Assessment of Drought Occurrences Over the Sahel Region of Nigeria using the Standardized Precipitation Index (SPI)

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Abstract:- This paper examines the assessment of drought occurrence over the Sahel region of Nigeria using Standardized Precipitation Index (SPI). Six Sahel stations was used which include (Sokoto, Kano, Postikum, Katsina, Nguru, and Maiduguri), the monthly mean rainfall data for the six Sahel stations in the study area was obtained from the operational headquarters of the Nigerian Meteorological Agency for a period of 35 years (1971 – 2006). The objectives are to examine the trend in rainfall over the region, to identify the drought years using the Standardized Precipitation Index (SPI) and classified the drought years respectively and finally to determine the percentage of rainfall contributed by each month in the drought years. The results shows that the rainfall trend over the Sahel region for the period under study exhibits an increasing trend for most of the stations except for Katsina and Nguru which exhibits a decreasing trend in rainfall. From the SPI graph values from -1.0 to -1.5 was taken as moderate drought years, values from -1.5 to -2.00 was taken as severe drought years and values from -2.00 or less are taken as extreme drought years respectively. Many cases of moderate drought years was recorded, while few cases of severe drought years and just one case of extreme drought year was recorded across the Sahel region for the period under investigation. Generally, the percentage of rainfall contributed by each month for all the stations based on the analysis it can be said that the months of Jan – April and Oct – Dec are very significant in determining the level of dryness over the Sahel region within a year, and it can also be used to predict/forecast drought over the Sahel region of Nigeria.

***Keywords**:-* *Standardized Precipitation Index (SPI), Rainfall Trend, and Drought.*

I. INTRODUCTION

Drought is a climatic phenomenon which is of serious concern globally; it is a period of below average rainfall or deficiency in water supply over a given region. A drought can last for months or years, or may be declared after as few as 15 days. It can have a substantial impact on the ecosystem and agriculture and also harm local economy of the affected region. Annual dry seasons in the tropics significantly increase the chances of a drought developing and subsequent bush fires. Meteorological drought is the earliest and the most explicit event in the process of occurrence and progression of drought conditions. Rainfall is the primary driver of meteorological drought[1]. There are numerous indicators based on rainfall that are being used for drought monitoring[2]. Deviation of rainfall from normal i.e. long term mean is the most commonly used indicator for drought monitoring. Meteorological drought is declared based on rainfall deviations measured using the season's total actual rainfall and long term mean rainfall. If the total season's rainfall is less than 75% of the long term mean, the meteorological sub-division is categorized to be under drought. Severe drought occurs when the season's rainfall is less than 25% of normal. The deviation criteria for declaring drought vary. In South Africa, less than 70% of normal precipitation is considered as drought and such a situation for two consecutive years indicates severe drought[2].Over West Africa rainfall pattern, the highest spatial and temporal variability due to the seasonal pattern, are generally, associated with the inter-tropical discontinuity (ITD) and other meso-scale features. Other factors which influence rainfall such as storm, ITD, disturbance lines, altitude, latitude, longitude, relief, continentality and general orography etc. over West Africa have been studied extensively by Omotosho[3] and Olaniran[4]. Nigeria before the middle of 1960s and until 1970s experienced a favorable condition over most areas partly because of the effects of man's activities on climatic variations was negligible[5].

Standardized Precipitation Index (SPI) expresses that actual rainfall as standardized departure from rainfall probability distribution function and, hence, this index has gained importance in recent years as a potential drought indicator permitting comparisons across space and time. Computation of SPI requires long term data on precipitation to determine the probability distribution function which is then transformed to normal distribution with mean of zero and standard deviation of one. Thus, the values of SPI are expressed in standard deviations with positive SPI values indicating greater than median precipitation and negative values indicating less than median precipitation[6]. Since SPI values fit a typical normal distribution, these values lies within one standard deviation at approximately 68% of the time, within two standard deviations 95% of the time and within three standard deviations 98% of the time. In recent years SPI has been increasingly used for assessment of drought intensity in many countries[7-9].The interpretation of drought at different time scales using SPI has also been proved to be superior to the Palmer Drought Severity Index[10]. Goodrich and Ellis (2006) have used both SPI and yearly values of the Palmer Drought Severity Index to rank the years according to drought severity.

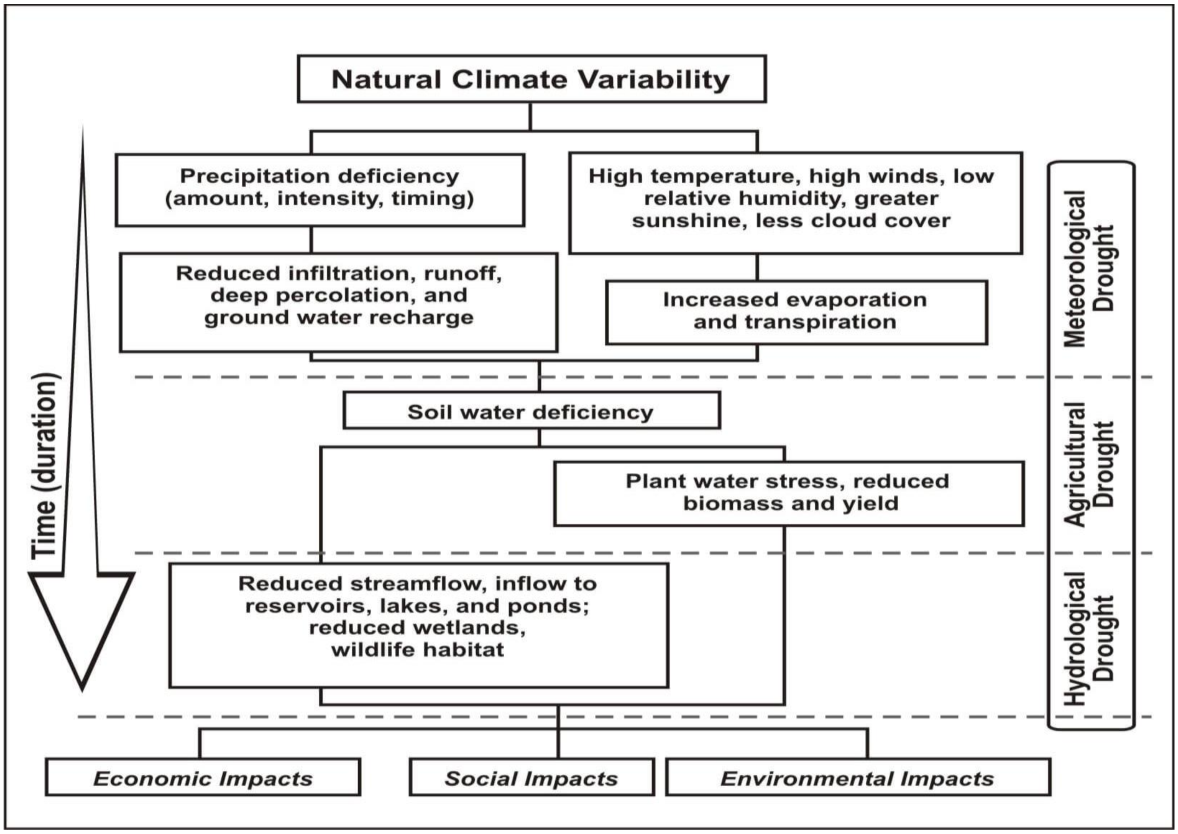

Fig 1:- Sequence of drought occurrence and impact for commonly accepted drought types.
Source: National drought mitigation center, University of Nebraska-Lincoln, U.S.A

