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Implications of Trends and Cycles of Rainfall on Agriculture and Water Resource in the Tropical Climate of Nigeria

Alli A. A., Oguntunde P. G., Olufayo A. A. and *Fasinmirin J. T.

Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria

*Corresponding author: E-mail - fasinmirin_johnson@yahoo.com

Abstract

Trends and cycles of rainfall over Nigeria, as well as their implications for water resources and agriculture, have been studied since 1960 on annual, seasonal and monthly bases. Rainfall data of 47 years (1960 – 2006) were obtained for twenty stations over Nigeria for the evaluation of trends using the Mann-Kendall test. Auto correlation spectral analysis was also used to detect cycles of rainfall. The result showed dominant peaks in rainfall return at various rates. For instance, Akure, Benin, Calabar, Maiduguri and Yola stations had decreasing trends of annual rainfall at rates of 1.084, 0.03, 1.80, 0.75, and 0.12 mm/month/yr, respectively with return periods between 1-2 years and 7-10 years. Rainfall trends increased in about 75 % of the locations with return period of dominant peaks varying between 1-2 years and 15 years. Abuja recorded the highest peak of rainfall in the month of October at the rate of 4.7 mm/month/yr with return period of 1-2 years. These results indicate different spatial effects on ecosystem and agriculture. Some of the implications of these trends on agriculture and water resources vary from one station to another, depending on the trends and magnitude of return period of rainfalls. Bauchi and Minna cities are expected to experience serious desertification and complete depletion of underground water due to the effects of no change in trend of rainfall. Meanwhile, agricultural activities are expected to thrive in places like Ibadan, Gusua, Osogbo and others that have moderate increase in trends of rainfall and temperature.

Key words: Rainfall, Trends, Cycles, Mann-Kendall and Auto correlation spectral analysis

Introduction

Climate change is assuming great dimensions but is just one of the factors that put pressure on the hydrological cycle and freshwater ecosystems (Oyebande et al., 2001). Population growth, land use change, change in the industrial sectors, and demands for ecosystem protection and restoration are all exerting pressures simultaneously on the hydrological cycle with various feed-back mechanisms. There is a broad scientific consensus that global climate change is a real problem and that it will alter the hydrological cycle in a variety of important ways (World Resource Institute Report., 2002). The stochastic nature of the complexity and uncertainty of climate change have impacts on the environment (Oyebande,et al.,2001). Cooper (1994) reported that physical change in the hydrological cycles in the case of reduced rainfall or increased evaporations would disconnect rivers from their flood plains and wetlands, slow water velocity in riverine systems and convert them into a chain of connected reservoirs or pools. These in turn would impact the migratory patterns of fish species and the composition of riparian habitat, open the way for exotic species, and contribute to an overall loss of fresh water biodiversity and inland fishery resources (World Resources Institute Report., 2000).

Inter- and Intra-annual variabilities in rainfall are the key climatic elements that determine the success of agriculture and characteristics of water resources in arid and semi-arid regions of Nigeria, where climatic control of soil water availability through rainfall and evaporation are prominent (Okpara and Anuforom, 2004). Alternating periods of variable length of relatively dry and wet years are also common in these regions (Duce et al., 2003). Smith (2000) reported that the great challenges for the coming decades will be the task of increasing food production to ensure food security for vastly growing world population, particularly in countries with limited water and land resources. The dependency on water for agriculture has become a critical constraint for development and threats to food security, which invariably aggravate rural poverty (Crowley, 2000).

Most studies on the subject have investigated the inter-annual time scale over West Africa through the role of surface characteristics (Zheng and Eltahir, 1998), and in particular, the interactions between ocean and atmosphere (Folland et al., 1986; Janicot et al., 2001) which are the basis of seasonal forecasts of rainfall amounts (Ward,1998; Fontaine et al.,1999) with potential benefits to agriculture (Sivakumar et al., 2000). However, the seasonal and intra-seasonal time scales are poorly documented in spites of their importance for agricultural strategy.

