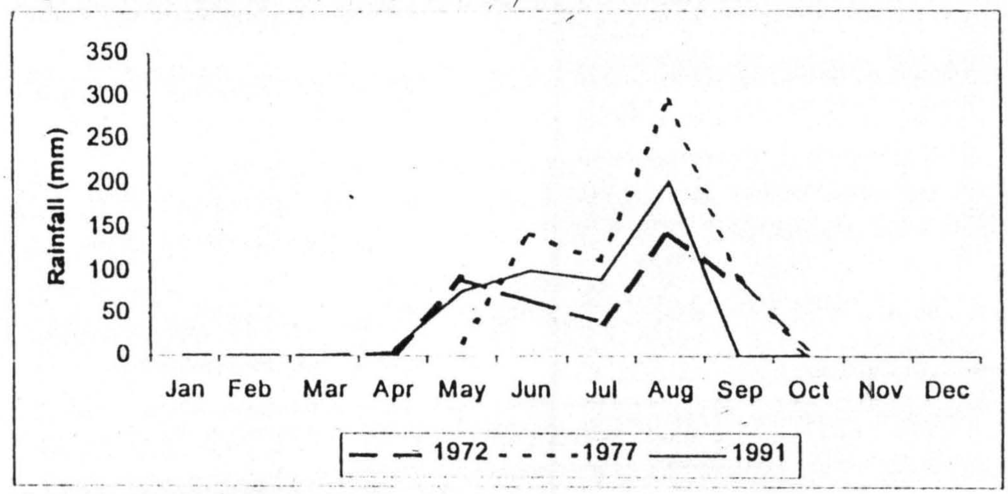

Fig. 4.124 Maiduguri Monthly Rainfall

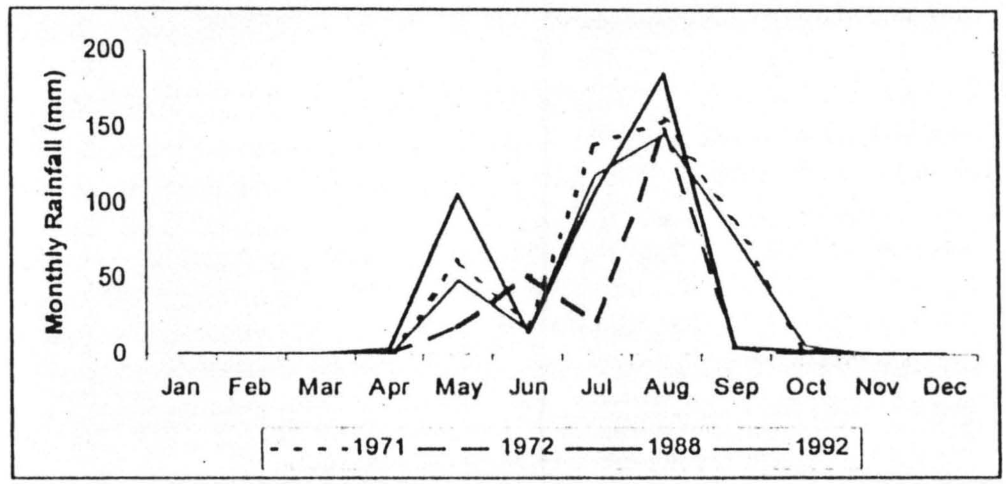

Fig. 4.125 Nguru Monthly rainfall

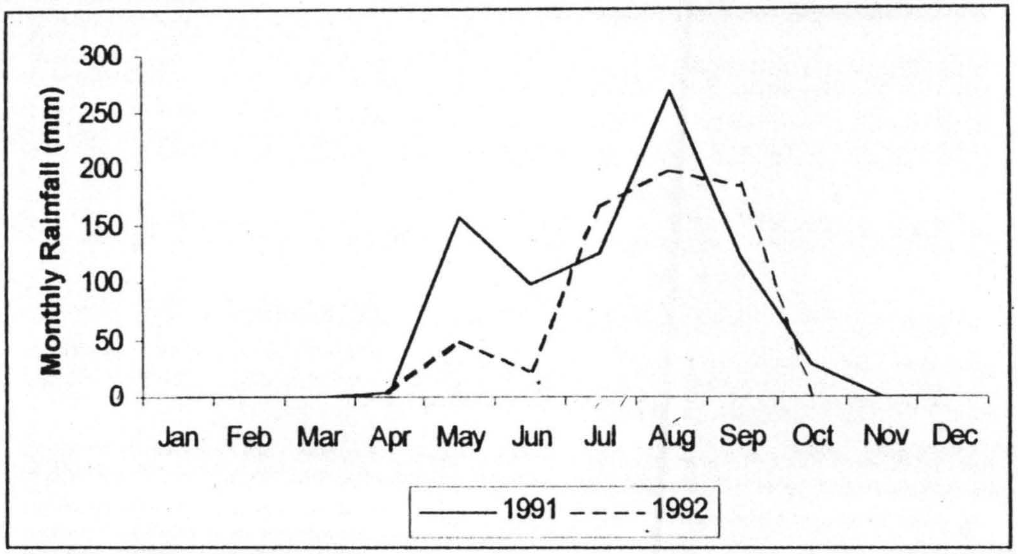

Fig. 4.126 Potiskum Monthly rainfall

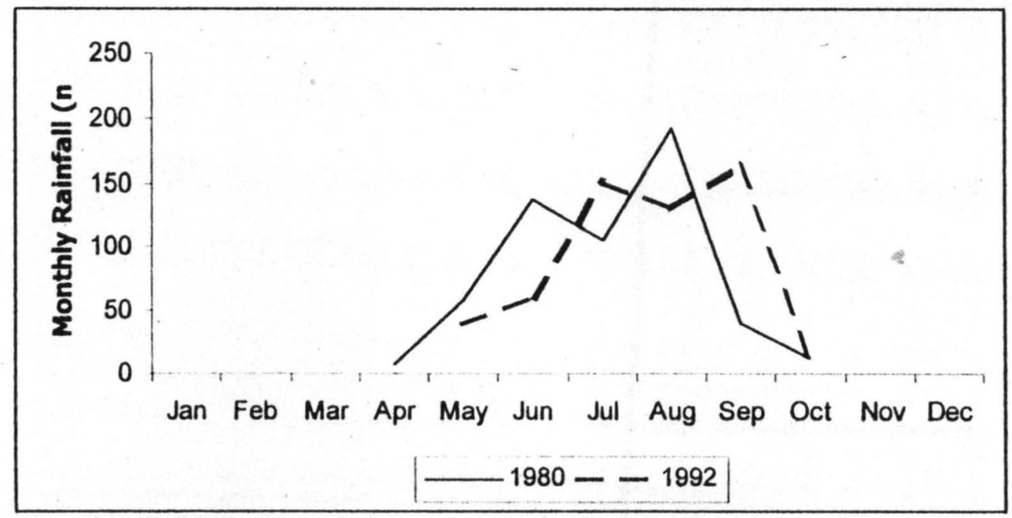

Fig. 4.127 Sokoto Monthly Rainfall

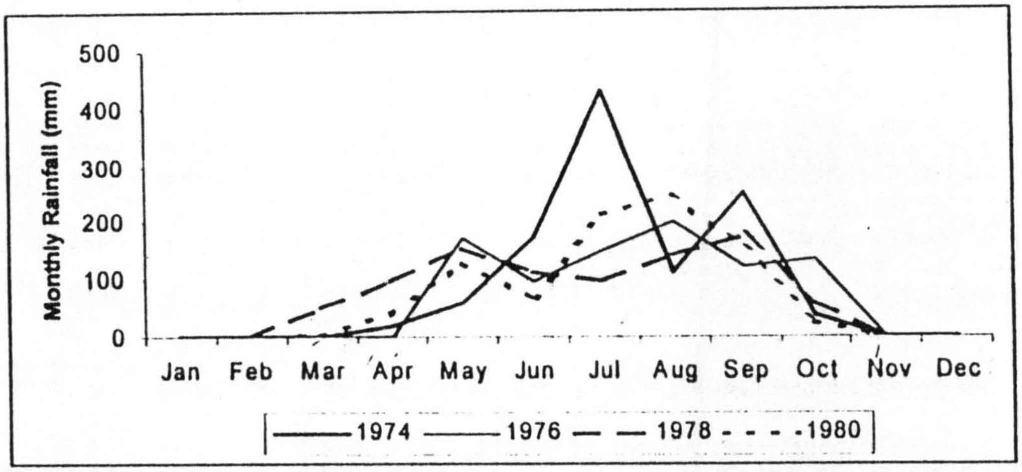

Fig.. 4.128a Yelwa Monthly Rainfall

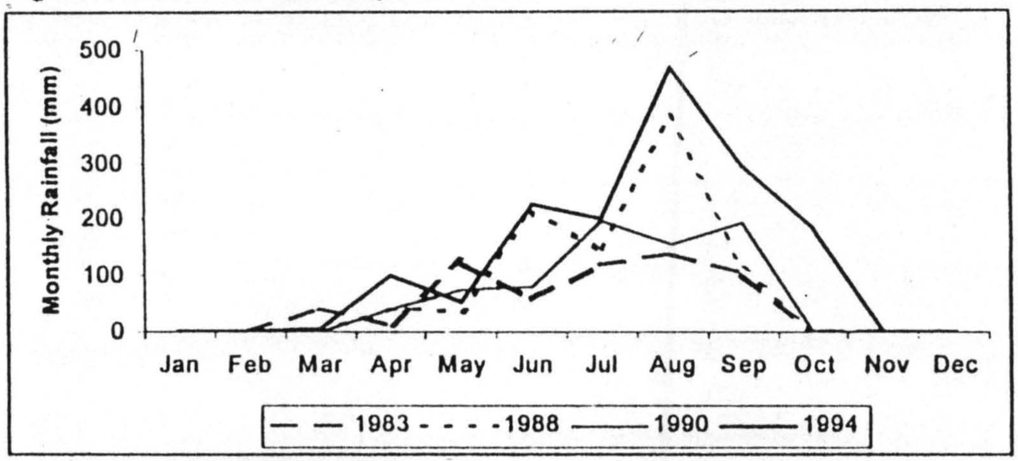

Fig. 4.128b Yelwa Monthly Rainfall

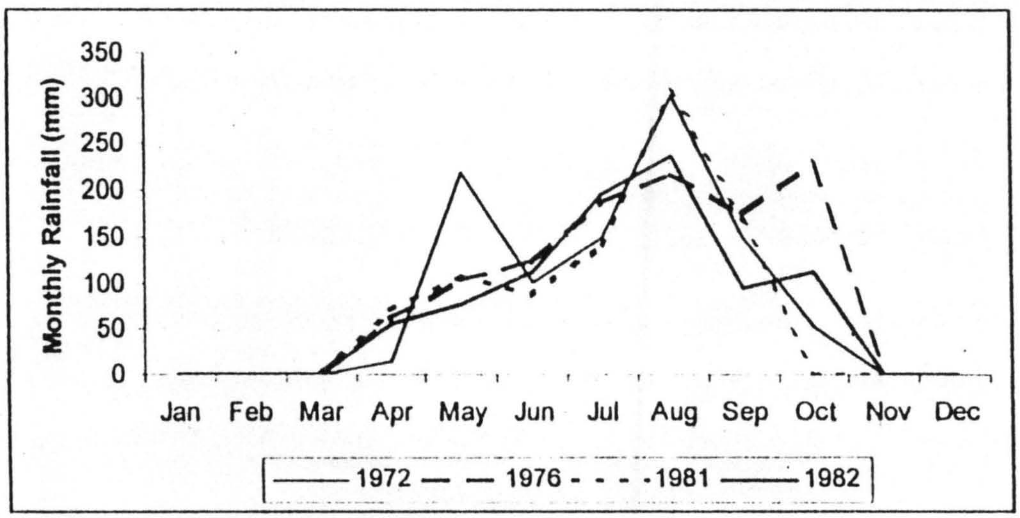

Fig. 4.129 Zaria Monthly Rainfall

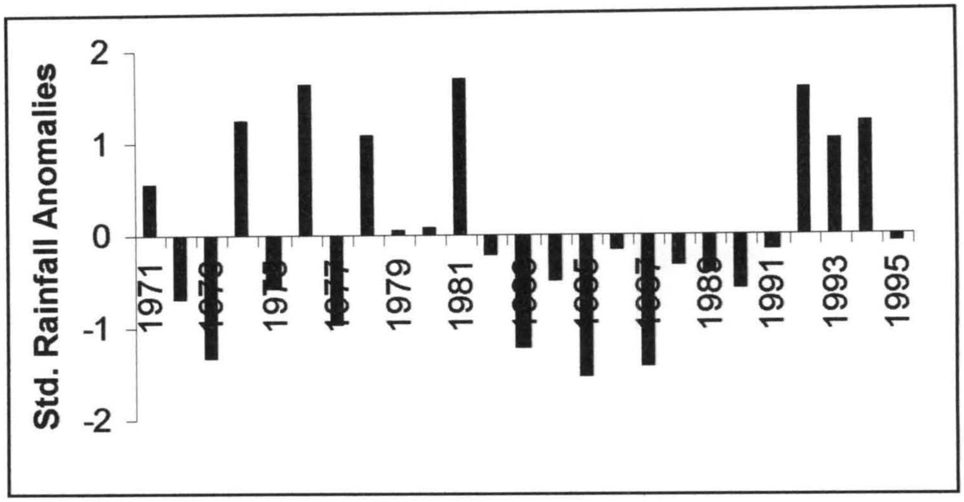

Fig. 4.140 Std. Rainfall Anomalies for Bauchi

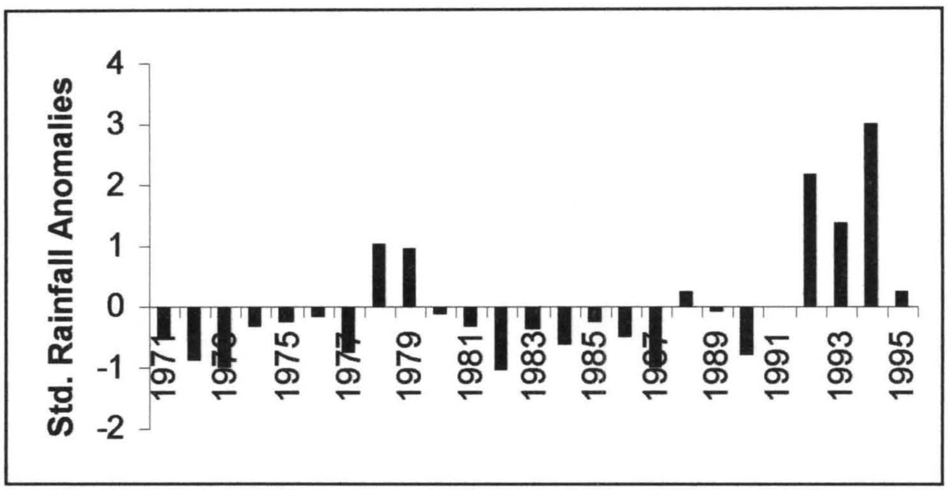

Fig. 4.141 Std. Rainfall Anomalies for Gusau

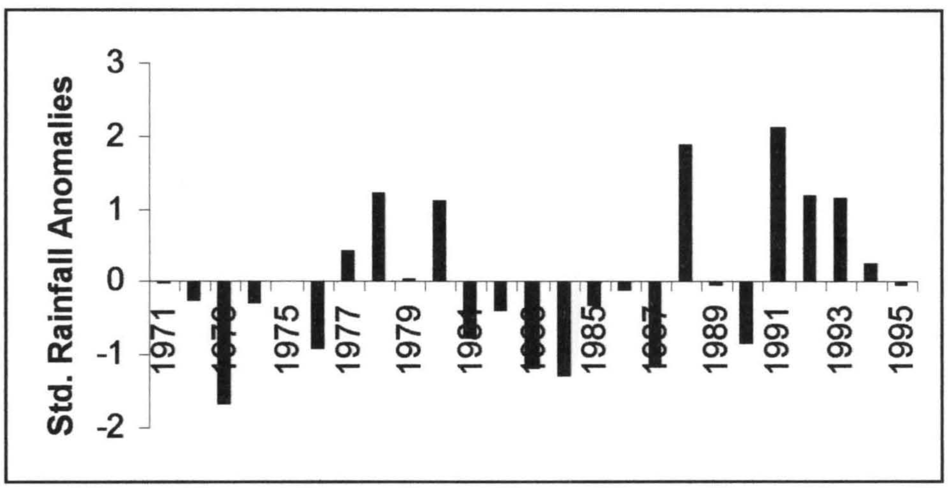

Fig. 4.142 Std. Rainfall Anomalies For Kano

As represented in Fig. 4.143 Katsina had below normal rainfall from 1971 to 1973, 1982 to 1985, 1987 and 1991 to 1995. It was however wet for the rest of the period. Maiduguri as can be seen in Fig. 4.144 had excess rainfall from 1974 to 1980, 1988, 1989, 1992 and 1995. The rest of the period recorded deficit rainfall. From Fig. 4.145 it can be observed that except for the years 1972, 1973, 1980, 1983, 1984, 1986, 1987, 1989, 1991, 1993 and 1995 when Nguru had less rainfall than normal, the rest of the period was wet.