II. MATERIAL AND METHODS

The study area is the Sahel region of Nigeria which includes Sokoto, Kano, Katsina, Nguru, Potiskum and Maiduguri it is bounded to the North by Republic of Niger and Chad to the West by Republic of Benin to the East by the Republic of Cameroon and to the South by Sudan savanna). The Sahel region lies between the latitude 10◦N and 14◦N and longitude 4◦E and 14◦E[12]. It should be noted that the region is classified as a tropical climate area and that it is dominated by the tropical maritime air mass, which brings rain from April to October, and by the dry, dusty tropical continental air mass that prevails from October to March. The region therefore has two marked seasons, the wet and dry seasons. Average annual rainfall in the region ranges from 500 to 1000 mm with rain days of between40 and 100 per year[13].

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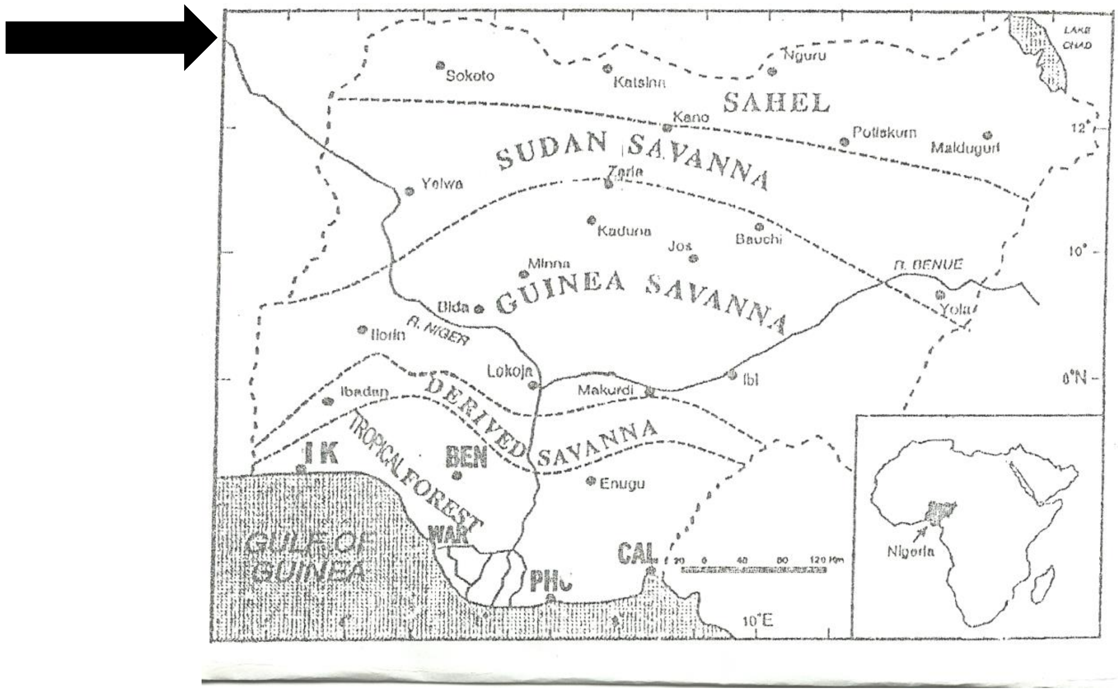

Fig 2:- Map showing the study area(Source: Gbuyiro et. al, 2000)[14]

The data used for this study is mainly secondary data, the monthly mean rainfall data for the six Sahel stations for a period of thirty years from 1971 – 2006, was obtained from the Operational Head Quarters of the Nigerian Meteorological Agency, Oshodi Lagos State.

➢ *Statistical analysis*

The method used in this study includes (Mean, standard deviation, trend analysis) was carried out. Excel package and other statistical software were used to carry out the analysis. The rainfall data was standardized.

- Data collected were subjected to quality control, standardiz ation and analyses.
- Raw data was transformed using the standardization method of climatic indexing.

A. Procedure and Formula for Computation of SPI by Edwards and McKee (1993)[15]

The transformation of the precipitation value in to standardized precipitation index (SPI) has the purpose of:

- Transforming the mean of the precipitation value adjusted to 0;
- Standard deviation of the precipitation is adjusted to 1.0; and
- Skewness of the existing data has to be readjusted to zero.

When these goals have been achieved the standardized precipitation index can be interpreted as mean 0 and standard deviation of 1.0.

➢ *Mean of the precipitation can be computed as*

$$\text{Mean} = \overline{X} = \frac{\sum X}{N} \quad (1)$$

Where N is the number of precipitation observations.

B. The standard deviation for the precipitation is computed as:

$$s = \sqrt{\frac{\sum (X - \overline{X})^2}{N}} \quad (2)$$

The skewness of the given precipitation is computed as:

$$\text{Skew} = \frac{N}{(N-1)(N-2)} \sum \left(\frac{X - \overline{X}}{s} \right)^3 \quad (3)$$

C. The precipitation is converted to lognormal values and the statistics U, shape and scale parameters of gamma distribution are computed:

$$\log \ \text{mean} = \overline{X}_{\ln} = \ln\left(\overline{X}\right) \quad (4)$$

$$U = \overline{X}_{\ln} - \frac{\sum \ln(X)}{N} \quad (5)$$

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$$\text{shapeparameter} = \beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \quad (6)$$

$$\text{scaleparameter} = \alpha = \frac{\overline{X}}{\beta} \quad (7)$$

Equations (1) – (8) are computed using built functions provided by EXCEL software.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event. The cumulative probability is given by:

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} \, dx}{\beta^{\alpha} \Gamma(\alpha)} \quad (8)$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \quad (9)$$

Where q is the probability of zero. The cumulative probability H(x)is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI following Edwards and McKee (1993);

SPI	Drought category
0 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 or less	Extreme drought

Table 1. Drought categories from SPI (source: McKee et al., 1993)

The table above was used for the basis of classification of the drought categories and values from -1.0 to -1.5 is taken as moderate drought, while value from -1.5 to -2.00 is taken to be a severe drought and from -2.00 0r less is taken as extreme drought.