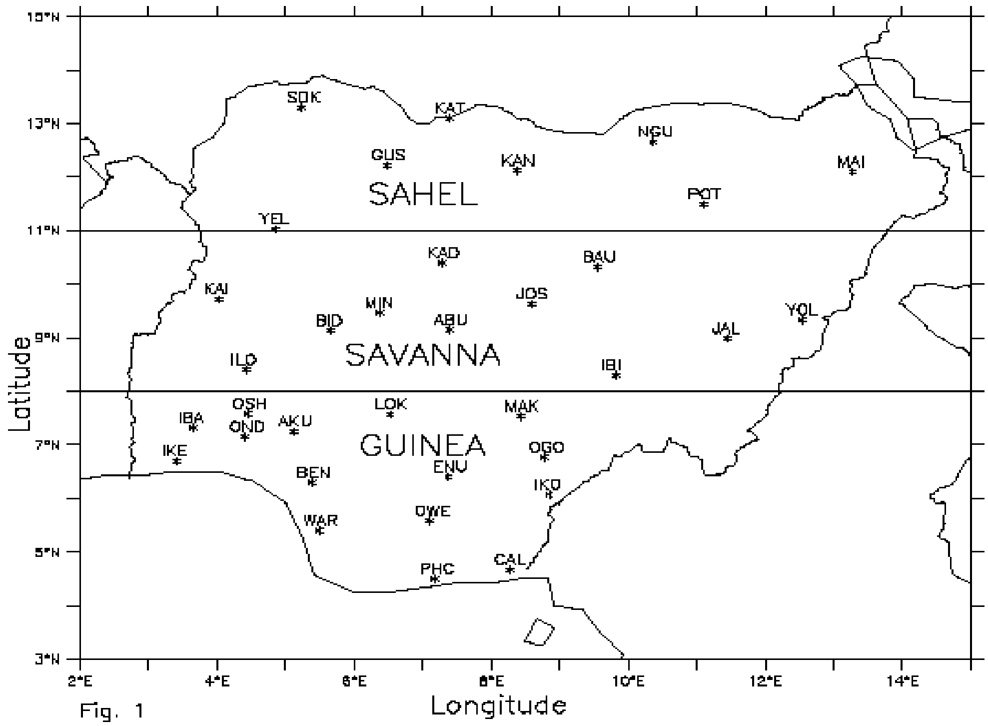
Oguntunde et al (2006) reported that understanding trends and variations of current and historical hydro-climatic variables is important to the future development and sustainable management of water resources in all regions. To achieve long-term water resources planning and management, trends and variability in hydrological variables, especially precipitation, must be quantified. In the recent years several extreme events have caused loss of life, as well as tremendous increase in economic losses from weather hazards. These losses have led to the alarm raised on the possibility that the adverse events were due to a climate change. Furthermore, agriculture that is the mainstay of Nigerian economy depends largely on spatial and temporal distribution of rainfall and temperature. Thus, valuable historical record of hydrologic patterns over a complex terrain such as Nigeria will assist the understanding of anthropogenic and climate effects on the large-scale terrestrial agro-ecosystems. This research therefore was aimed at determining the magnitude, periodicity and the presence of significant monotonic increase and decrease in trends of rainfall over the tropical climate of Nigeria.

Materials and Methods

Study Area

Nigeria is located in West Africa between latitude 4^0 N and 14^0N and between longitudes 2^0 E and 15^0 E. It has a total area of 925,796 km^2. The ecological zones of the country are broadly grouped into three, which are; Sahel, Savannah and the Guinea zones as shown in Figure 1. Nigeria is affected by the Tropical Continental and Tropical Maritime air masses. The Tropical Continental is responsible for the dry season while the Tropical Maritime is responsible for the rainy season. The intervening periods of transition from the real onset and cessation of rain falls between February and April and between September and November respectively. Also a depression is indicated in the rainfall amount during the month of August and this has been named “the little dry season” or “August break” or “midsummer” (Adefolalu, 1972; Fasinmirin and Olufayo, 2008). The onset of rainy season begins about April and ends in late October or early November every year. The dry season begins in early November and ends in March. The mean monthly rainfall for November is about 54 mm while it could be very low (between 0 – 12 mm) in January. The climate is semi-arid in the north and humid in the south with rainfall average below 750 mm and over

1500 mm in the dry north and humid south, respectively. It rains almost all year round with highest peak in the period of June to September. About two thirds of the cropped area of Nigeria is in the north, with the rest of the cropped areas distributed between the middle belt and the south. According to the results of 2006 census, Nigeria is by far the most populous country in Africa, with over 140 million in population and population density of



138 inhabitants per km^2

Figure 1. Map of Nigeria showing ecological zones.

