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Correlogram Analysis of Trends and Cycles in Rainfall Over Southeastern Nigeria

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Abstract: Water resources in Southeastern Nigeria mainly depend on rainfall which is subject to great variability. Since, the wake of urbanization water use in the region has increase resulting in change in hydrological cycle. This study investigated the characteristics of oscillations that appear in the time series of annual rainfall amounts in Southeastern Nigeria with a view to predicting rainfall extremes. The analysis was carried out using the Autocorrelation Function Method. It was found that no significant trend was observed in all the climatic stations expect for Uyo within the periods of study (1982-2005). A general increase in annual rainfall amount was identified in almost all the stations from 1980 up to the end of the 20th century followed by a gradual decline or steady slope in the trend line of rainfall amounts. The study showed that highest rainfall amounts were mostly recorded between 1995 and 1997. From the correlogram analysis, a sequence of 4 years (Onitsha), 4, 6 and 15 years (Owerri), 5 years (Enugu), 3 years (Port-Harcourt), 1 year (Uyo), 10 years (Calabar), 1 year (Ikom) and 8 years (Ogoja) periodicities in cycles of high rainfall were determined in the study area. Cycles in rainfall deficiencies on the other hand yielded periodicities sequence of 10 and 11 years (Onitsha), 8 and 14 years (Owerri), 14 years (Enugu), 4, 7 and 10 years (Port-Harcourt), 12 years (Uyo), 12 years (Calabar), 3 years (Ikom) and 3 years (Ogoja). From the sequence of periodicities of cycles for rainfall deficiencies over Southeastern Nigerian similarities was observed between Uyo and Calabar and between Ikom and Ogoja pointing to the unique physical factors controlling the rainfall of these areas. Finally, results of the analysis are expected to provide information that would be helpful in formulating policies for mitigating flooding and drought in the region.

Key words: Cycles, periodicities, rainfall, flood, drought, Nigeria

INTRODUCTION

Rainfall, unlike many other meteorological elements such as temperature and pressure is non-continuous in time and space with very high variability. As a result, the statistical description of rainfall depths and occurrences is quite complex (Kavvas and Delleur, 1975).

Rainfall patterns usually have spatial and temporal variabilities. These variabilities affect the agricultural production, water supply, transportation, the entire economy of a region and the existence of its people (Oduro-Afriyie and Adukpo, 2006). In West Africa, Washington *et al.* (2006) have shown that rainfall is of paramount importance in the socio-economic life of the people and has also been described as the most significant climatic determinant of the landscape in terms of natural vegetation and land use activities. The spatial and temporal variability of precipitation has long generated considerable interest in natural sciences (Ishihara and Ikebuchi, 1973; Woolhiser *et al.*, 1973; Winkler *et al.*, 1988). Understanding the spatial and temporal of rainfall variability is important element in gaining knowledge of water balance dynamics on various scales for water resources management and planning. In regions where the year to year variability is high, people often suffer great calamities due to floods or droughts.

As the agriculture of developing countries increasingly advances, the impact of rainfall on day to day operations increased. The economy of West Africa is predominantly agro-based and subsistence farming occupies almost 90% of the people (El-Khawas, 1976). In agriculture practice, rainfall amount in terms of spatial and temporal distributions assume significance in the region for determining the extents, adequacy and dependability of water supply for irrigation as well as in nearly every phase of the timing of cultivation, planting and harvesting operations, variety selection and transplantation. Climate, water resources, biophysical and socio-economic systems are interconnected in complex ways so, a change in any one of these induces a change in another. Anthropogenic climate change adds a major pressure to nations that are already confronting the issue of sustainable freshwater use Parry and IPCC (2007). Climate warming observed over the past several decades is consistently associated

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with changes in a number of components of the hydrological cycle and hydrological systems such as changing precipitation patterns, intensity and extremes, widespread melting of snow and ice, increasing atmospheric water vapour, increasing evaporation and changes in soil moisture and runoff characteristics (Huntington, 2006). Floods have been the most reported natural disaster events in many regions affecting 140 million people per year on average (Walter, 2003, 2004). Flooding during the monsoon season causes heavy human and economic losses in West Africa countries bordering the Niger river and its tributaries.