III. RESULTS AND DISCUSSION

➢ *Rainfall Trend and Variability*

The trend in rainfall over the Sahel region of Nigeria for the period under investigation (1971 – 2006), was examined and it was observed that most of the stations involved in the study area exhibits an increasing trend in the rainfall (Sokoto, Kano, Potiskum and Maiduguri) shows an increasing trend while (Katsina and Nguru) shows a decreasing trend in rainfall for the period under study.

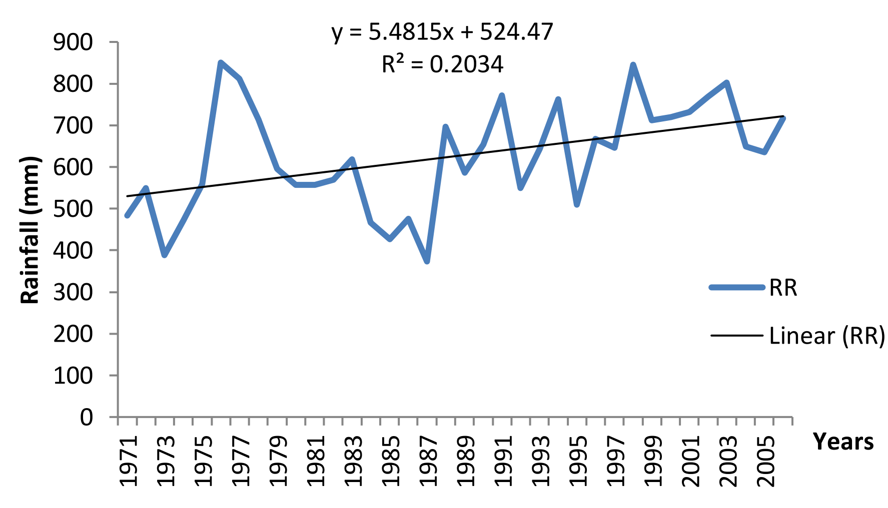

Fig 3:- Sokoto annual mean rainfall from 1971-2006

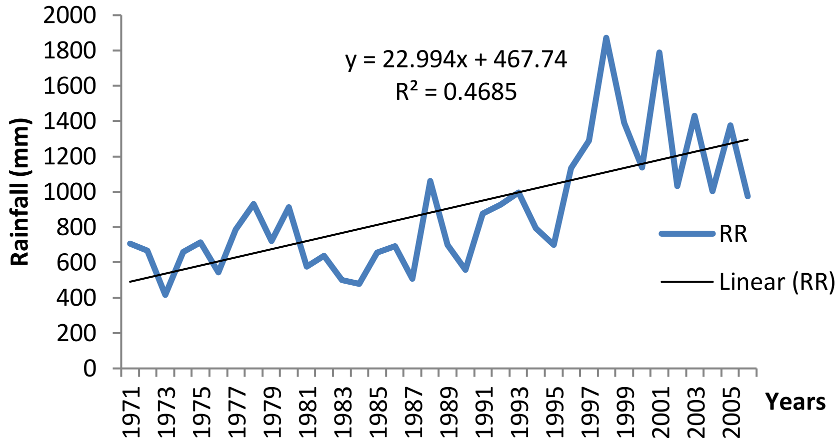

Fig 4:- Kano annual mean rainfall from 1971-2006

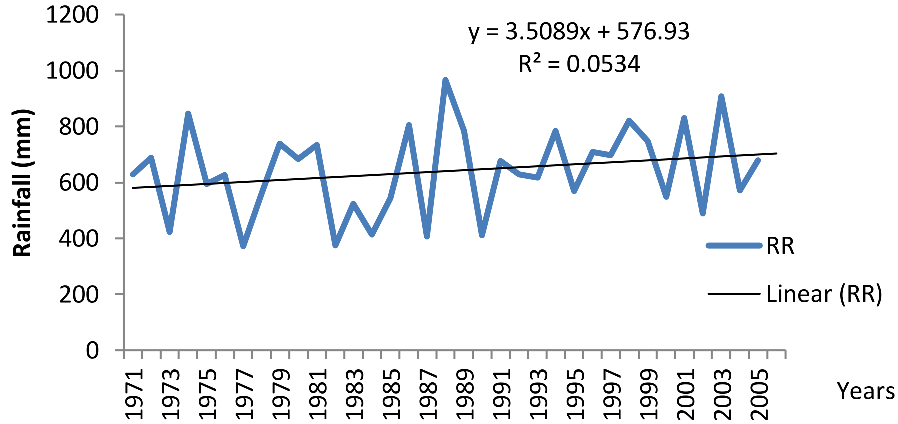

Fig 5:- Potiskum annual mean rainfall from 1971 - 2006

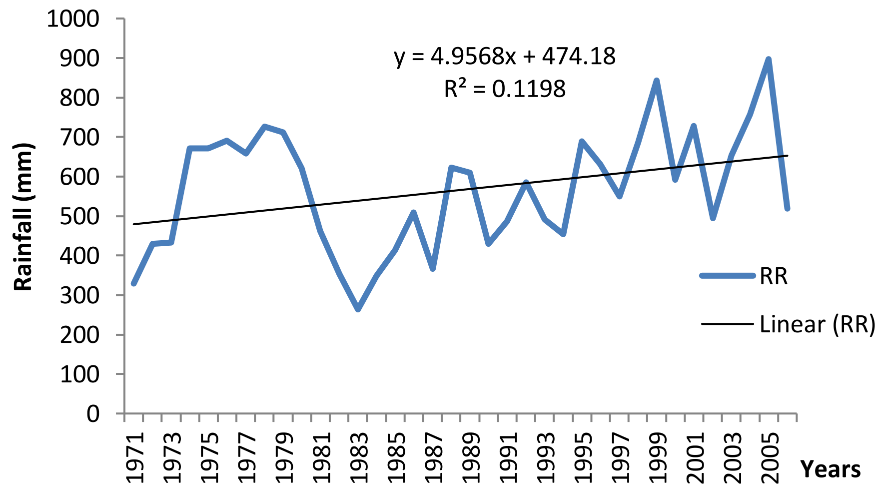

Fig 6:- Maiduguri annual mean rainfall from 1971 - 2006

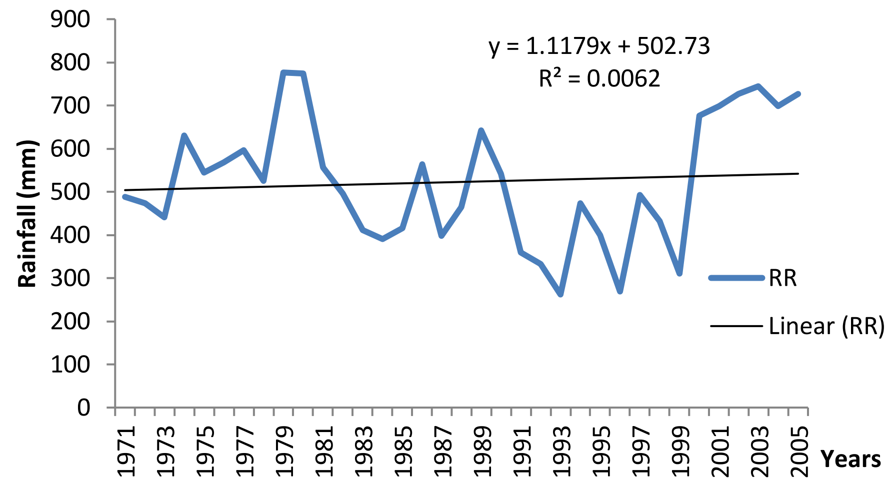

Fig 7:- Katsina annual mean rainfall from 1971-2005

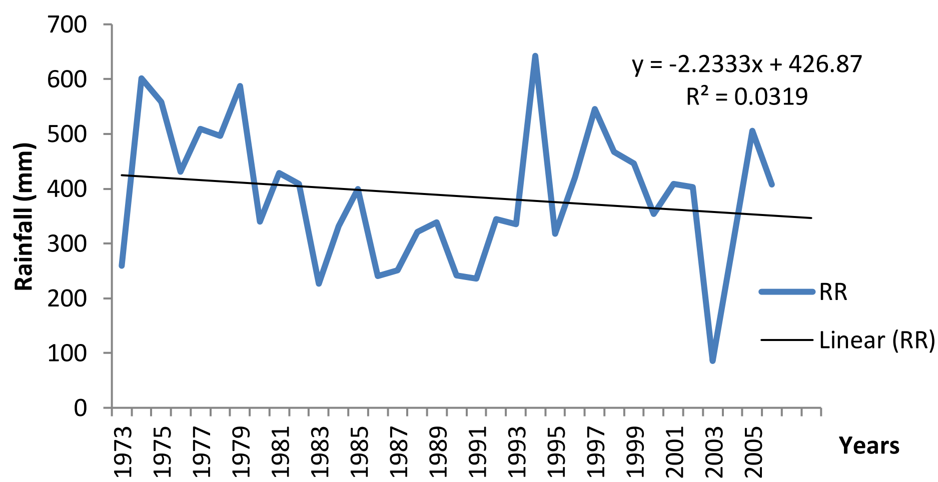

Fig 8:- Nguru annual mean rainfall from 1971-2006

Figure (2 – 7) Above shows the trend analysis/variability of rainfall over the Sahel region of Nigeria for the period (1971-2006). And from the analysis it can be said that just few cases of drought were recorded for the period under study as most of the station in the Sahel region exhibit an increasing trend in rainfall.

IV. STANDARDIZED PRECIPITATION INDEX (SPI)

The standardized precipitation index was used to identify the years with above and below normal rainfall, and classify the below normal rainfall into either moderate, severe, or extreme drought years since the focus of this paper is on drought occurrences not wet years. The graph below depleted in figure 8 - 13show the annual trends of the Standardized Precipitation Index values for each of the stations in the study area.