Data Sourcing and Analysis

The data used for this study were collected from the Nigerian Meteorological Service, Oshodi, Lagos. Data on rainfall are available between 1960 and 2006 (47 years) for twenty (20) stations scattered across the northern and southern areas of Nigeria. Data collected were processed and used on annual, monthly and seasonal basis for analytical convenience. The seasons are April, May and June (AMJ); July, August and September (JAS) and October, November and December (OND). The fourth season, which is January, February and March (JFM), was assumed to be a period of no rainfall and therefore neglected. The Mann-Kendall test was applied when the data values *xi* of a time series can be assumed to obey the model;

$$\chi = f(t) + \sum \tau \qquad (1)$$

where χ is the data value, *f(t)* is a continuous monotonic increase or decrease function of time and the residual (□*t*) was estimated from the same distribution with zero mean. The Mann-Kendall test statistic *S* was calculated as described in Oguntunde et al (2006), using the formula.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \tag{2}$$

where x_j and x_k are the annual values in years *j* and *k*, *j* > *k*, respectively, and

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma^2(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{\sigma^2(S)}} & if \quad S < 0 \end{cases} \tag{3}$$

The variance of S is computed by Equation 4 to take care of ties that may be present.

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \tag{4}$$

where *q* is the number of tied groups and *tp* is the number of data values in the *p*th group. The presence of a statistically significant trend is evaluated using the *Z* value. The positive and negative values of *Z* indicate upward and downward trends, respectively. The statistic *Z* has a normal distribution. The Sen's nonparametric method was used to estimate the true slope of the trend (change per year). The Sen's method was used in cases where the trend was assumed linear i.e. where *f (t)* in Equation (1) becomes:

$$f(t) = Qt + B \tag{5}$$

where Q is the slope and B is a constant.

Fourier transform was used to convert a continuous time signal into the frequency domain. The Fourier transform *X(f)* of a continuous time function *x(t)* was described in Oguntunde et al. (2006) and can be expressed as;

$$X(f) = \int_{-\infty}^{\infty} x(t)\, e^{-i\,2\pi f t}\, dt \tag{6}$$

The inverse transform is given as

$$x(t) = \int_{-\infty}^{\infty} X(f)\, e^{i\,2\pi f t}\, df \tag{7}$$

The discrete Fourier transform was used in the case where both the time and the frequency variables are discrete. The Discrete Fourier Transform (DFT) is given by:

$$X(mF) = \sum_{n} x(nT)\, e^{-inm\,2\pi FT} \tag{8}$$

where *X*(*n*T) represents the discrete time signal, and X(*m*F) represents the discrete frequency transform function.

where

$$x(nT) = \frac{1}{N}\sum_{m} X(mF)\, e^{inm\, 2\pi FT} \tag{9}$$

Results and Discussions

Peaks and Monthly Trends of Rainfall

The summary of the Mann-Kendall and Auto-correlation spectral analysis of rainfall data from 20 meteorological stations in Nigeria is presented in Table 1. The Table shows that Abuja recorded a peak annual rainfall of 4.66 mm/mo/yr in the month of October with a cycle of 3-5 years, followed by Ibadan that has a peak annual rainfall of 2.614 mm/mo/yr in the month of July with a cycle of 5-7 years. Benin recorded the lowest peak annual rainfall of 0.003 mm/mo/yr in the month of August with a cycle of 3-5 years.

Tables 3 and 4 show the Mann-Kendall test statistics of monthly rainfall for Abuja, Akure and Bauchi stations in the north-central, south-west and north-west regions of Nigeria respectively. In Abuja, the months of January, November and December showed no change in trends of rainfall while the months of August, September and October were increasing in rainfall at the rate of 1.78 mm/mo/yr, 1.273 mm/mo/yr, and 4.660 mm/mo/yr respectively. The results show that the highest rainfall occurred in the month of October. In Akure, the months of January and December showed no change in trend of rainfall while months of October and November were increasing in trends of rainfall at the rate of 1.083 mm/mo/yr and 0.436 mm/mo/yr repectively. The months of February, March, April, May, June, July, followed by August and September were decreasing in rainfall at the rate of 0.888 mm/mo/yr, 1.375 mm/mo/yr, 0.609 mm/mo/yr, 1.392 mm/mo/yr, 0.5 mm/mo/yr, 0.263 mm/mo/yr, 1.264 mm/mo/yr and 0.963 mm/mo/yr respectively with various significance levels. The results show that the month of October experienced the highest rainfall. In Bauchi, the months of January, February, March, June, July, October, November and December showed no change in trend of rainfall while the month of September decreased in rainfall at the rate of 0.335 mm/mo/yr. The months of April, May, and June were increasing at the rate of 0.15 mm/mo/yr, 0.221 mm/mo/yr and 1.139 mm/mo/yr respectively. The results showed that the month of June experienced the highest change in rainfall.