In 1997 when the authority of NEPA (National Electricity Authority of Nigeria) opened the spillway gates of the Kainji dams to let out excess water at peak of rain, this resulted in flooding of downstream communities. The floods caused great damages and untold hardships to lives and property downstream. The occurrence of the flood had great effect on Bacita sugar cane fields downstream of Jebba dam and farming activities downstream of Shiriro dam. The cost of rehabilitation in 1994, 1998 and 1999 due to the effect of flood at Bacita sugar irrigation field was about $10.8 million (Sule *et al.*, 2009).

Similarly, Lawal and Nagya (1999) showed that the effect of the Kainji flood at Mokwa, Rabba and its environs between 1994 and 1998 destroyed properties worth >₦500 million and submerged several houses, farmland and crops and disrupted social services. Apart from floods, droughts have become more common, especially in tropics since the 1970's. Decreased inland rainfall and increased temperatures which enhance evapotranspiration and reduce soil moisture are important factors that have contributed to more regions experiencing drought as measured by the Palmer Drought Severity Index (PDSI) (Dia *et al.*, 2004).

Generally, research has shown that there is still substantial uncertainty in trends of hydrological variable because of large regional difference and because of limitations in spatial and temporal coverage of monitoring networks (Huntington, 2006). According to Nicholls (1980) damage due to extremes of rainfall cannot be avoided completely yet a forewarning could certainly be useful (Oduro-Afriyie and Adukpo, 2006). Identification of cycles and periodicities in environmental data is important as an aid to prediction and adaptation of suitable responses. More so, it helps in determining the causative factors of these fluctuations.

Even when rainfall patterns fall within seasonal expectations, short-range precipitation forecast can be a major importance. More so although, accurate rainfall forecast cannot prevent flooding, they help to provide advance warming, so that people and governments can be better prepared (Diallio and Frank, 1986). Methods of prediction of rainfall extremes have often been based on studies of physical effects of rainfall or on statistical studies of rainfall time series. Lansford (1977) reported a study of tree rings in USA and concluded that a 20-22 years periodicity was evident indicating a possible drought in the 1990s. Trends in land precipitation have also been analyzed using a number of data set; notably the Global Historical Climatology Network (GHCN: Peterson and Vose, 1997), Precipitation Reconstruction over Land (PREC/L: Chen *et al.*, 2002), the Global Precipitation Climatology Project (GPCP: Robert *et al.*, 2003), the Global Precipitation Climatology Centre (GPCC: Beck *et al.*, 2005) and the Climatic Research Unit (CRU: Mitchell and Jones, 2005).

In recent years, annual rainfall series have been studied for detection of periodicities mostly by the Autocorrelation Method of Blackman and Tukey (1958). Nicholson and Entekhabi (1986) conducted a detailed power spectrum analysis of African rainfall series using Blackman-Tukey and Fourier Methods. Their analysis revealed quasi-periodicities clustered in four bands at 2.2-2.4, 2.6-2.8, 3.3-3.8 and 5.0-6.3 years, common throughout equatorial and Southern Africa but only weakly evident in Northern Africa. Other workers (Tabony, 1979; Kane and Trivedi, 1982) have used the sophisticated method of Maximum Entropy Spectral Analysis (MESA), formulated by Burg (1967) and reviewed by Ulrych and Bishop (1975). Periodicities ranging from 2-3 years (Quasi-Biennial Oscillation) to several tens of years with varying amplitudes have been reported for various regions. Many researchers are inclined to conclude that the series are random or quasi-random and quasi-stationary (Winstanley, 1973a; Nicholson, 1980).

Water resources in Southeastern Nigeria mainly depend on precipitation which is subject to great variability. Meanwhile water use in the region has increased over recent decades due to population and economic development, change in lifestyle and expanded water supply systems with irrigation water use being by far the most important cause. The challenges related to water resources in the Southeastern Nigeria include having too much water having too little water and having too much polluted water. With a universal concern about the variability of climate and rainfall, coupled with increasing pressure on natural resources, more research is necessary on the spatial and temporal variability of precipitation, the amount of precipitation per occurrence, the variations between dry and wet season precipitation as well as the impacts of these variabilities on agriculture and other aspects of water uses. In this study, spatial variability in annual rainfall time series was investigated for climatic stations for Southeastern Nigeria. The aim is to determine the characteristics of oscillations that appear in the time series of annual rainfall amounts with a view to predicting rainfall extremes in the region.