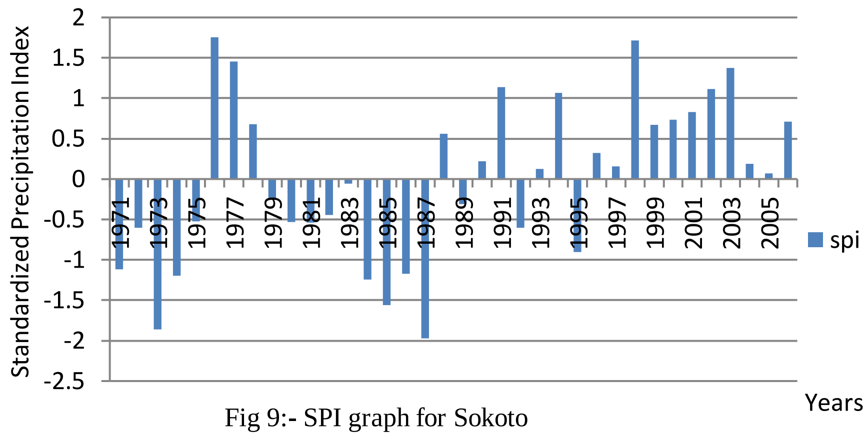

Fig 9:- SPI graph for Sokoto

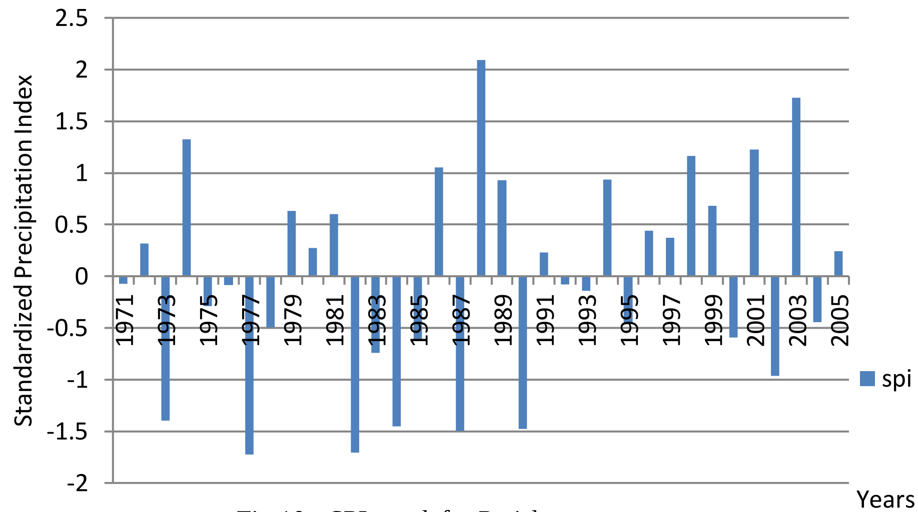

Fig 10:- SPI graph for Potiskum

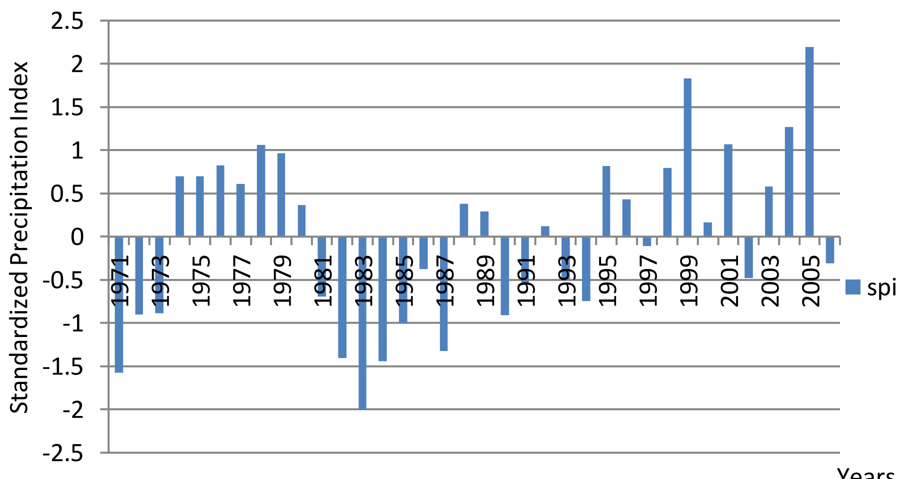

Fig 11:- SPI graph for Maiduguri

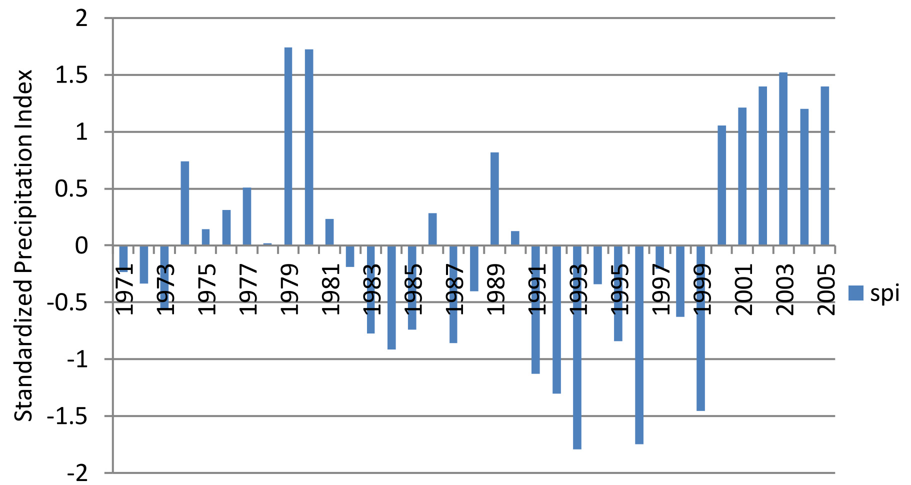

Fig 12:- SPI graph for Katsina

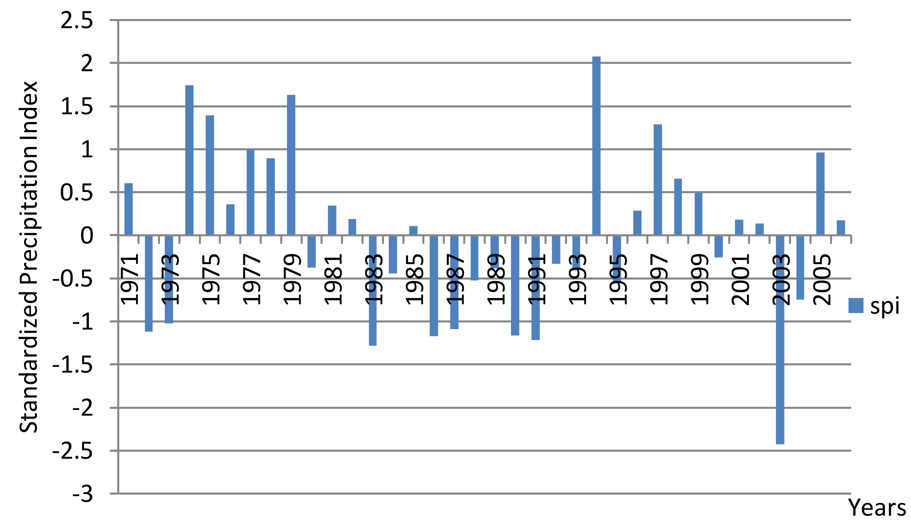

Fig 13:- SPI graph for Nguru

For Sokoto (figure 8), the Standardized Precipitation Index (SPI) graph shows that Sokoto has seven drought years (1971, 1973, 1974, 1984, 1985, 1986, 1987), four of which are moderate drought years (1971, 1974, 1984, 1986) and three severe drought years respectively (1973, 1985, 1987).

In the case of Kano (figure 9), the Standardized Precipitation Index (SPI) graph shows that Kano has five drought years (1973, 1976, 1983, 1984, 1987), all of which are moderate drought years respectively.

For Potiskum (figure 10), the standardized Precipitation Index (SPI) graph shows that Potiskum has six drought years (1973, 1977, 1982, 1984, 1987, 1990), of which (1973, 1984, 1987, 1990) are moderate drought years while (1977, 1982) are severe drought years.

In the case of Maiduguri (figure 11), the Standardized Precipitation Index (SPI) graph shows that Maiduguri also has six drought years which are (1971, 1982, 1983, 1984, 1985, 1987). Maiduguri recorded four years of moderate drought which are (1982, 1984, 1985 1987), and two years of severe drought which are (1971, 1983) respectively.

For Katsina (figure 12), the Standardized Precipitation Index (SPI) graph shows that Katsina recorded five years of drought for the period under study, of which three of the years falls under the moderate drought (1991, 1992, 1999), while the remaining two years fall under the severe drought category, they are (1993, 1996).