Inter-Annual Trends of Rainfall and Temperature

The residual mass curve of Abuja, Akure and Bauchi monthly rainfalls is shown in Figures 2 - 4. There was decrease in annual rainfall from 1980 until 2000 and thereafter the trend became positive. The highest rainfall occurred in 1965 and 2004. Decrease in rainfall was observed in AMJ months in the last two decades while JAS months experienced increase in rainfall in the last two decades with highest rainfall in early 2000. In OND months, increase in rainfall was observed in 1978 until 2006 with highest rainfall in 1980. In Akure, an increase in rainfall was observed for the last two decades. The AMJ months was characterized by negative trend in rainfall for the last one and half year. Negative trend of rainfall was observed in JAS months in the last decade, while rainfall increase was observed in the last one and half decades during the OND months.

Figure 4 shows the residual mass curve of rainfall for Bauchi. Decrease in annual rainfall was experienced between 1975 and 1980 and afterwards increased until late 1990s before decreasing monotonic trend set in again. AMJ months experienced slight increase in rainfall in the last two and half decades. JAS months experienced decrease in rainfall from 1960s to

1980 and started increasing until 1990 when negative trend set in. OND months had decreases in rainfall since the last two and half decades

Table 1: The Summary of the Result of Mann-Kendall and Auto-correlation Spectral Analysis of Rainfall in 20 Stations over Nigeria

Stations	Rainfall Peak (mm/month/yr)/month	Annual Rainfall cycles (years)
Abeokuta	1.76 / May	1-2 yrs
Abuja	4.66 / October	3-5 yrs
Akure	-1.084 / October	2 & 20-25 yrs
Bauchi	1.139 / June	3-5 & 13-15
Benin	-0.033 / August	3-5
Calabar	-1.97 / October	6-7
Enugu	0.18 / July	2-3 & 3-4
Gusua	0.10 / August	1-2 & 3-4
Ibadan	2.614 / July	5-7
Ikeja	0.753 / April	1-2 &7-10
Iseyin	0.45 / April	3-5
Lagos	0.82 / June	1-2
Maiduguri	-0.75 / June	1-2 & 3-4
Minna	0.2 / June	5-6
Oshogbo	2.196 / September	1-2 &3-4
PortHarcourt	1.138 / October	5-6 & 8-10
Sokoto	0.867 / July	1-2, 4-5 & 13-15
Warri	1.133 / March	2-3
Yelwa	0.33 / May	1-2 & 3-4
Yola	-0.1 / July	4-5

-ve and +ve signs show decreasing and increasing trends respectively.

Table 2: Mann-Kendall test statistics for monthly rainfall and mean monthly temperature for Abuja station

Time series	First year	Last year	Test Z	Slope Q
			Rain	Rain
Jan	1960	2006	-1.77*	0.000
Feb	1960	2006	-2.21*	-0.124
March	1960	2006	4.54***-	-1.538
April	1960	2006	-3.94***	-1.904
May	1960	2006	-2.35*	-1.961
June	1960	2006	-2.05*	-2.129
July	1960	2006	-0.28	-0.380
Aug	1960	2006	2.07*	1.780
Sept	1960	2006	1.56	1.273
Oct	1960	2006	5.51***	4.660
Nov	1960	2006	2.00*	0.000
Dec	1960	2006	-2.07*	0.000

*** if significance level (a) is 0.001, ** if (a) is 0.01, * if (a) is 0.05, + if (a) is 0.1

Table 3: Mann-Kendall test statistics for monthly rainfall for Akure station

Time series	**First year**	**Last year**	**Test Z** Rainfall	**Slope Q** Rain
Jan	1960	2006	-0.56	0.000
Feb	1960	2006	-1.73+	-0.888
March	1960	2006	-1.58	-1.375
April	1960	2006	-1.30	-0.606
May	1960	2006	-1.62	-1.392
June	1960	2006	-0.83	-0.500
July	1960	2006	-0.68	-0.268
Aug	1960	2006	-1.45	-1.264
Sept	1960	2006	-1.78+	-0.963
Oct	1960	2006	1.45	1.083
Nov	1960	2006	1.34	0.436
Dec	1960	2006	0.41	0.000

*** if significance level (a) is 0.001, ** if (a) is 0.01, * if (a) is 0.05, + if (a) is 0.1

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Table 4: Mann-Kendall test statistics for monthly rainfall for Bauchi station (Savannah zone)