Potiskum as indicated in Fig. 4.146 was dry in 1973, 1975, 1977, 1978, from 1982 to 1985, 1987, 1990, 1993 and 1995. The rest of the years for the period have above normal rainfall. Surplus rainfall was recorded over Sokoto from 1976 to 1979, 1983, 1988, 1990, 1991, 1993 and 1994. The rest of the period experienced rainfall deficit as exhibited in Fig. 4.147. Yelwa as represented in Fig. 4.148 had below normal rainfall in 1972, 1973, from 1976 to 1978, 1980, 1981, 1983, 1985, 1987, from 1988 to 1990 and 1993. The rest of the period reported above normal rainfall. In 1972, 1974, 1976, 1978, 1979, 1985, 1988, 1991, 1994 and 1995, Zaria had surplus rainfall as can be seen in Fig. 4.149, while the rest of the period was dry.

4.2.0 SEASONAL RAINFALL CORRELATION WITH SST

Here the intention is to investigate the relationship between the seasonal rainfall and the various global Oceans' sea surface temperatures (SSTs).

4.2.1 SEASONAL RAINFALL CORRELATED WITH INDIAN OCEAN SST

Represented in Figures 4.211 to 4.218 are seasonal rainfall data correlated with the Indian Ocean. Gusau as represented in Fig. 4.211 had a correlation coefficient of up to 0.6 over some areas of the ocean. The area with the highest correlation coefficient is located at Lat. 10°S and Equator, Long. 60°E and 85°E for the seasonal rainfall MJJ. For Kano seasonal rainfall JAS, the area with the highest correlation coefficient is located at Lat. 20°S and 10°S,