In the case of Nguru (figure 13), the Standardized Precipitation Index (SPI) graph shows the Nguru has eight drought years which are (1972, 1973, 1983, 1986, 1987, 1990, 1991, 2003) respectively, of which (1972, 1973, 1983, 1986, 1987, 1990, 1991) are moderate drought years while (2003) is an extreme drought year.

The effect of the drought years experienced over the Sahel region of Nigeria over the past years cannot be overemphasized because of its adverse impact on the crops being planted and affect the farmers produce in this part of the country[16]. However drought is associated with protracted absence, and or poor distribution of precipitation. This situation is often experienced when the rain is unable to meet the evapotranspiration demand on crops and when this occurs, we experience general water stress and we start seeing crop failure all around the region where this situation is manifested[16].

- *Percentage of Rainfall Contributed By Each Month in the Drought Years*

For each of the Sahel station used, two years among the drought years was selected randomly for analysis in order to determine their monthly contribution to the dryness (drought), for all the stations one moderate year and one severe year was selected except for Kano that does not have a severe drought year, so two moderate years was selected, and Nguru no severe drought year but has an extreme drought year which was selected for the analysis and are depicted in figures 14a-b for Sokoto, Figure 15a-b for Kano, Figure 16a-b for Potiskum, Figure 17a-b for Maiduguri, Figure 18a-b for Katsina, and Figure 19a-b for Nguru respectively.