Time series	First year	Last year	Test Z Rainfall	Slope Q Rainfall
Jan	1960	2006		
Feb	1960	2006		
March	1960	2006		
April	1960	2006	1.03	0.150
May	1960	2006	0.74	0.221
June	1960	2006	1.26	1.139
July	1960	2006	-0.12	0.000
Aug	1960	2006	0.27	0.000
Sept	1960	2006	-0.78	-0.335
Oct	1960	2006	0.14	0.000
Nov	1960	2006		
Dec	1960	2006		

** if significance level (a) is 0.01, * if (a) is 0.05.

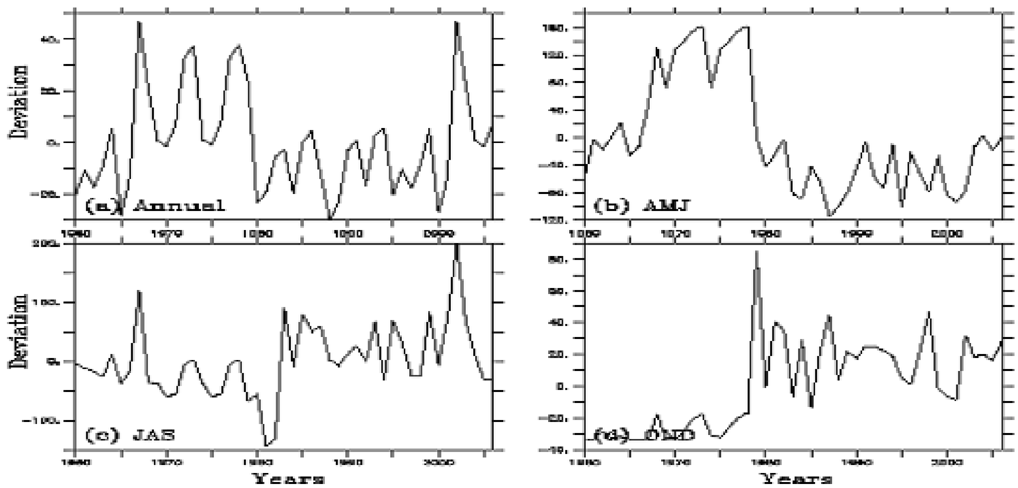

Figure 2: Residual mass curve of Abuja monthly rainfall for, (a) Annual, (b) AMJ, (c) JAS & (d)

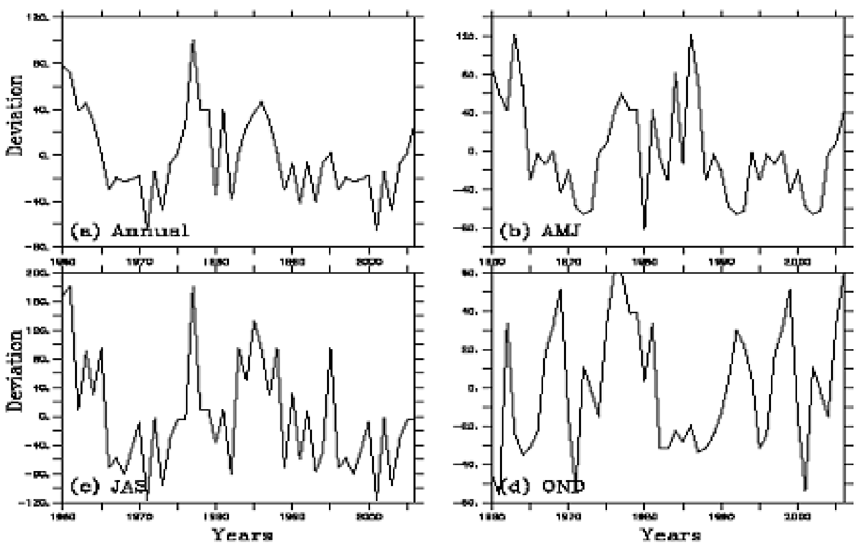

Figure 3: Residual mass curve of Akure monthly rainfall for (a) Annual (b) AMJ (c) JAS & (d) OND