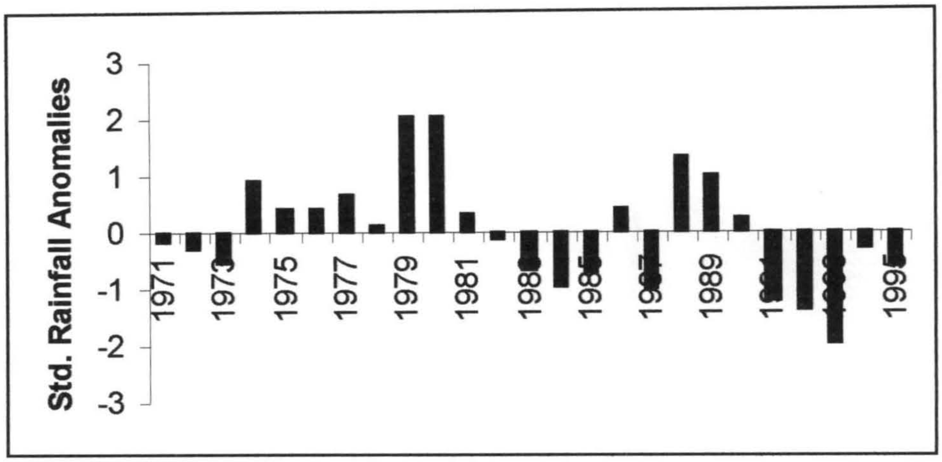

Fig. 4.143 Std. Rainfall Anomalies For Katsina

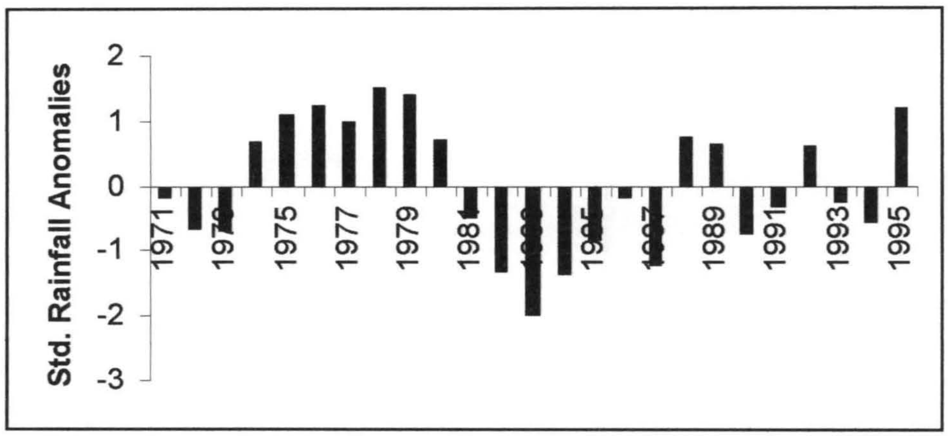

Fig. 4.144 Std. Rainfall Anomalies for Maiduguri

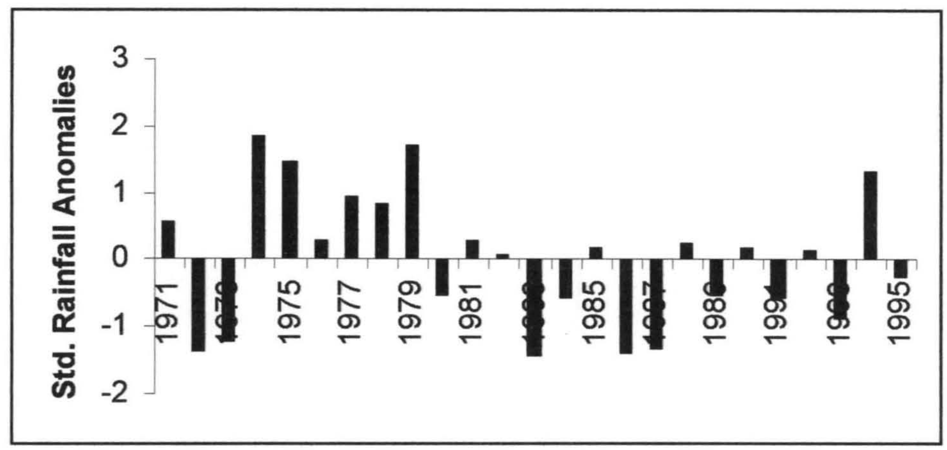

Fig. 4.145 Std. Rainfall Anomalies for Nguru

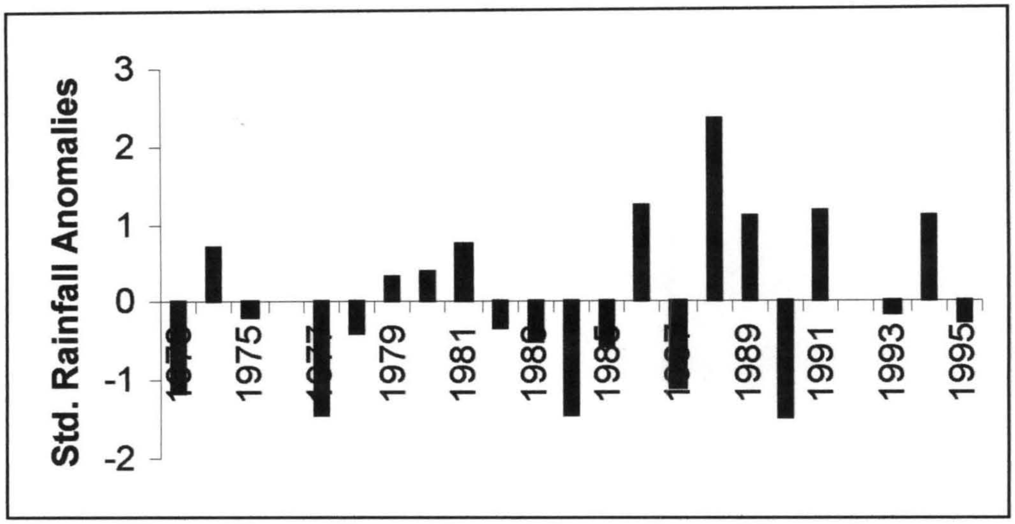

Fig. 4.146 Std. Rainfall Anomalies for Potiskum

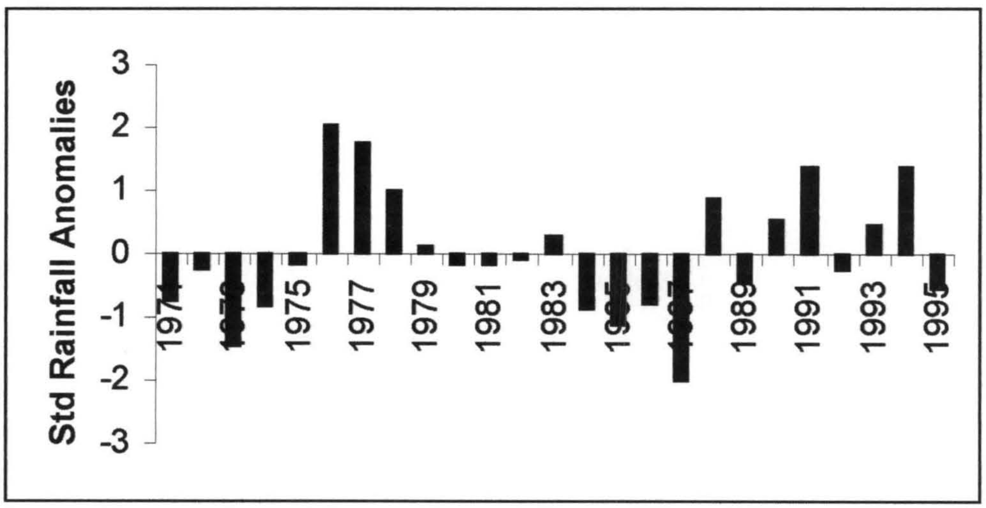

Fig. 4.147 Std. Rainfall Anomalies for Sokoto

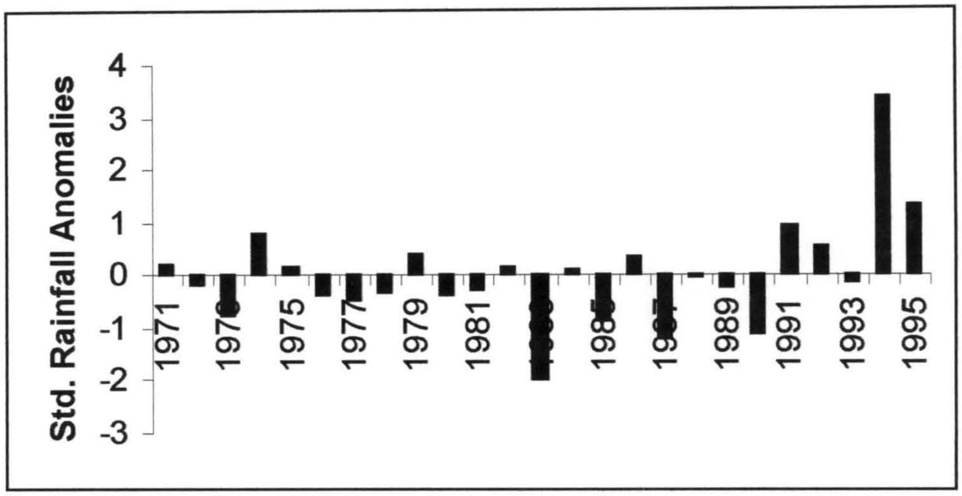

Fig. 4.148 Std. Rainfall Anomalies for Yelwa

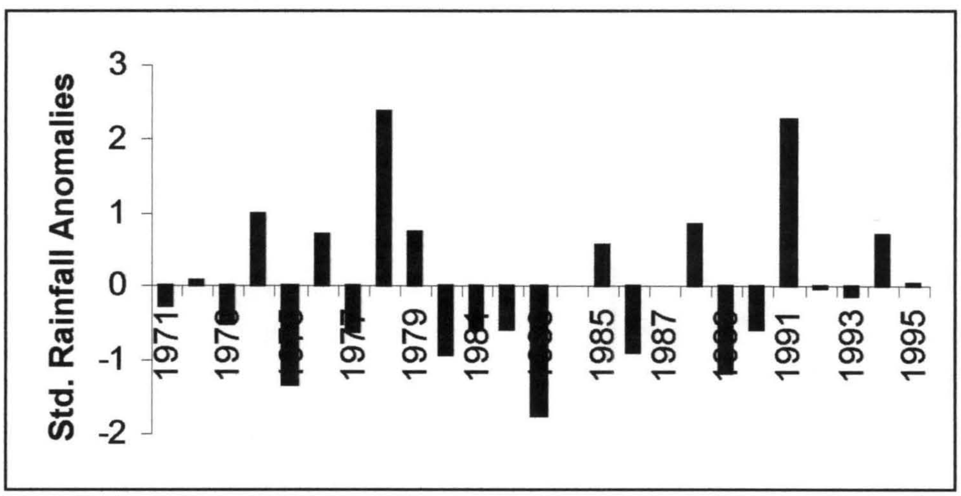

Fig. 4.149 Std. Rainfall Anomalies for Zaria

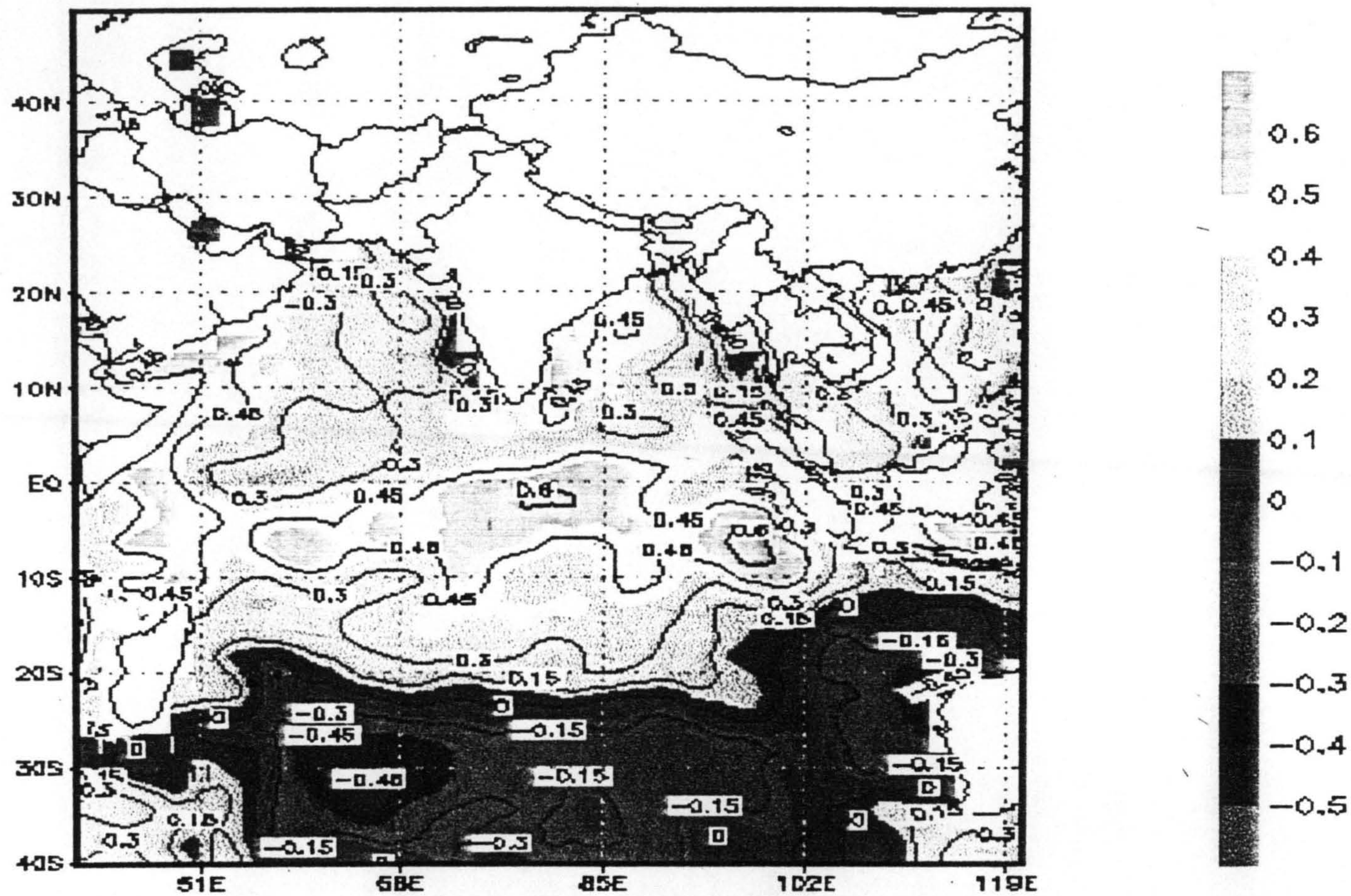

Fig. 4.211 Gusau MJJ Seasonal Rainfall correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

Long. 58°E and 82°E as can be seen in Fig. 4.212. As indicated in Fig. 4.213, Katsina JJA seasonal rainfall is highly correlated with the area enclosed by Lat. 08°N and 18°N, Long. 55°E and 62°E. The area enclosed by Lat. 10°N and 20°N, Long. 52 E and 62°E is highly correlated with the MJJ seasonal rainfall for Maiduguri (Fig 4.214).

Nguru MJJ seasonal rainfall as exhibited by in Fig. 4.215 shows a high correlation coefficient with the area represented by Lat. 15°N and 20°N, Long. 57°E and 76°E. Potiskum as depicted in Fig. 4.216 has its JAS seasonal rainfall highly correlated with the area enclosed by Lat. 30°S and 20°S, Long. 76°E and 95°E. The area enclosed by Lat. 10°N and 20°N, Long. 52°E and 60°E is highly correlated with the JAS seasonal rainfall for Sokoto as represented in Fig. 4.217. The JJA seasonal rainfall for Zaria as in Fig. 4.218 has a high correlation coefficient with the area represented by Lat. 00°N and 10°N, Long. 51°E and 58°E.

4.2.2 SEASONAL RAINFALL CORRELATED WITH NORTH ATLANTIC OCEAN SST

From Figures 4.221 to 4.228 are seasonal rainfall data correlated with the North Atlantic Ocean. The area bordered by Lat. 10°N and 20°N, Long. 50°W and 28°W is highly correlated with the MJJ seasonal rainfall for Gusau as in Fig. 4.221. Kano JAS seasonal rainfall as represented by Fig. 4.222 has a high correlation coefficient with the area enclosed by Lat. 22°N and 32°N, Long. 50°W and 25°W. As indicated in Fig. 4.223 the JAS seasonal rainfall for Katsina is highly correlated with the area bordered by Lat. 00 N and 10°N, Long. 50°W and 40°W. The JAS seasonal rainfall for Maiduguri as in Fig. 4.224 has a high correlation coefficient with the area represented by Lat. 28°N and 38°N, Long. 45°W and 20°W.