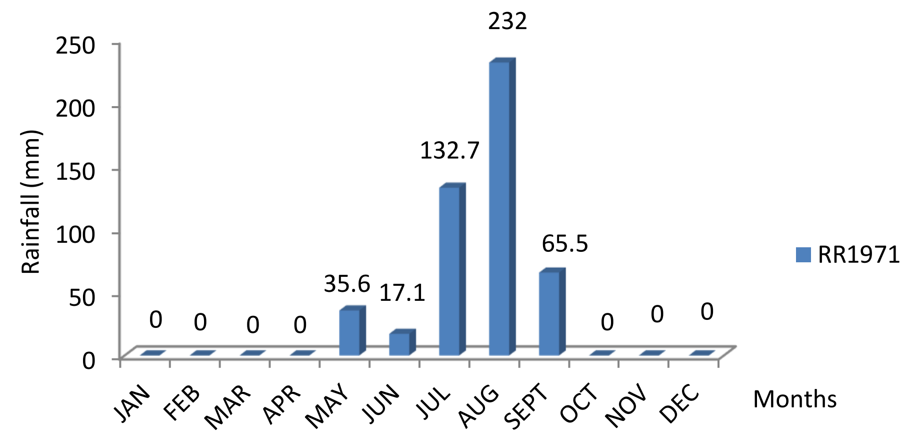

Fig 14a:- Rainfall monthly percentage for Sokoto 1971

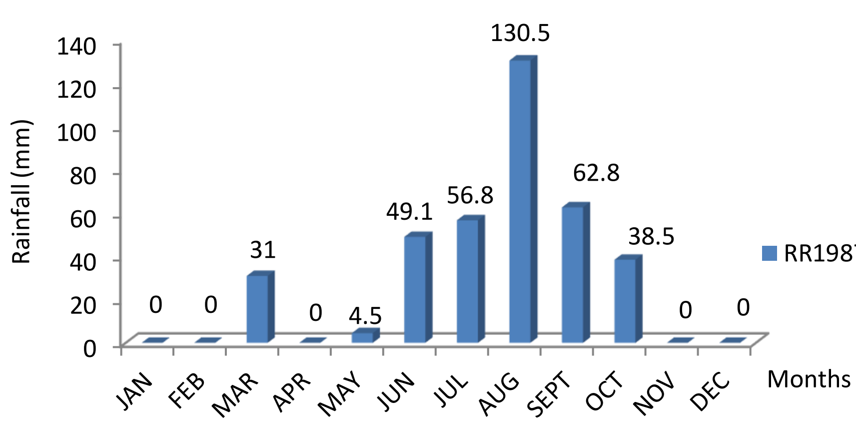

Fig 14b:- Rainfall monthly percentage for Sokoto 1987

From the rainfall monthly percentage graph for Sokoto, in 1971 which is a moderate drought year it was observed that Jan – April and Oct – Dec all contributed 0% to the total rainfall over Sokoto in the year 1971, while May contributed 4.3%, Jun. 2.1%, Jul. 15.9%, Aug. 27.8%, Sept. 7.7% respectively, which means that Jan – April and Oct – Dec in 1971 are very significant to the dryness over Sokoto. While in 1987 which is a severe drought year in Sokoto, it was also observed that the months of Jan, Feb, April, Nov, and Dec all have 0% rainfall over Sokoto, while the months of Mar contributed 3.7%, May 0.5%, Jun 5.9%, Jul 6.8%, Aug 15.7%, Sept 7.5%, and Oct 4.6% respectively.

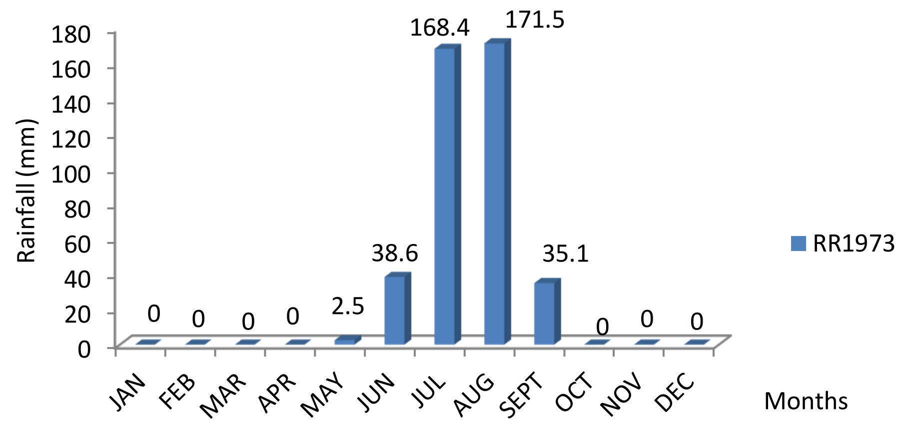

Fig 15a:- Rainfall monthly percentage for Kano 1973

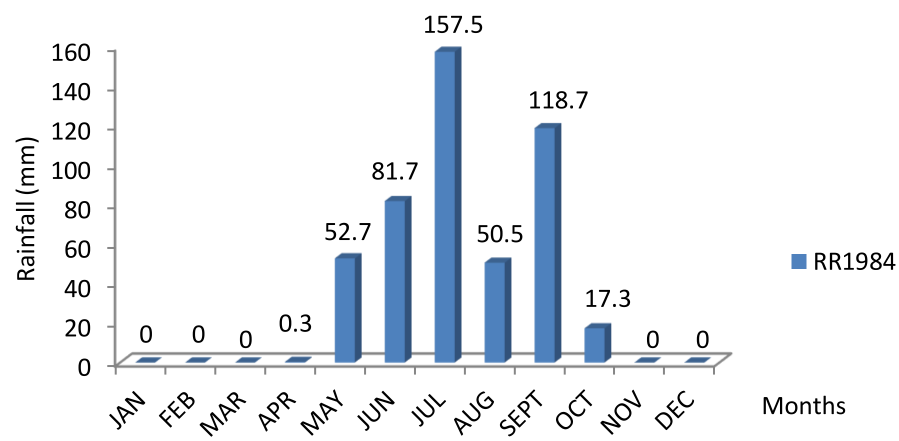

Fig 15b:- Rainfall monthly percentage for Kano 1984

For Kano, from the rainfall monthly percentage graph it was observed that in 1973 which is a moderate drought year in Kano, Jan – April 0% and Oct – Dec 0% as no rainfall recorded at all, while the months of May contributed 0.3%, Jun 4.6%, Jul 20.2%, Aug 20.6% and Sept 4.2% respectively to the total rainfall in the 1973 over Kano. In 1984 which is also a moderate drought year in Kano, the month of Jan – Mar and Nov – Dec recorded 0% rainfall, while the months of April contributed 0.04%, May 6.3%, Jun 9.8%, Jul 18.9%, Aug 6.1%, Sept 14.2%, Oct 2.1% to the total rainfall recorded over Kano in the year 1984.