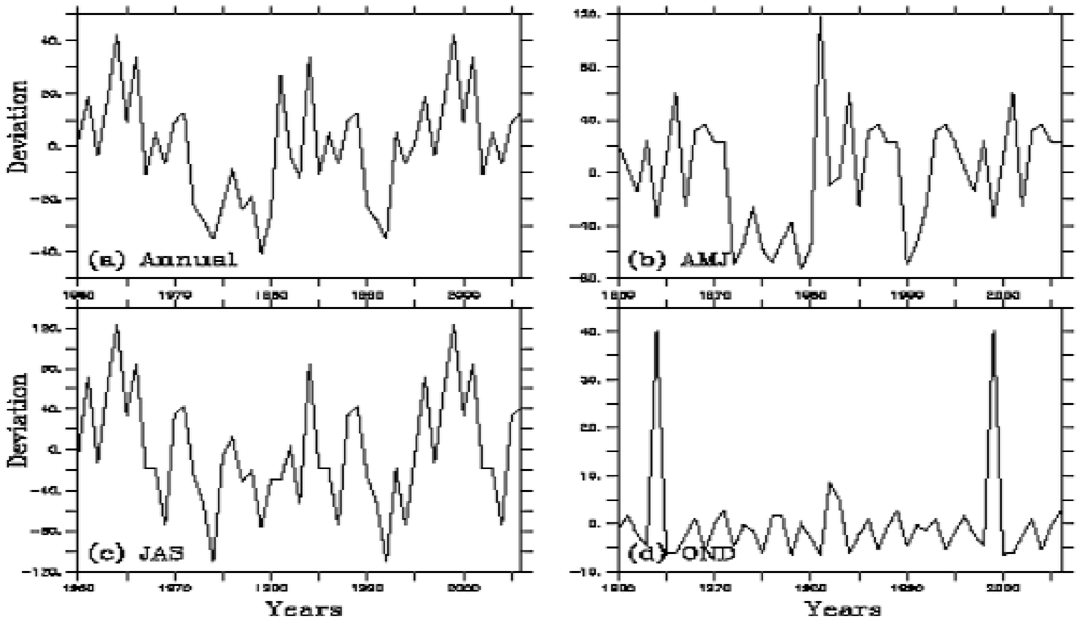

Figure 4: Residual mass curve of Bauchi monthly rainfall for (a) annual (b) AMJ (c) JAS & (d) OND

Rainfall Cycles over Nigeria

Figure 5 shows the Auto Correlation Spectral Analysis of Abuja monthly rainfall for (a) annual (b) AMJ (c) JAS (d) OND. The annual rainfall was characterized with a dominant peak of 3-5 years as return period. AMJ monthly rainfall have dominant peak of 6-8 years return period. JAS monthly rainfall have dominant peak of 5-7 years return period, while OND monthly rainfall have dominant peak of 10-12 years as return period. Figure 6 shows auto correlation spectral analysis (ASA) of Akure monthly rainfall for (a) annual (b) AMJ (c) JAS (d) OND. AMJ and annual rainfall have dominant peaks of 15 and 25 years as return period, while JAS and OND had dominant peaks of 20-22 and 22-25 years, respectively as return periods.

Auto Correlation Spectral Analysis for Bauchi monthly rainfall is presented in Figure 7. Annual dominant peak of rainfall has return period of 13-15 years. AMJ dominant peak of rainfall has 20-23 years as return period, while JAS and OND had return periods of 5-6 and 2-3 years, respectively.

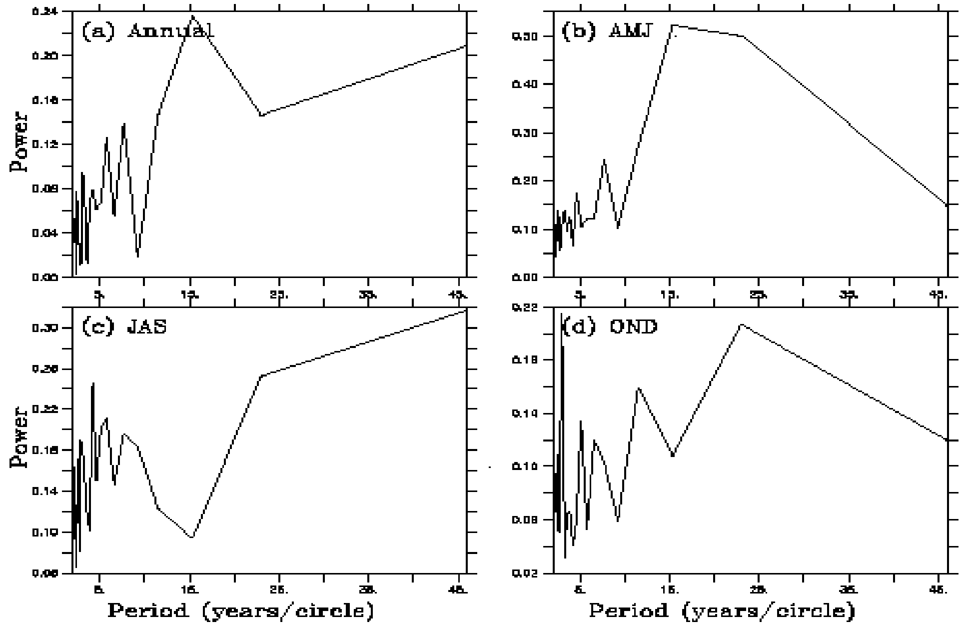

Figure 5: Auto Correlation Spectral Analysis of Abuja monthly rainfall for; (a) Annual (b) AMJ (c) JAS and (d) OND