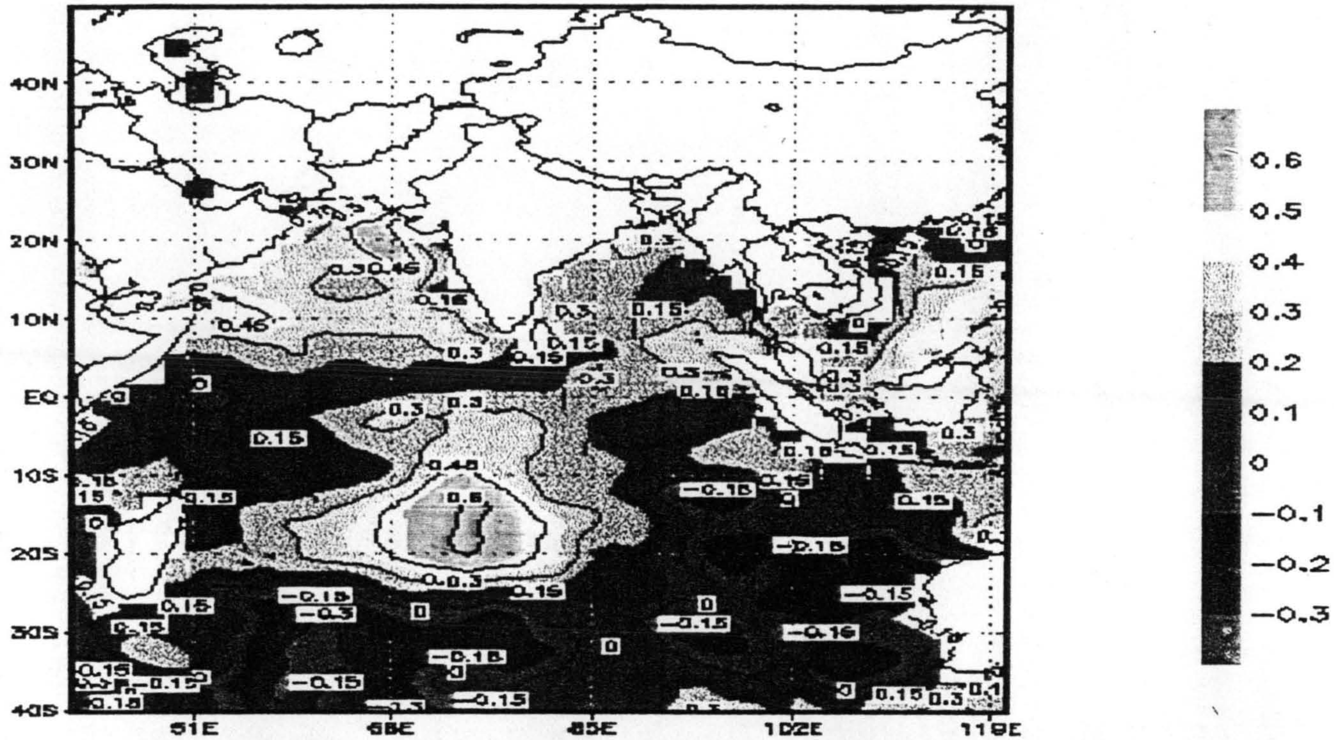

Fig. 4.212 Kano JAS Seasonal Rainfall correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

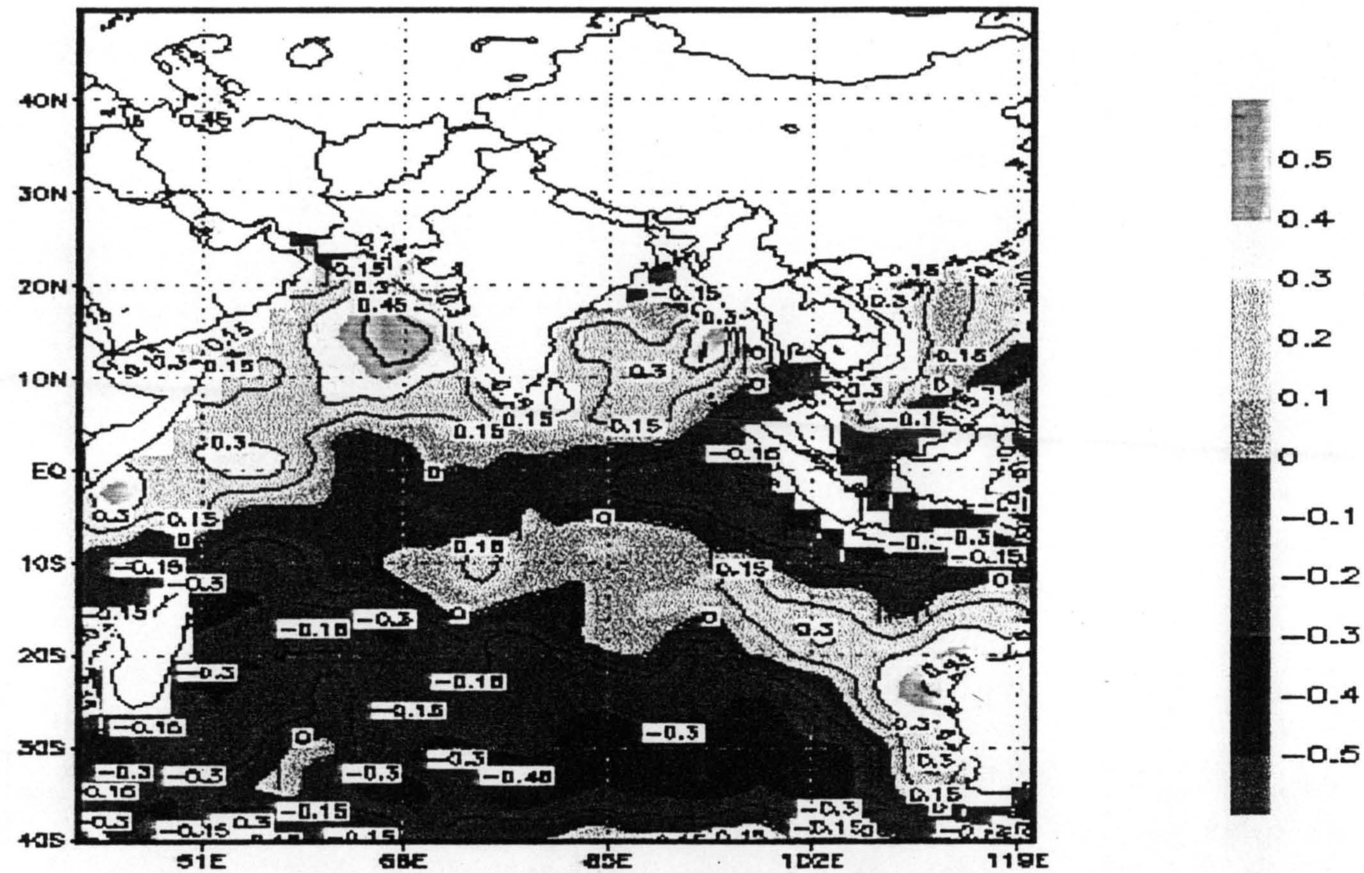

Fig. 4.213 Katsina JJA Seasonal Rainfall correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

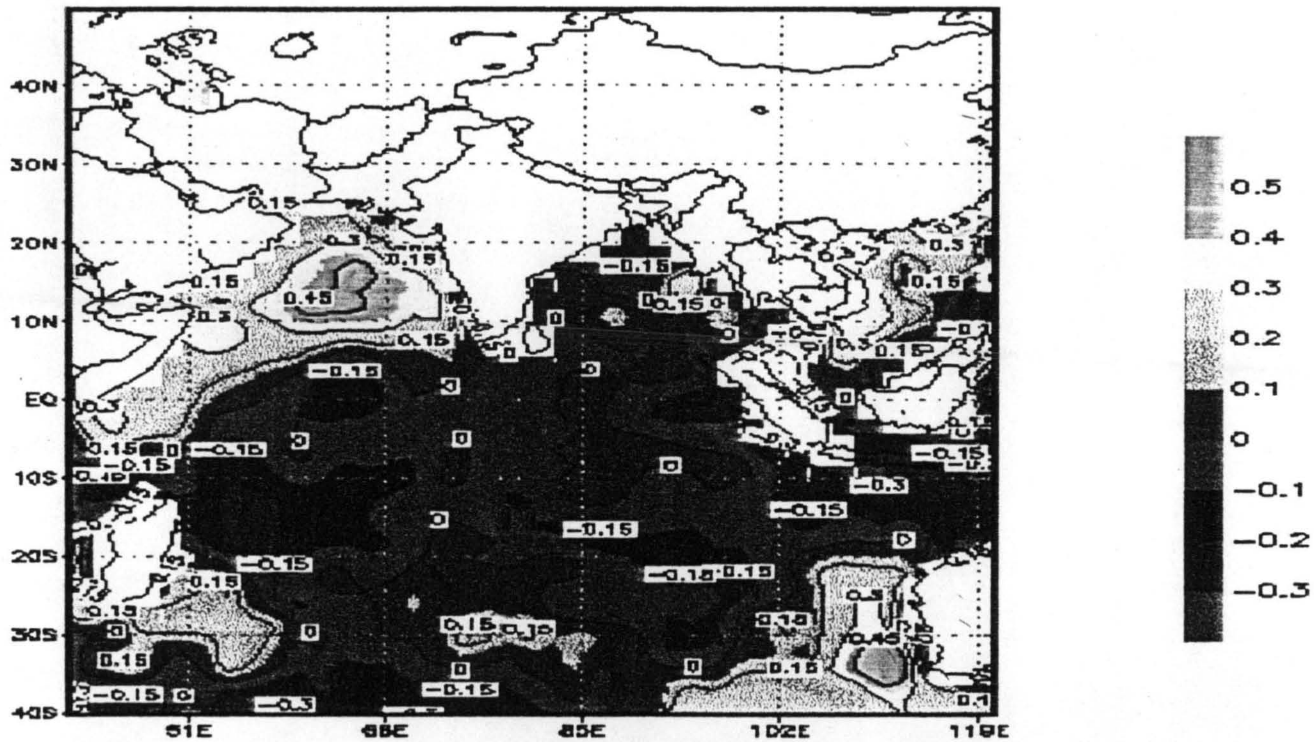

Fig. 4.214 Maiduguri MJJ Seasonal Rainfall correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

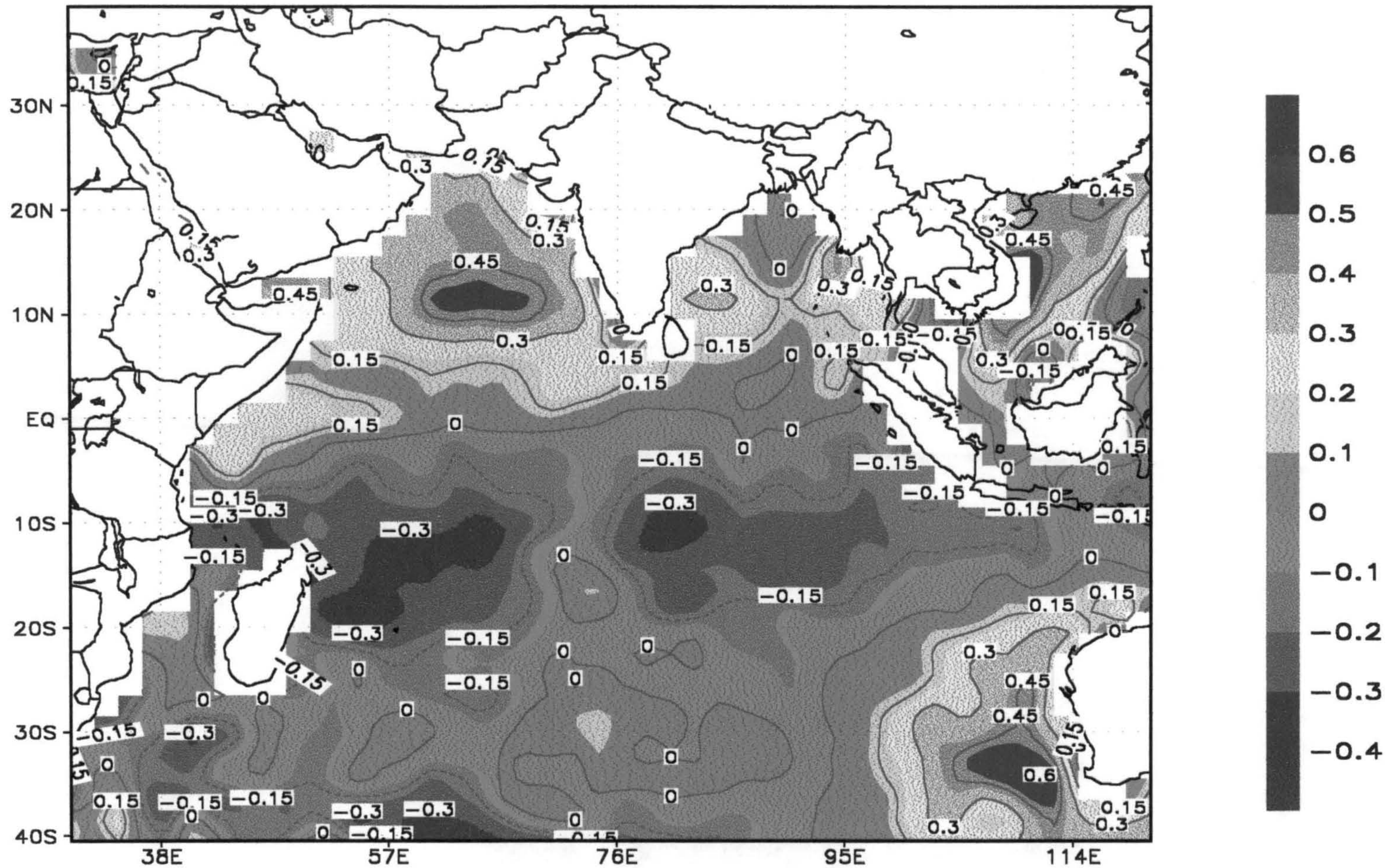

Fig. 4.215 Nguru MJJ Seasonal rainfall Correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