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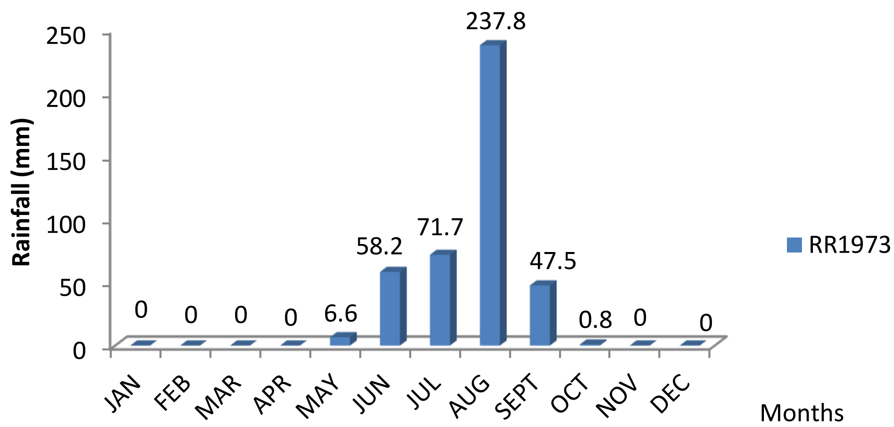

Fig 16a:- Rainfall monthly percentage for Potiskum 1973

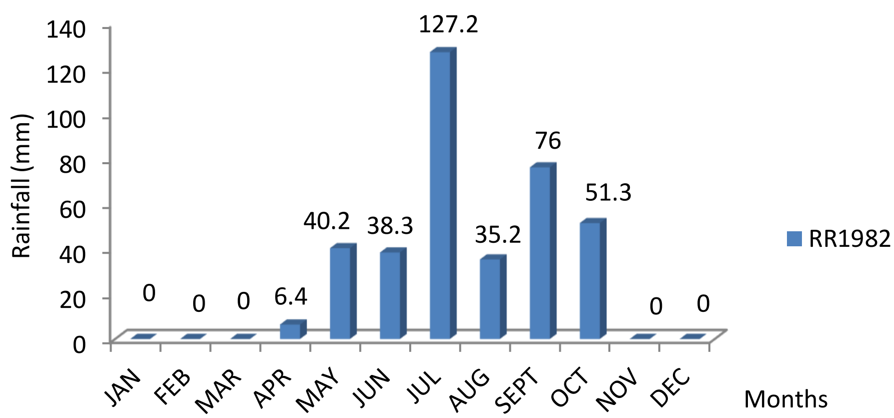

Fig 16b:- Rainfall monthly percentage for Potiskum 1982

For Potiskum, from the rainfall monthly percentage graph in 1973 which is a moderate drought year it was observed again that the months Jan – April and Nov – Dec recorded no rainfall at all 0%, while the months of May contributed 0.8%, Jun 6.9%, Jul 8.6%, Aug 28.5%, Sept 5.7% and Oct 0.09% respectively. And in 1982 which is a severe drought year in Potiskum, the months of Jan – Mar and Nov – Dec recorded 0% rainfall, the months of April recorded 0.8%, May 4.8%, Jun 4.6%, Jul 15.3%, Aug 4.2%, Sept 9.1%, and Oct 6.2% to the total rainfall recorded in 1982 over Potiskum.

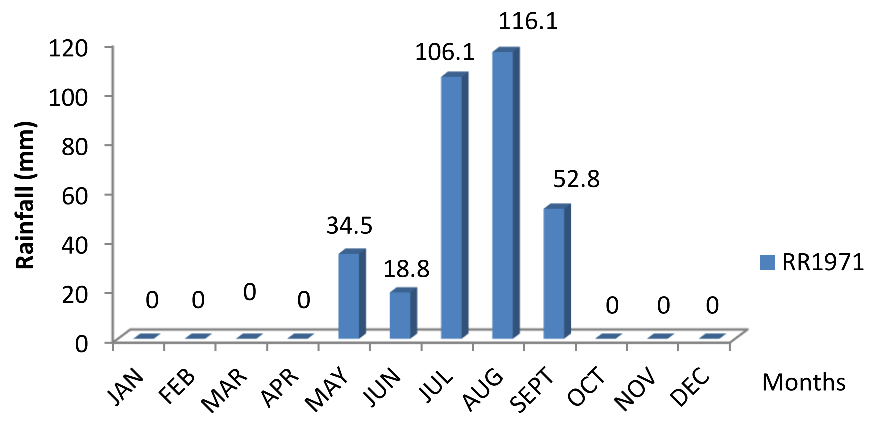

Fig 17a:- Rainfall monthly percentage for Maiduguri 1971

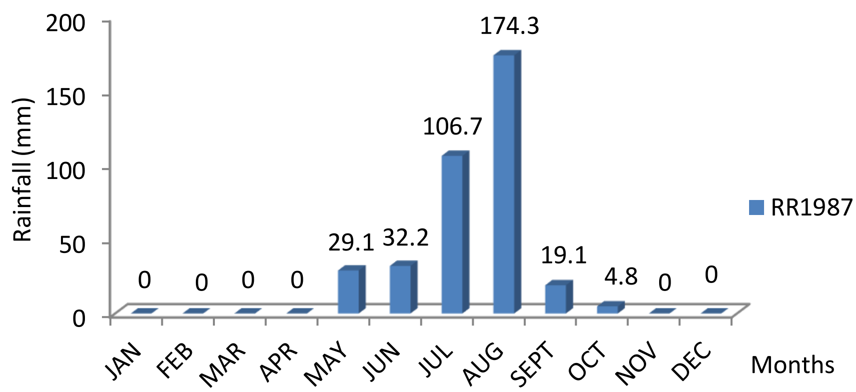

Fig 17b:- Rainfall monthly percentage for Maiduguri 1987

For Maiduguri, from the rainfall monthly percentage graph in 1971 which is a severe drought year in Maiduguri, it was observed that the months of Jan – April and Oct – Dec also recorded 0% rainfall, while the months of May contributed 4.1%, Jun 2.3%, Jul 12.7%, Aug 13.9%, and Sept 6.3% respectively to the total rainfall recorded over Maiduguri in 1971. And in 1987 which is a moderate drought year Jan – April and Nov – Dec also recorded 0%, while the months of May contributed 3.5%, Jun 3.9%, Jul 12.8%, Aug 20.9%, Sept 2.3% and Oct 0.6% respectively.

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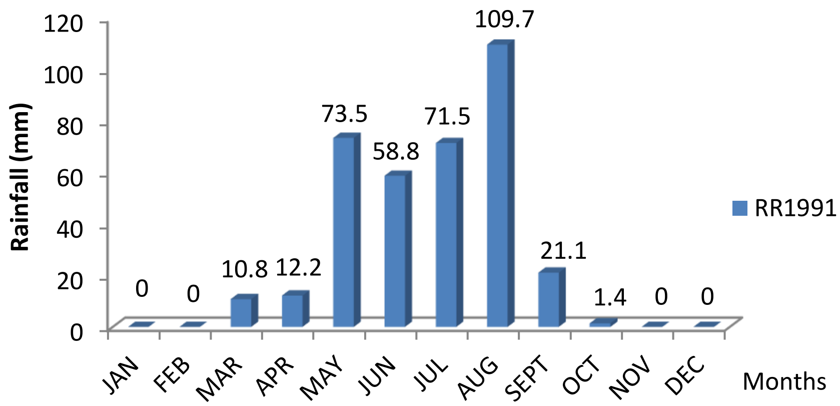