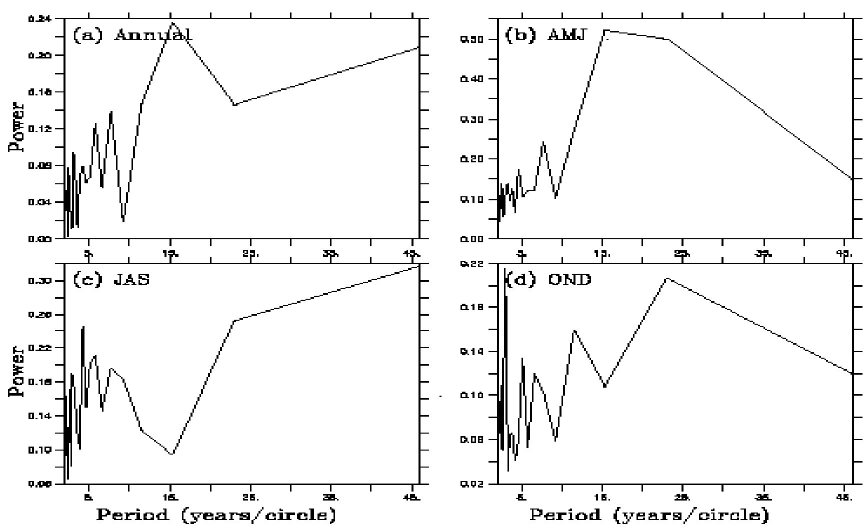

Figure 6: Auto Correlation Spectral Analysis of Akure monthly rainfall for; (a) Annual (b) AMJ (c) JAS & (d) OND

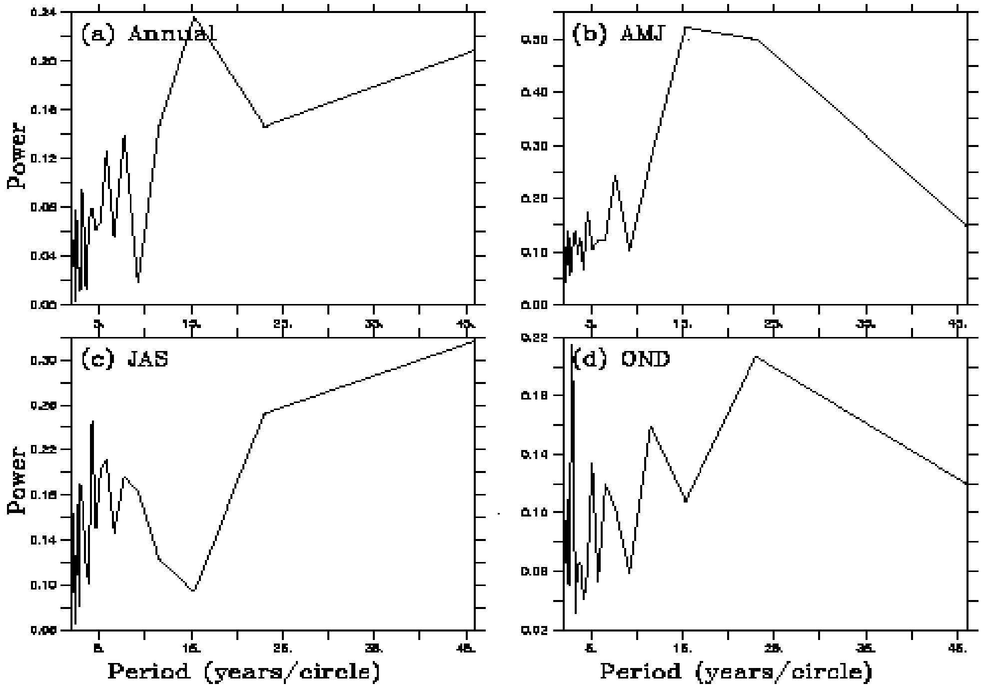

Figure 7: Auto Correlation Spectral Analysis of Bauchi monthly rainfall for; (a) Annual (b) AMJ (c) JAS (d) OND