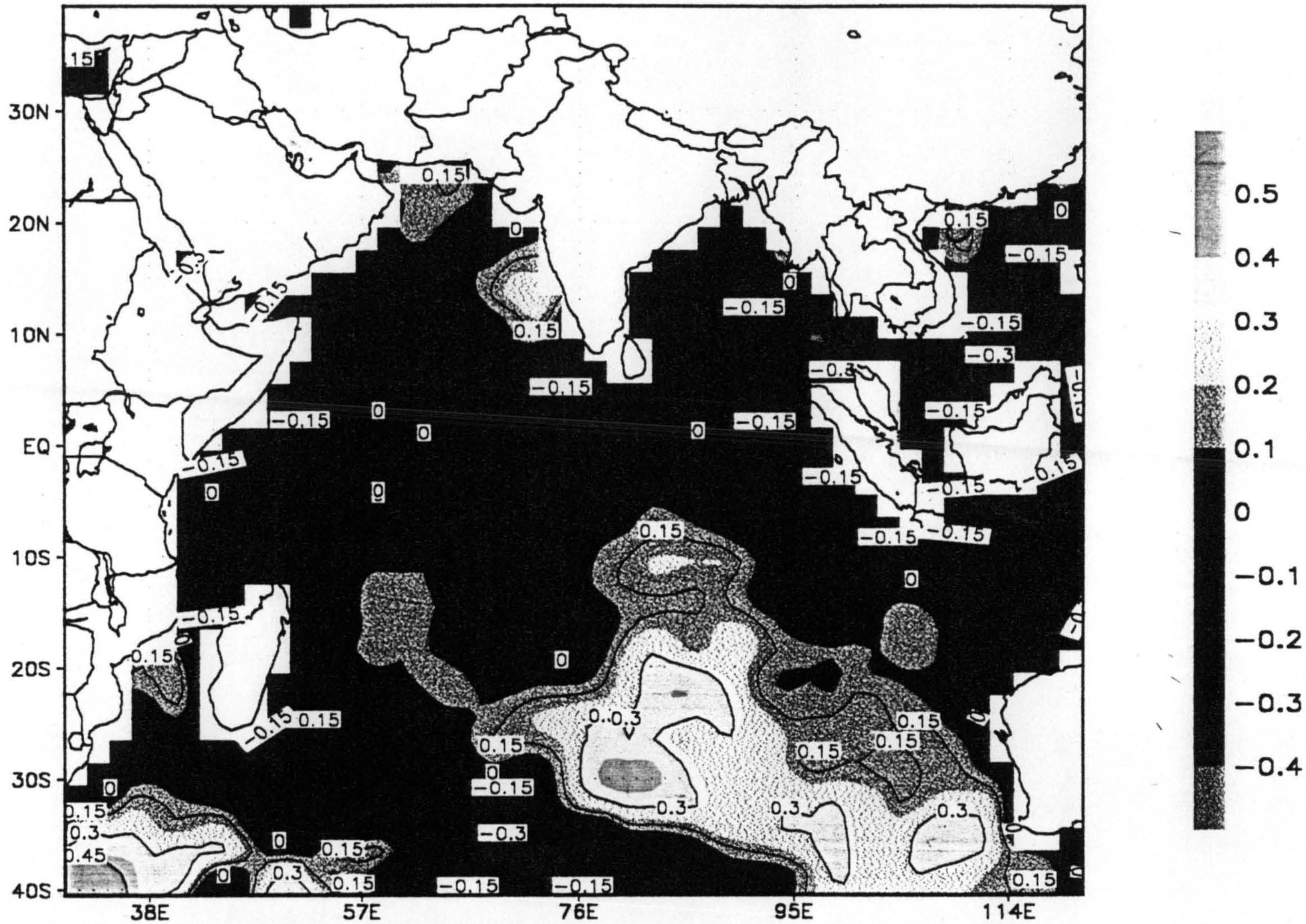

Fig. 4.216 Potiskum JJA Seasonal rainfall correlated with the Indian Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

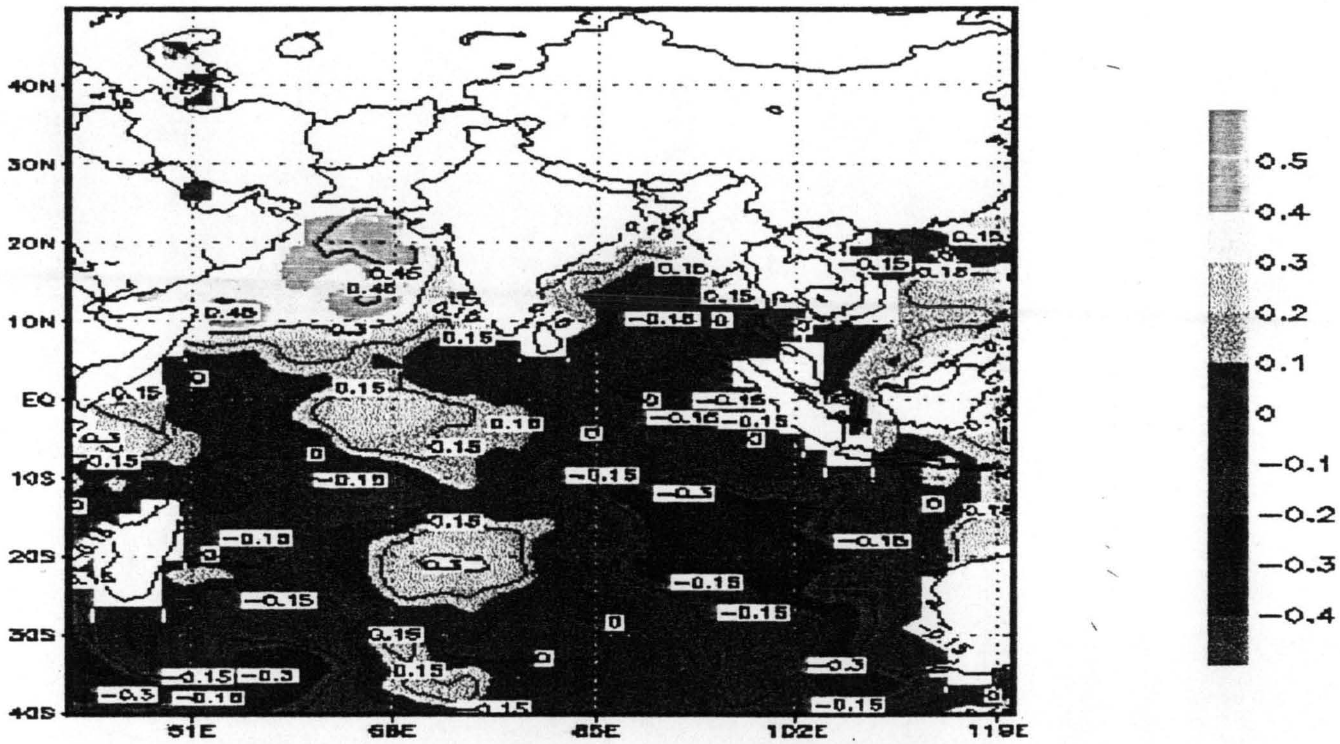

Fig. 4.217 Sokoto JAS Seasonal Rainfall correlated with the Indian Ocean
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

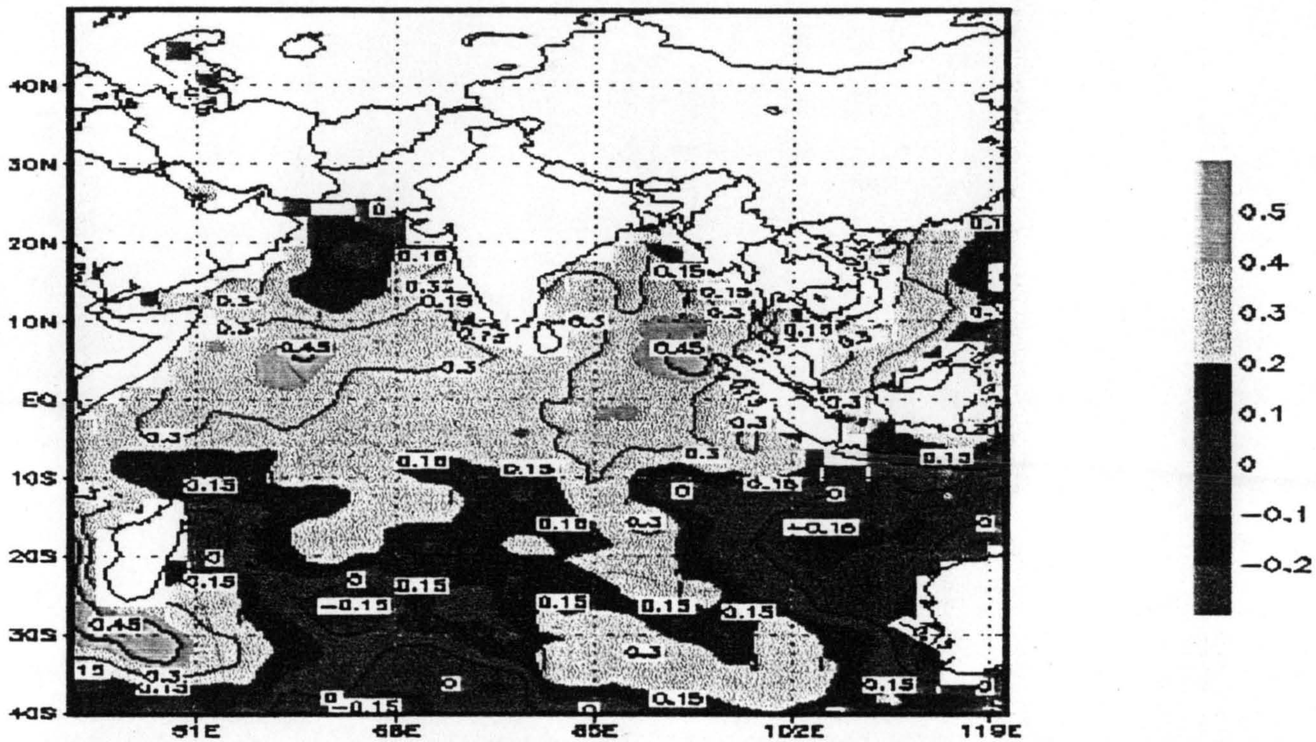

Fig. 4.218 Zaria JJA Seasonal Rainfall Correlated with Indian Ocean.
The Legend shows the correlation coefficients.
The figure was produced using CLIMLAB.