Fig 18a:- Rainfall monthly percentage for Katsina 1991

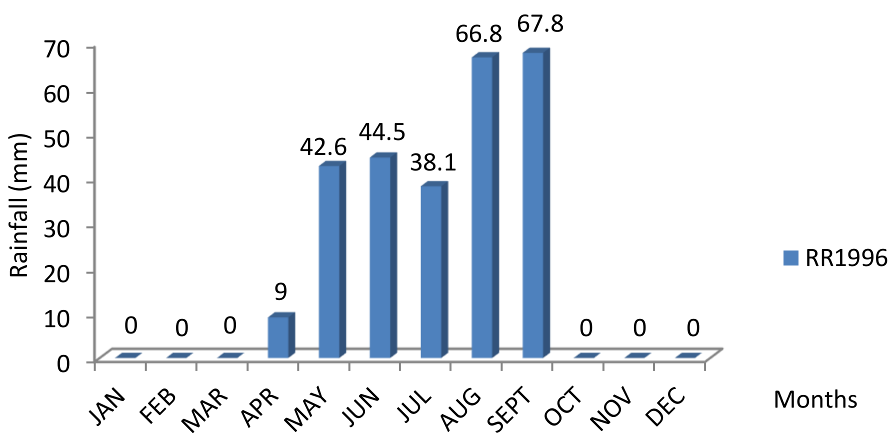

Fig 18b:- Rainfall monthly percentage for Katsina 1996

For Katsina, from the rainfall monthly percentage graph in 1991 which is moderate drought year, it was observed that Jan – Feb and Nov – Dec there was no rainfall recorded at all 0%, and the months March recorded 1.3%, April 1.5%, May 8.8%, Jun 7.1%, Jul 8.6%, Aug 13.2%, Sept 2.5%, and Oct 0.2% respectively. While in 1996 which is a severe drought year, it was noticed that in Jan – Mar and Oct – Dec there was no rainfall recorded 0%, while the months of April recorded 1.1%, May 5.1%, Jun 5.3%, Jul 4.6%, Aug 8%, and Sept 8.1% respectively to the total rainfall recorded over Katsina in 1996.

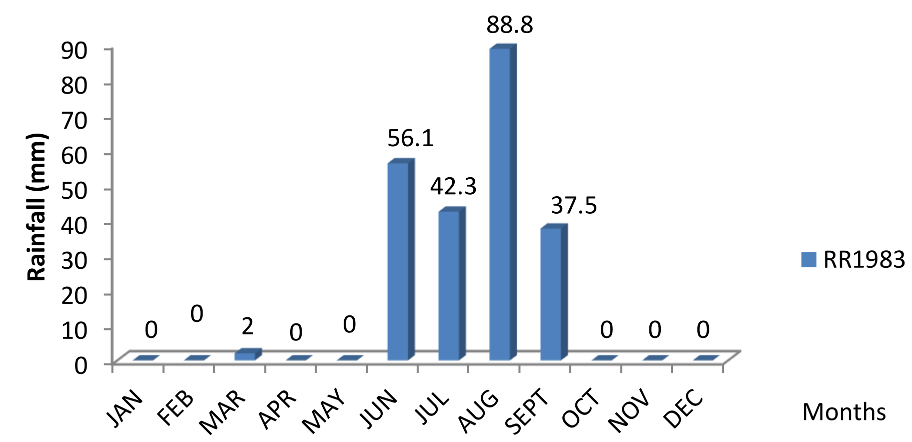

Fig 19a:- Rainfall monthly percentage for Nguru 1983

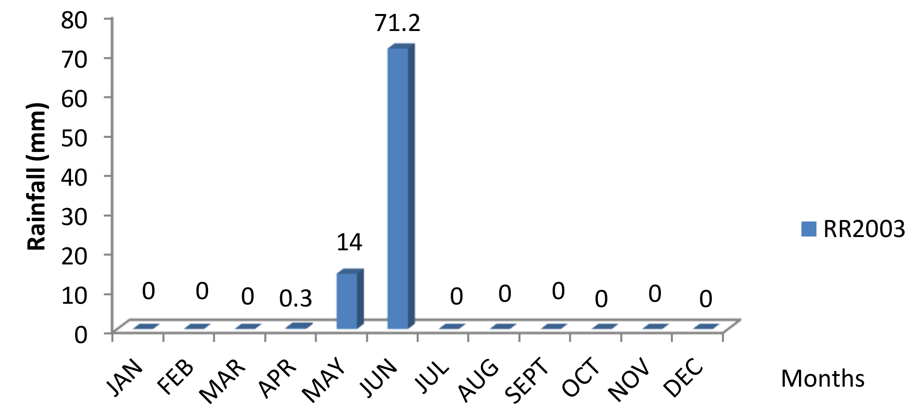

Fig 19b:- Rainfall monthly percentage for Nguru 2003

For Nguru, from the rainfall monthly percentage graph in 1983 which was a moderate drought year, it was observed that in the months Jan – Feb, April – May, and Oct – Dec no rainfall was recorded 0%, and the months of March recorded 0.2%, Jun 6.7%, Jul 5.1%, Aug 10.7% and Sept 4.5% respectively, while in the case of 2003 which was an extreme drought year over Nguru it was observed that Jan – Mar and Jul – Dec recorded 0% rainfall, while April recorded 0.04%, May 1.7%, and Jun 8.5%.

Generally, for all the stations from the analysis it revealed that the months of Jan – April and Oct – Dec are very significant in determining the level of dryness over the region for a year, and it can also be used to predict drought over the Sahel region of Nigeria.

V. CONCLUSION

This study uses SPI as the basis for identifying and classifying the drought years, rainfall record for 5 Sahel station was collected and analyzed, the results shows an increasing trend in rainfall in almost all the stations in Sahel. The months of Jan – April and Oct – Dec are very significant in determining the level of dryness over the region for a year, and it can also be used to predict drought over the Sahel region of Nigeria. Generally speaking, drought has a vast effect on mass starvation, famine and cessation of economic and agricultural activities especially in the Sahel region where rain fed agriculture is the main stay of the rural economy. This effect has forced human migration and environmental refugees, deadly conflicts over the use of dwindling natural resources, food insecurity and starvation, destruction of critical habitats and loss of biological diversity. This study however, validates earlier works by Adefolalu D.O (1986) on the rainfall trend in Nigeria; also Nwokocha Chibueze (2016) on the effect of drought over the northern region of Nigeria, but it is also good to note that there are other factors that may lead to drought such as human causes, global warming etc.

VI. SIGNIFICANT STATEMENTS

This study discovers the most important months that contribute to dryness over the Sahel region of Nigeria, the months of Jan – April and Oct – Dec are very significant and can be used to predict for drought over the region. This study adds to existing knowledge of drought occurrence and intensity and will also help researcher to uncover the years of occurrence of drought over the Sahel region that many studies did not focus on. Hence a new methodology may be arrived at.

VII. ACKNOWLEDGEMENTS

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