Discussion

Drastic changes were observed in the trends of rainfall in the twenty locations covered in this study. Locations which were predominantly known for upward or downward trends of rainfall as the case may be now experience the reverse. The results showed specifically that Akure and Maiduguri stations were decreasing in trends of rainfall with magnitude of return period put at an average of 2 years. On the other hand, Osogbo, Port Harcourt, Sokoto, Warri and Yelwa stations experienced upward trends of rainfall on annual basis. Stations that experienced downward trends of rainfall are Abuja, Benin, Calabar, Lagos and Yola. Abeokuta, Enugu, Ikeja and Iseyin experienced upward trends in rainfall, while Minna and Bauchi stations experienced no change in trend.

Precipitation was noticed to be decreasing in the last two decades (Tosic and Unkasevic, 2000; Oguntoyinbo, 1979). Subbaramayya and Naidu (1992) made a detailed analysis of the monsoon rainfall for various sub-divisions of India using data for 1871-1988. They documented a decreased trend of rainfall till the end of the previous century followed by an increase trend till the middle of the 20th century. Afterwards, rainfall trends started decreasing from 1970 to end of the year under study. In a nutshell, there was a decrease in trends of rainfall in the last two and half decades. Rainfall remains an important meteorological parameter which has direct influence on agricultural production and other aspects such as water resource (Maidu et al, 1999). Temperature and rainfall are principal

controlling elements which determine the growing season and timing of agricultural activities most especially in Nigeria, as well as in other tropical regions (Odekunle, 2004).
The implications of the findings of this study on both agriculture and water resource are summarized in the Table 5. The stations that experienced downward trends in rainfall and temperature had the tendency of facing problems of drought and shortage of soil moisture. Akure, Benin and Maiduguri stations were under this category. Other stations that experienced upward trends of temperature and downward trend of rainfall may have experienced desertification and serious depletion of underground water. Abuja, Calabar, Lagos and Yola stations were under this category but the effect of desertification and depletion of underground water is more felt in Abuja and Yola than in Calabar and Lagos due to sharp variations in increasing trend of temperature and decreasing trend of rainfall. Stations that experienced upward trends of both temperature and rainfall tended to have fair and clement weather conditions for agricultural activities. Gusua, Ibadan, Osogbo, Port Harcourt, Sokoto, Warri and Yelwa fall under this category except that Port Harcourt, Sokoto and Warri are more prone to flood due to high intensity of rainfall. Mean while, Bauchi and Minna stations are prone to serious desertification and complete depletion of underground water because of no change in trend of rainfall and continuous monotonic increase in the trend of temperature.
IITA Annual Report (1992) stated a declining annual rainfall in Nigeria over both time and space with reductions of 100 - 313 millimeters. The shift in balance between increasing temperature trend and decreasing rainfall trend may affect the crops that can be grown on residual soil moisture, which may render post rainy season cultivation extremely risky without supplemental irrigation.

Table 5: Summary of the Implications of the study on Agriculture and Water Resource

Trends Status	**Stations under the Category**	**Implications on Water Resource and Agriculture**
Decrease in temperature and rainfall trends	Akure, Maiduguri	Drought and shortage of moisture content are probable in the stations. Benin is inclusive.
Increase in temperature and rainfall trends	Oshogbo, P/Harcourt, Sokoto, Warri, and Yelwa	Fair weather for Agriculture in the stations, except that Warri, Ibadan and P/Harcourt are likely to experience flood due to excess rainfall
Increase in temperature and decrease in rainfall	Abuja, Benin, Calabar, Lagos and Yola	Desertification and high level of under ground water depletion are probable.
Decrease in temperature and increase in rainfall	Abeokuta, Enugu, Ikeja, and iseyin	Flood is probable.
Increase in temperature and zero trend of rainfall	Minna and Bauchi	Desertification and high level of under ground water depletion are probable

Conclusion

Trends and cycles of rainfall over Nigeria were determined through Auto correlation spectral analysis and Mann-Kendall non-parametric test. There were variations in the rainfall distributions on annual and monthly basis over Nigeria. The rates at which dominant rainfall peaks return also vary, impacting differently on climate and agriculture. Areas experiencing positive trends and dominant temperature peak of short return period will likely be prone to drought and desertification and therefore adequate drought and desertification management as well as irrigation scheme must be put in place to supplement the shortfalls that may be experienced during cropping season. However, areas that had positive trends and dominant rainfall peak of short return period will likely be prone to flood and therefore flood control measures must be put in place to check erosion hazards.

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