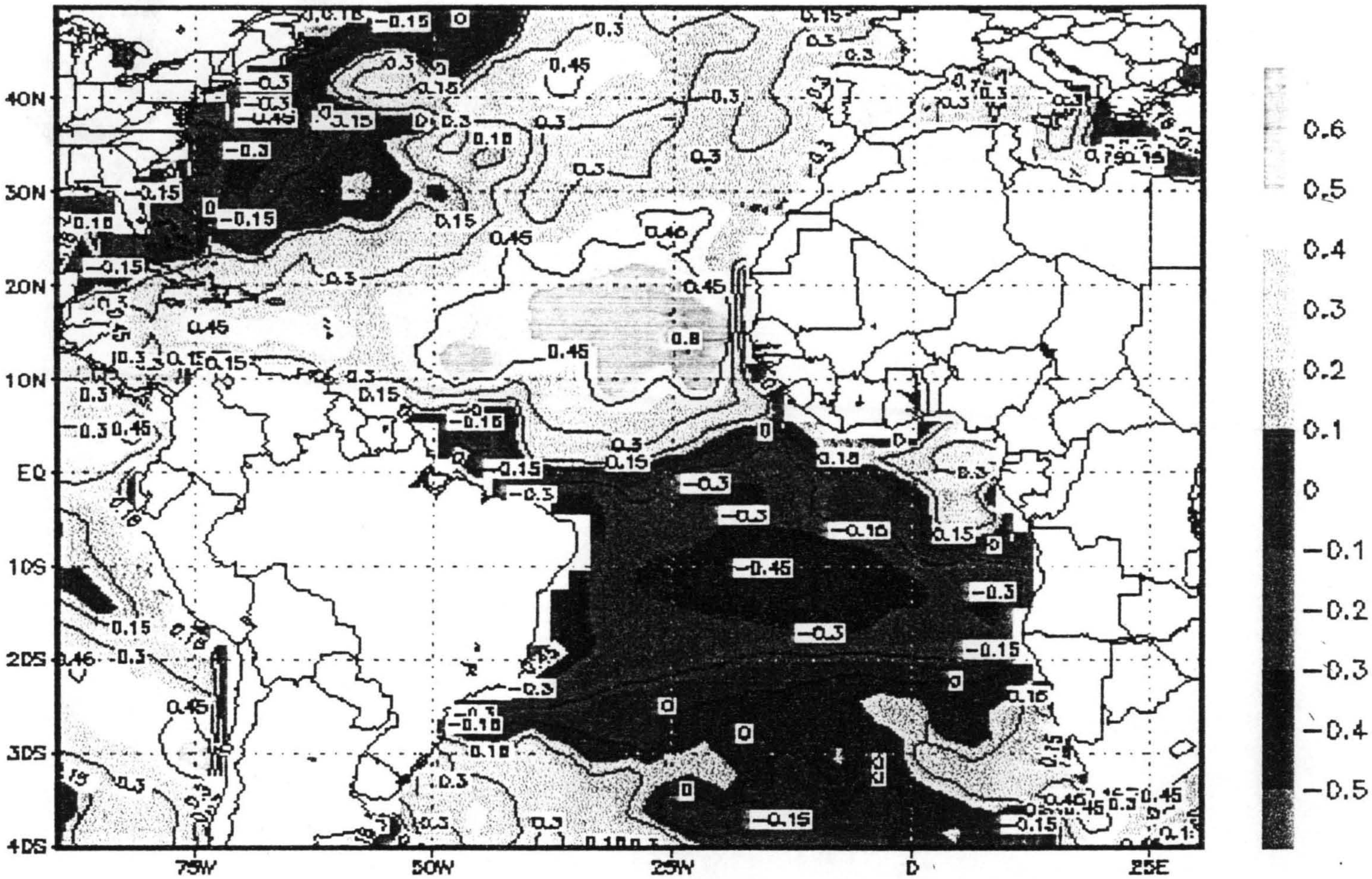

Fig. 4.221 Gusau MJJ Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

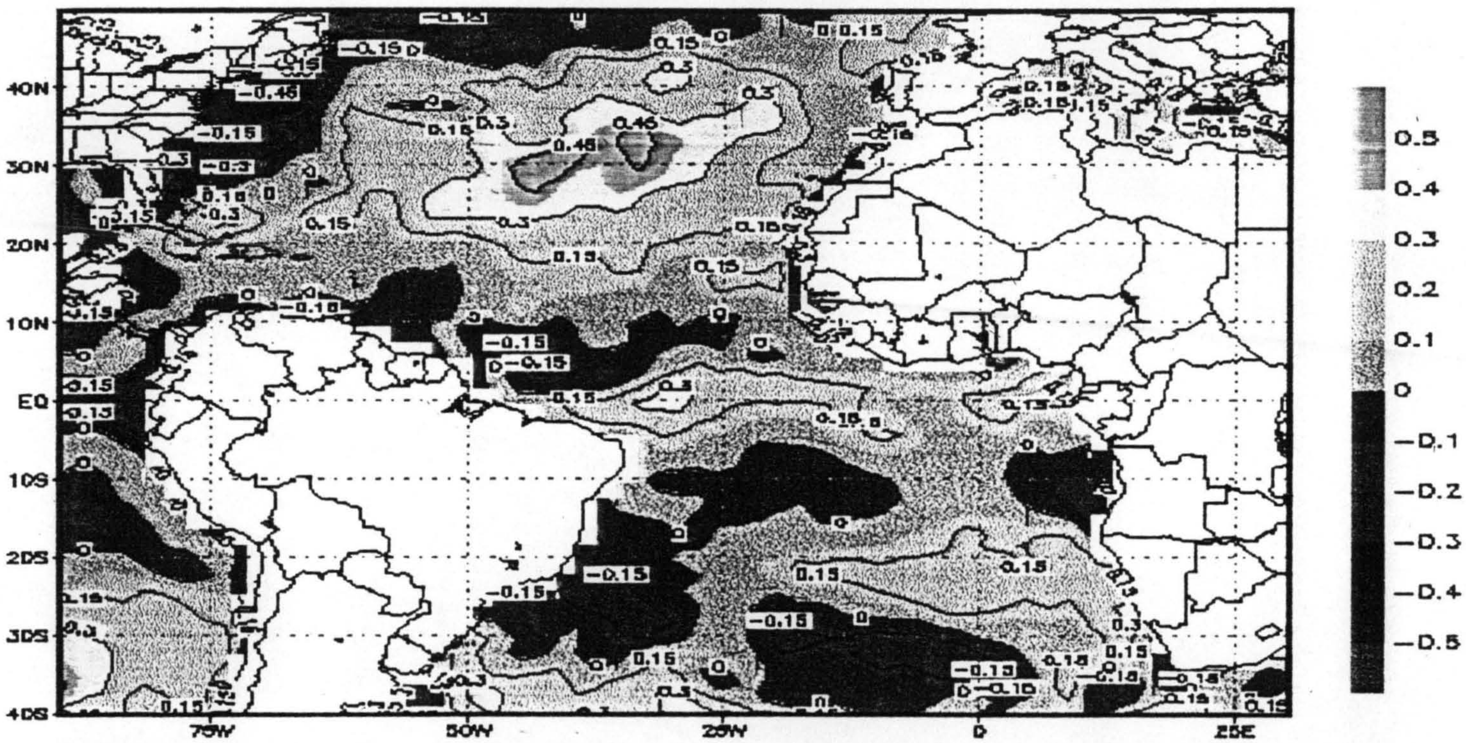

Fig. 4.222 Kano JAS Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

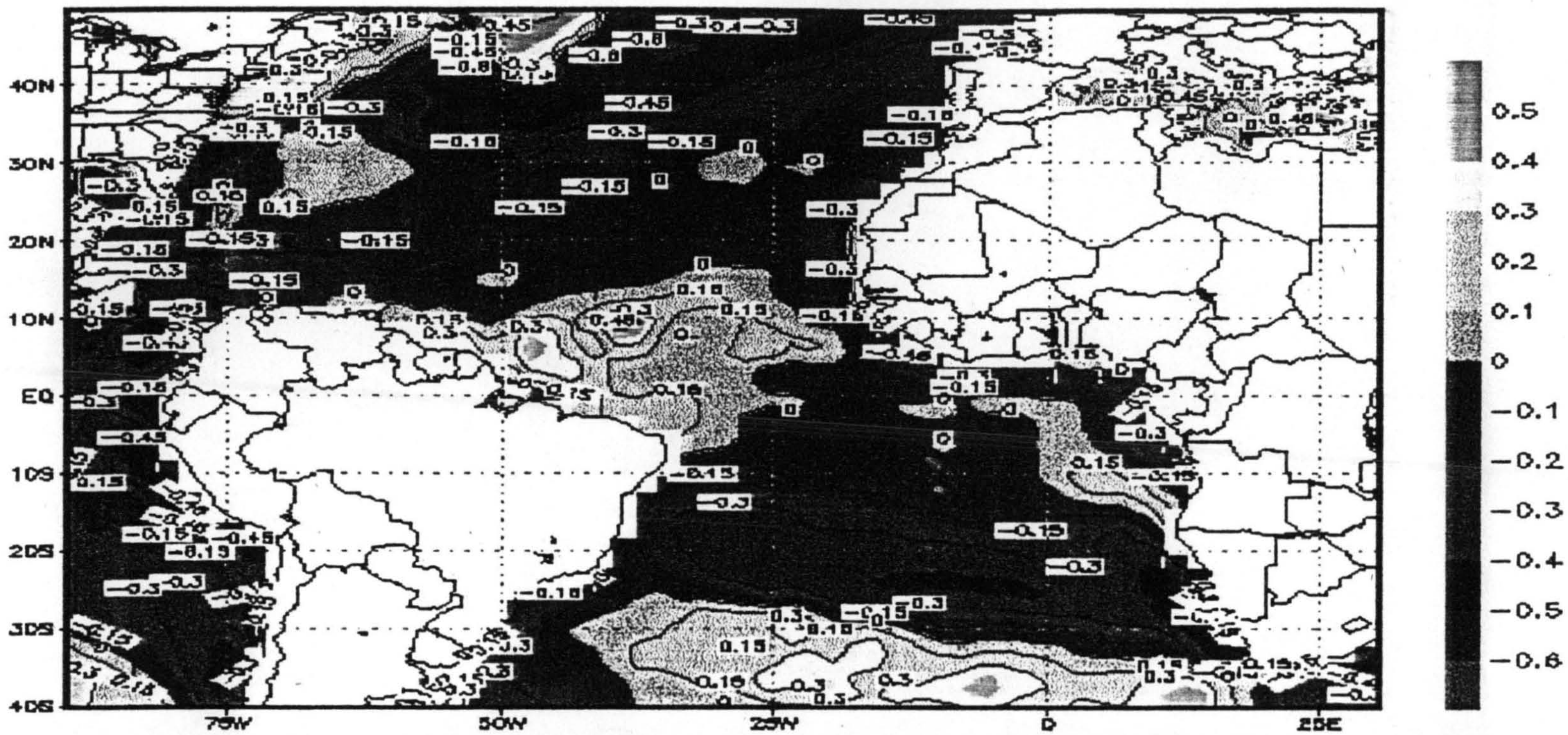

Fig. 4.223 Katsina JAS Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced Using CLIMLAB.