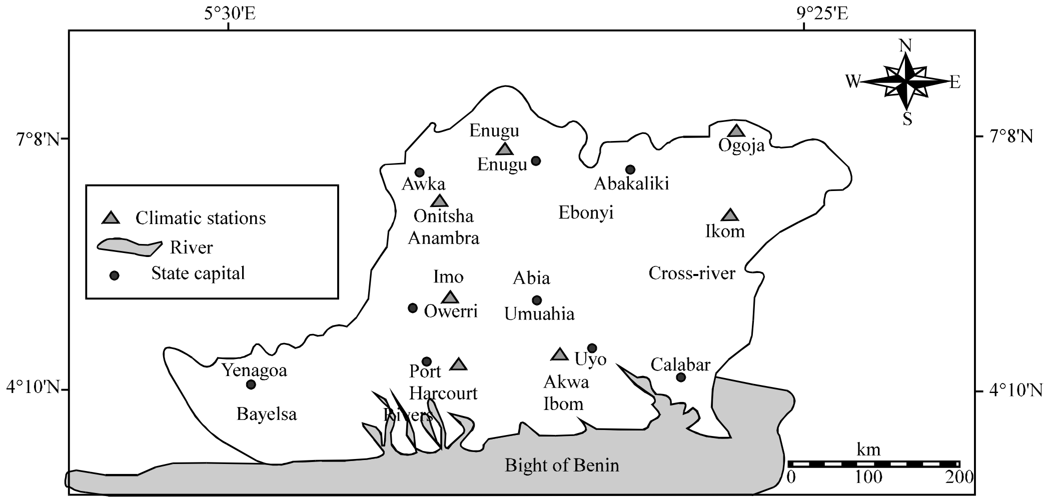

Fig. 1: Southeastern Nigeria showing climatic stations

MATERIALS AND METHODS

Rainfall data for the periods of 24 years (1982-2005) from eight climatic stations over Southeastern Nigeria were used for the study (Fig. 1). These stations are Enugu, Owerri, Onitsha, Port Harcourt, Uyo, Ikom, Ogoja and Calabar.

These data were collected from the Nigeria Meteorological agency, Oshodi Lagos. In this study, statistical technique is the main tool used for identifying fluctuations, tends and cycle in the annual rainfall pattern.

Fluctuations of annual rainfall at different synoptic stations and a 4 years smoothing sequence were achieved using the Microsoft Office Excel Function. To investigate for trends in the time series of rainfall amounts, simple scatter plots were conducted using the Statistical Package for Social Sciences of Version 17. The Pearson product moment correlation was used to determine the strength and direction of trends in annual rainfall patterns while the Student t-test was used to test for significance of observed trends. Cycles and periodicities in inter-annual rainfall variability was arrived at using the Autocorrelation function of Independence Model (Blackman and Tukey, 1958).

RESULTS AND DISCUSSION

In Fig. 2-9, pattern of fluctuations in time series of annual rainfall over Southeastern Nigeria have been presented. From the Fig. 2-9, variations in annual rainfall were observed from one synoptic station to another on a 4 years moving average.

In Fig. 2-4 and 6, a general rise in rainfall amounts were observed reaching peaks towards the end of the 20th century before receding. In Fig. 5, 7 and 8 trends in fluctuations in rainfall amounts were observed to be gentle from 1982-1995 but show a noticeable increase towards the remaining parts of the 20th century before decline. Figure 9 is characterized by marked variation in annual rainfall. Two peaks periods were identified; first is between 1990-1994 and 1995-2000. As with other stations, there was gradual decline in rainfall amounts