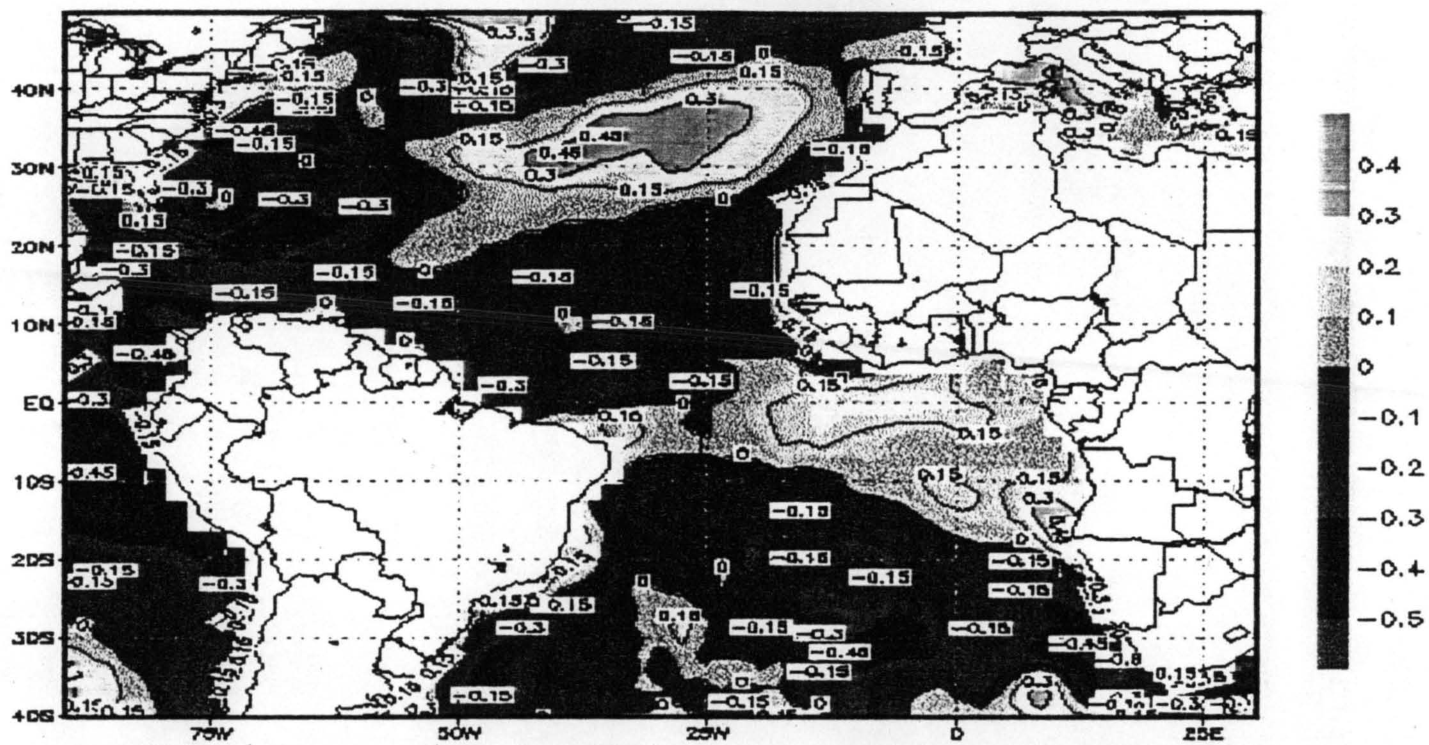

Fig. 4.224 Maiduguri JAS Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

Nguru MJJ seasonal rainfall as represented by Fig. 4.225 is highly correlated with the area bordered by Lat. 05°N and 15°N, Long. 55°W and 40°W. The area bordered by Lat. 20°N and 30°N, Long. 70°W and 50°W has a high correlation coefficient with the JAS seasonal rainfall for Potiskum as in Fig. 4.226. The MJJ seasonal rainfall for Sokoto as in Fig. 4.227 has a high correlation coefficient with the area represented by Lat. 10°N and 22°N, Long. 45°W and 25°W. As indicated in Fig. 4.228 the MJJ seasonal rainfall for Zaria is highly correlated with the area bordered by Lat. 25°N and 30°N, Long. 40°W and 28°W.

4.2.3 SEASONAL RAINFALL CORRELATED WITH THE NINO REGIONS

The Nino regions are as indicated below.

Nino 1 (Latitude 5S----10S , Longitude 80W---90W).

Nino2 (Latitude 0 S----5S , Longitude 80W----90W).

Nino 3 (Latitude 5S ----5N , Longitude 90W---150W).

Gusau JAS seasonal rainfall has a correlation coefficient of –0.32 with the Nino 1+2 region and –0.27 with the Nino 3 region. The correlation between the Nino regions and Kano JAS seasonal rainfall is -0.21 and –0.22 for Nino 1+2 and Nino 3 respectively. The correlation coefficient between Katsina JAS seasonal rainfall is -0.31 for Nino 1+2 and –0.37 for Nino 3+4. For the Maiduguri JAS seasonal rainfall, the correlation between the Nino regions are –0.30 for Nino1+2 and –0.28 for Nino3. Nguru JAS seasonal rainfall has a correlation coefficient of –0.40 with the Nino 1+2 region, -0.25 with the Nino 3 region and –0.43 for Nino3+4 region. The correlation coefficient between the Nino1+2 region and the Sokoto JJA seasonal rainfall is –0.13 and –0.31 for JAS seasonal rainfall.

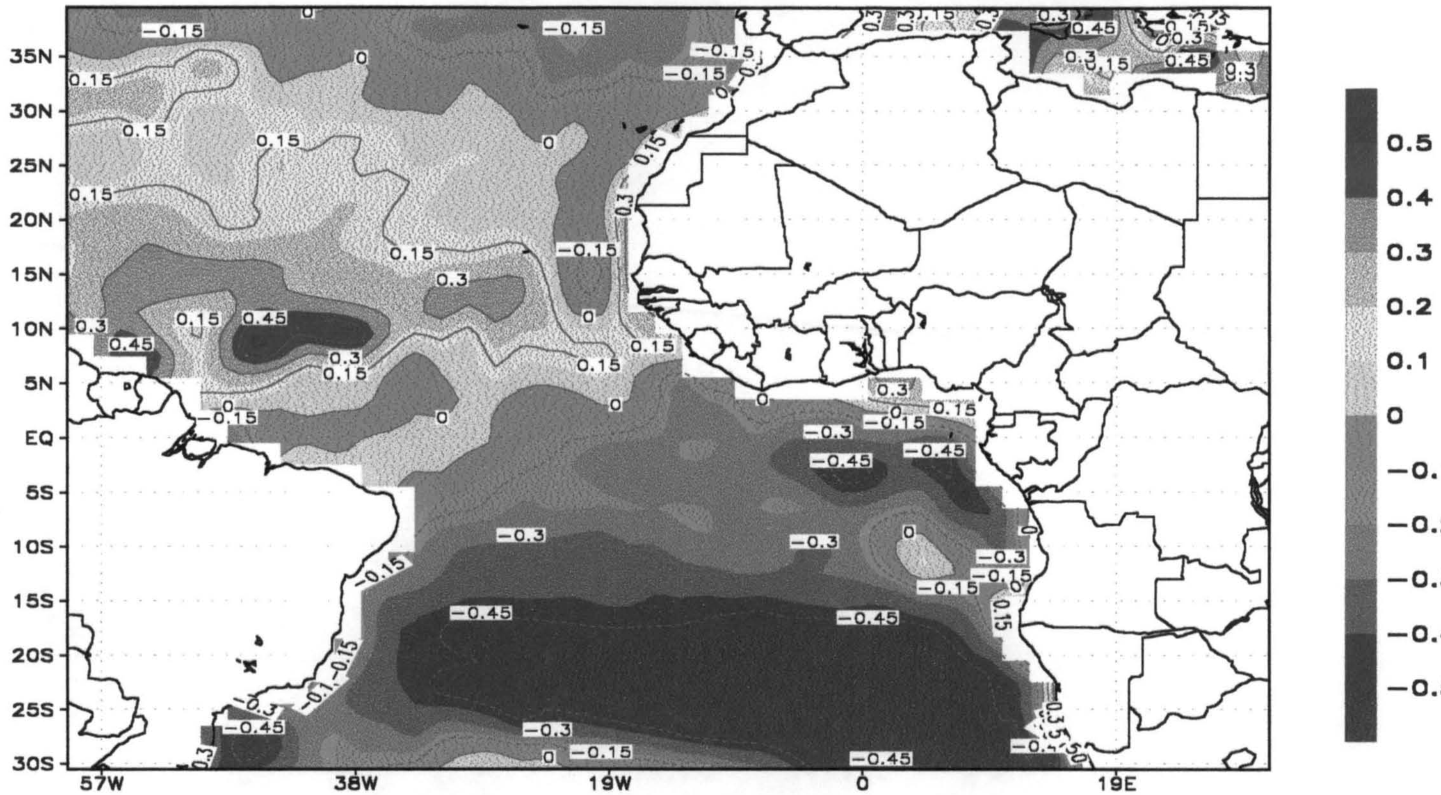

Fig. 4.225 Nguru MJJ Seasonal rainfall Correlated with the Atlantic ocean
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

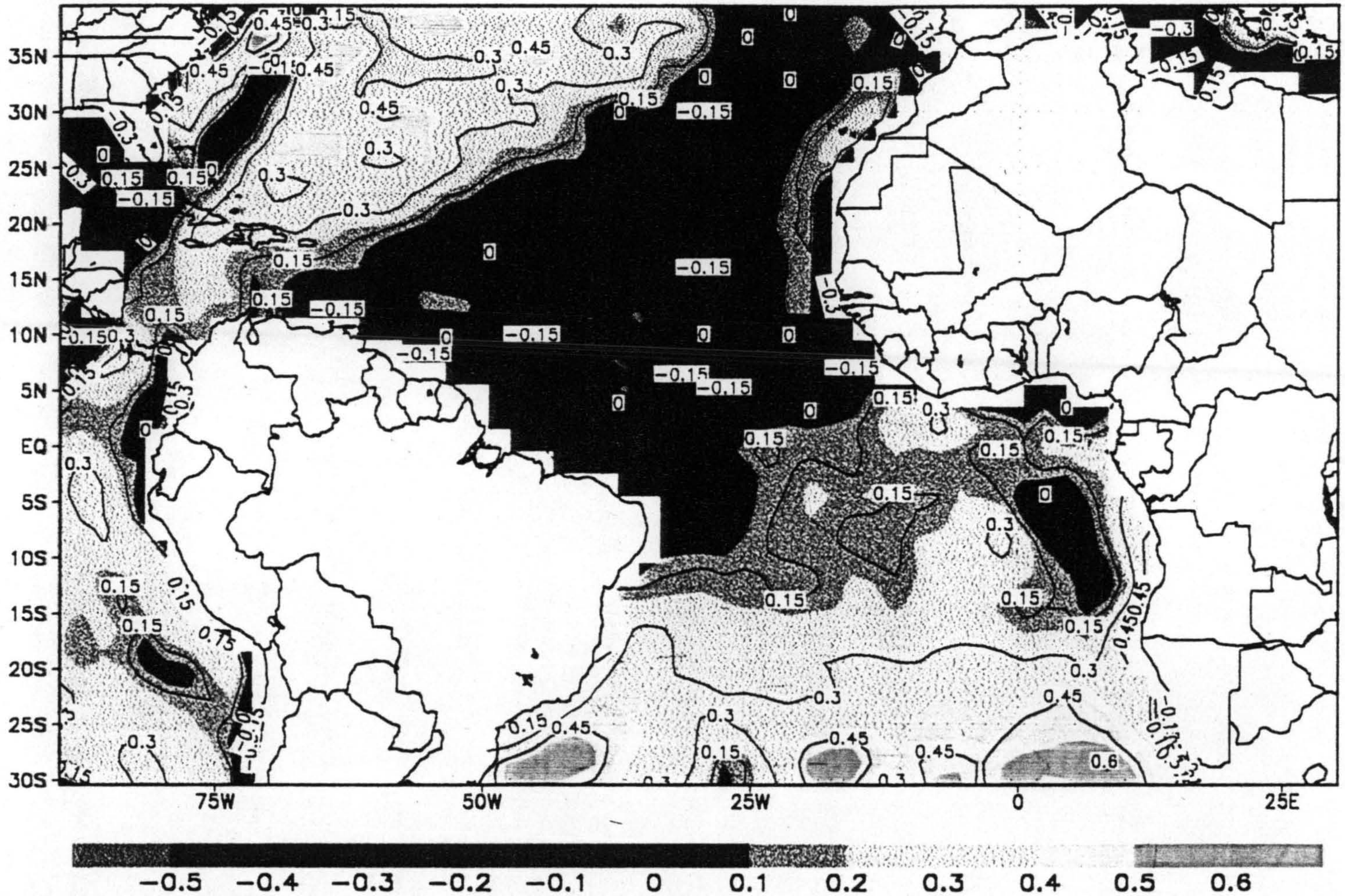

Fig. 4.226 Potiskum JAS Seasonal rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation Coefficients.
The Figure was produced using CLIMLAB

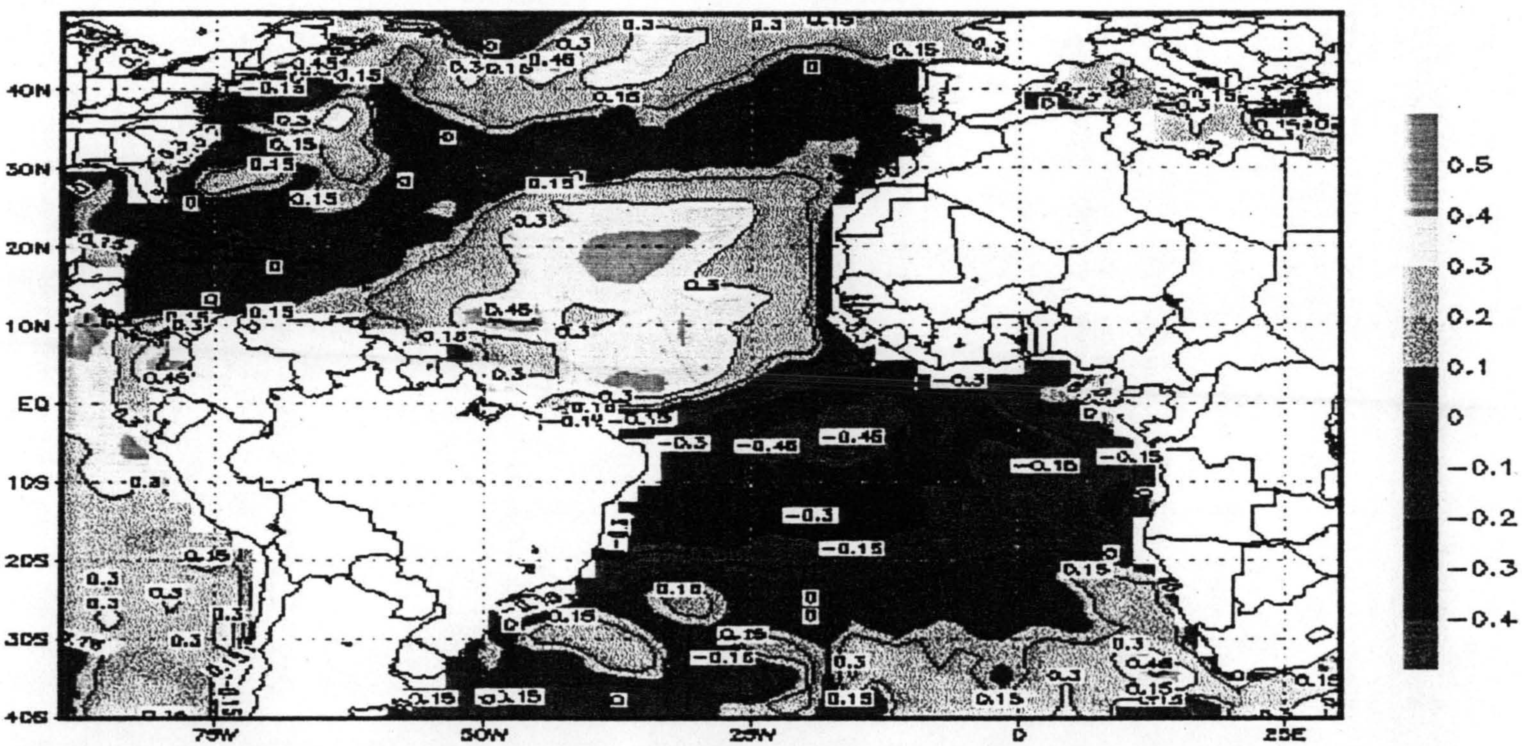

Fig. 4.227 Sokoto MJJ Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

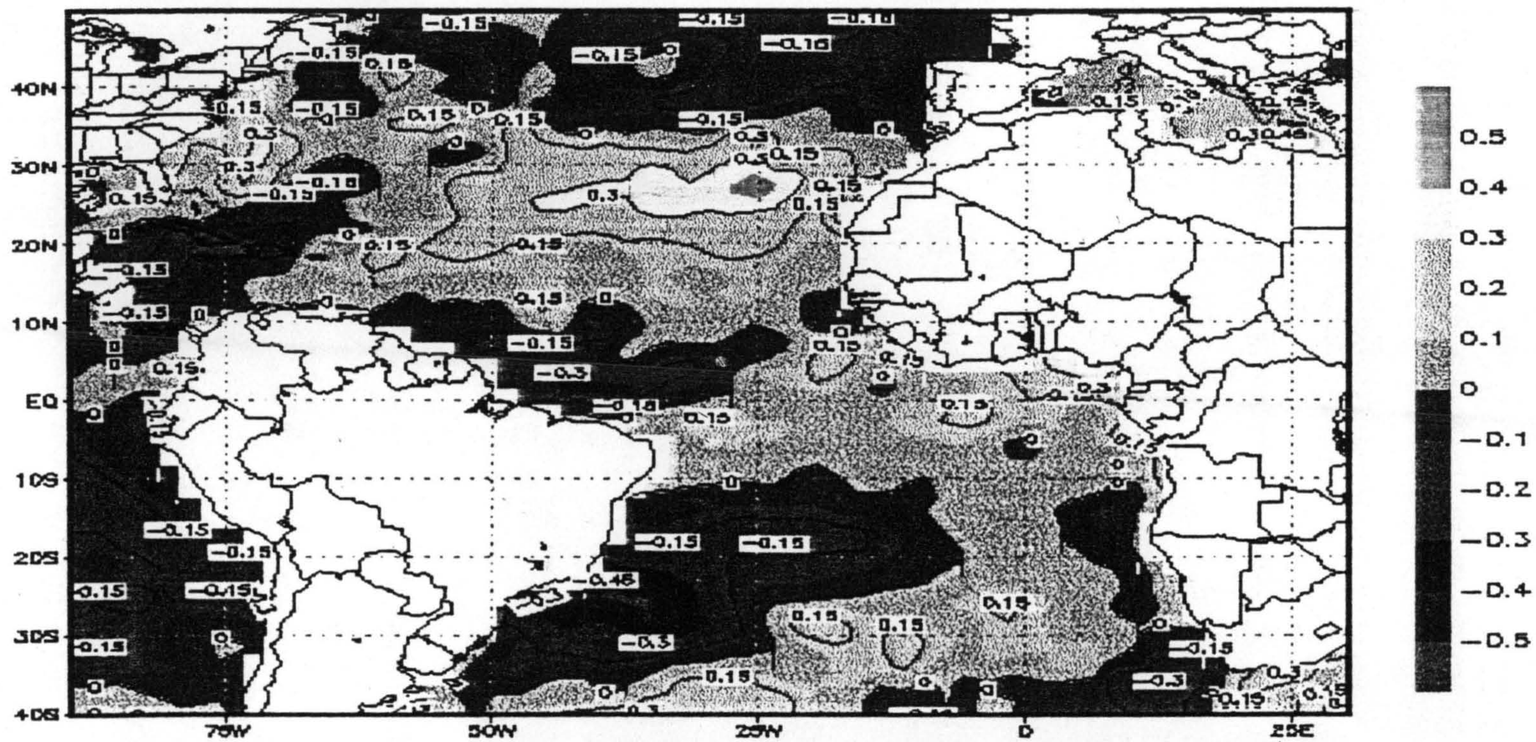

Fig. 4.228 Zaria MJJ Seasonal Rainfall correlated with the Atlantic Ocean.
The Legend shows the correlation coefficients.
The Figure was produced using CLIMLAB.

4.3 DISCUSSION

The rainfall in the North usually spans from late May to September or early October. There are however few occasions when the rain starts as early as March. The plotted yearly rainfall data in the study area show mostly a single peak, although some stations showed double peaks in some years. In the study area, the rainfall amount showed low values especially in 1972-73, 1982 –83 and 1987. However some few stations observed low rainfall at various times. These years of general rainfall deficits coincided with the El–Nino years. It has been generally agreed that during the occurrence of El –Nino in 1972 –73 , 1976 –77 and 1982 -83, there were rainfall deficit all over the West African Sub – region with the resultant drought problems. The seasonal rainfall May-June-July (MJJ), June-July-August (JJA) and July-August-September (JAS) for the various stations have different correlation coefficients over the different oceans. The Indian and North Atlantic oceans have positive correlation with these seasonal rainfall, while the Nino regions have negative correlation. This relationship though not very strong in many cases as can be seen from the correlation coefficients of the individual Nino areas, when the collective contribution is taken, the effect becomes pronounced. During the El-Nino (warm) episode, the rainfall anomalies are found to be below the average values. While during the La -Nina (cold) episode, the rainfall anomalies are found to be above the normal values.

The significance levels were tested using Mack probability test levels. Where C>1.98, 2.25 and 3.29 – the no correlation hypothesis was rejected at 5%, 1% and 0.1% level respectively.

C was computed using

$$C = |r|\sqrt{(n-1)}$$

Where r = is the correlation coefficient

n = is number of data set

Table 4. 1 Correlation coefficients between seasonal rainfall And SSTs in some areas of the global oceans

Station	Region	MJJ	JJA	JAS .	C for (JJA)
Gusau	North Atlantic	0.24	0..56	0.27	2.74
	Nino3	0.07	-0.04	-0.27	0.20
	Nino1+2	0.04	-0.23	-0.32	1.13
	Indian Ocean	0.40	0.49	0.14	2.40
	Nino3.+4	0.35	0.21	0.20	1.03
Sokoto	North Atlantic	-0.14	0..37	-0.01	1.81
	Nino3	-0.06	0.08	0.15	0.39
	Nino1+2	0.37	-0.13	-0.31	0.64
	Indian Ocean	0.48	0.48	0.42	2.35
	Nino3+.4	0.29	-0.03	-0.10	0.15
Katsina	North Atlantic	0.30	0.39	-0.21	1.91
	Nino3	0.03	0.44	0.17	2.16
	Nino 1+2	-0.11	-0.25	-0.30	1.20
	Indian Ocean	0.33	0.26	0.31	1.23
	Nino 3+4	-0.16	-0.29	-0.37	1.42
		MJJ	JJA	JAS	
Kano	North Atlantic	0.44	0.36	0.44	1.76
	Nino3	-0.20	-0.23	-0.22	1.13
	Nino1+2	- 0.17	-0.15	-0.21	0.74
	Indian Ocean	0.35	0.35	0.29	1.86
	Nino3+4	-0.18	-0.08	-0.10	0.39
Nguru	North Atlantic	0.03	-0.20	0.10	0.98
	Nino3	-0.34	-0.11	-0.25	0.54
	Nino 1+2	-0.37	-0..39	-0.40	1.91
	Indian Ocean	0.21	0.40	0.21	1.96
	Nino3+4	-0.32	-0.33	-0.43	1.62

Station	Region	MJJ	JJA	JAS .	C for (JJA
Potiskum	North Atlantic	-0.15	-0.05	-0.05	0.24
	Nino3	0.02	-0.10	0.03	0.49
	Nino 1+2	0.22	0.32	0.29	1.57
	Indian Ocean	0.32	0.32	0.30	1.57
Maiduguri	North Atlantic	-0.22	0.14	0.25	0.69
	Nino3	-0.17	0.17	-0.28	0.83
	Nino1+2	-0.19	-0.18	- 0.30	0.88
	Indian Ocean	0.24	0.29	-0.01	1.42
	Nino3+4	-0.23	-0.22	-0.33	1.08

CHAPTER FIVE

5.0 SUMMARY

The study showed that there were wide variation of rainfall over the area during the period under investigation. The annual over the area ranged from 236.7mm to 1537.5mm. The rainfall progressively decreased as we from south to north as some stations nearer the south like Bauchi, Yelwa and Zaria recorded higher rainfall than the stations further north. The general rainfall pattern over the area is unimodal but there are occasions when the stations exhibited double rainfall peaks. The Indian and North Atlantic ocean SST anomalies have positive correlation coefficient with the seasonal rainfall. The Nino region SST anomalies have negative correlation coefficient with the seasonal rainfall. The rainfall over the area is not homogenous because the stations have different terrains.

5.1 CONCLUSIONS

From the different correlation coefficient obtained, a single predictive model may not be feasible for all the stations. Although the relationship between SST and seasonal rainfall is low, it gives indication of whether the rainfall is going to be normal, below normal or above normal for the season. With adequate monitoring as the rainy season progresses, decision can be made to release more water from dams or conserve water. In this case, disaster due to flooding caused by dams can be avoided.

5.2 RECOMMENDATION

It is recommended that other predictors like pressure, temperature and upper air data where available should be used to forecast the seasonal rainfall. A combination of these factors may give a better forecast.

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