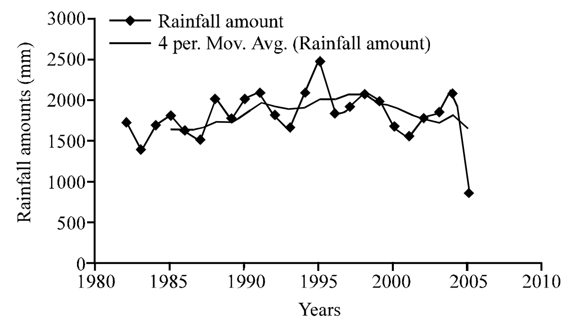

Fig. 2: Fluctuations in annual rainfall of Onitsha and smoothed sequence

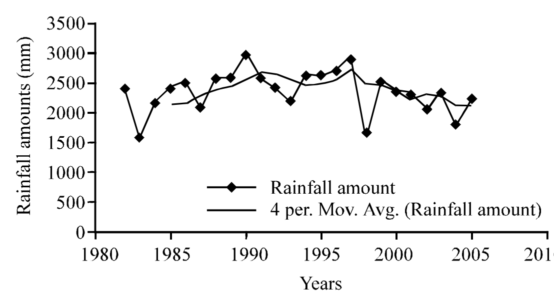

Fig. 3: Fluctuations in annual rainfall of Owerri and smoothed sequence

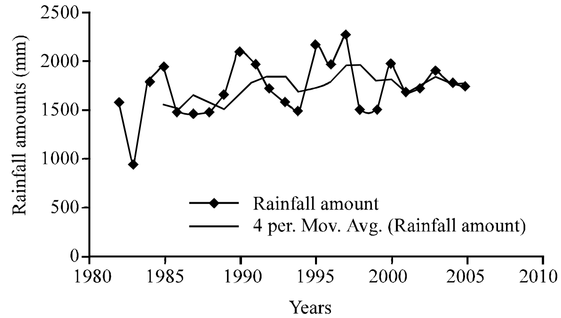

Fig. 4: Fluctuations in annual rainfall of Enugu climatic station and smoothed sequence

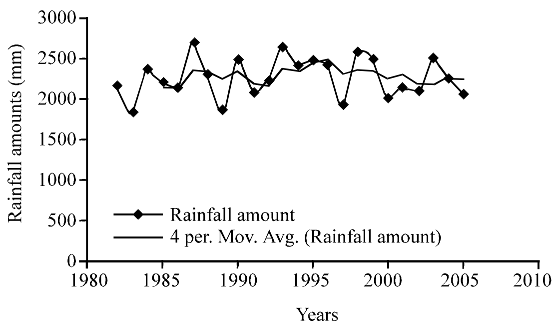

Fig. 5: Fluctuations in annual rainfall of Port-Harcourt and smoothed sequence

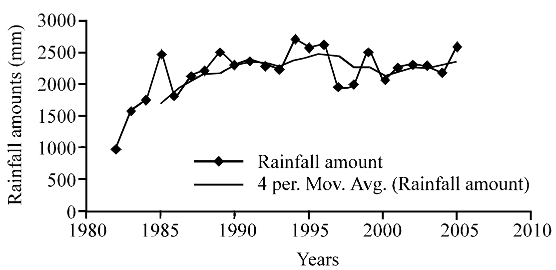

Fig. 6: Fluctuations in annual rainfall of Uyo and smoothed sequence

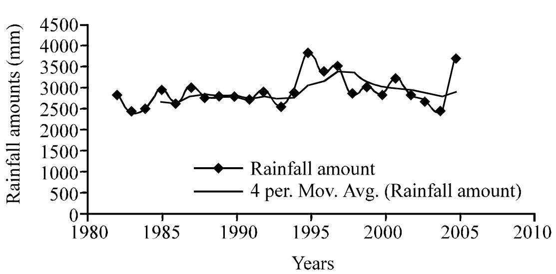

Fig. 7: Fluctuations in annual rainfall of Calabar and smoothed sequence

towards the 20th century. In Fig. 10-13, time series of yearly average of normalized rainfall departure for climatic stations over Southeastern Nigeria are presented.

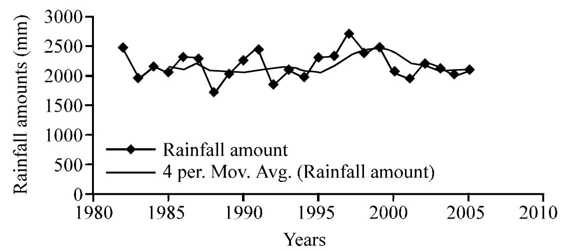

Fig. 8: Fluctuations in annual rainfall of Ikom and smoothed sequence

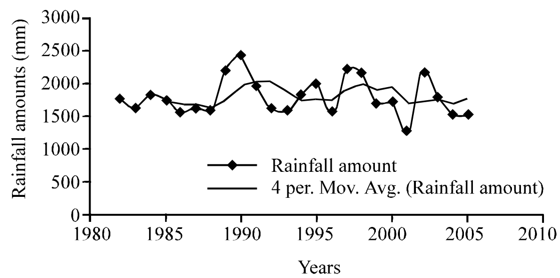

Fig. 9: Fluctuations in annual rainfall of Ogoja and smoothed sequence

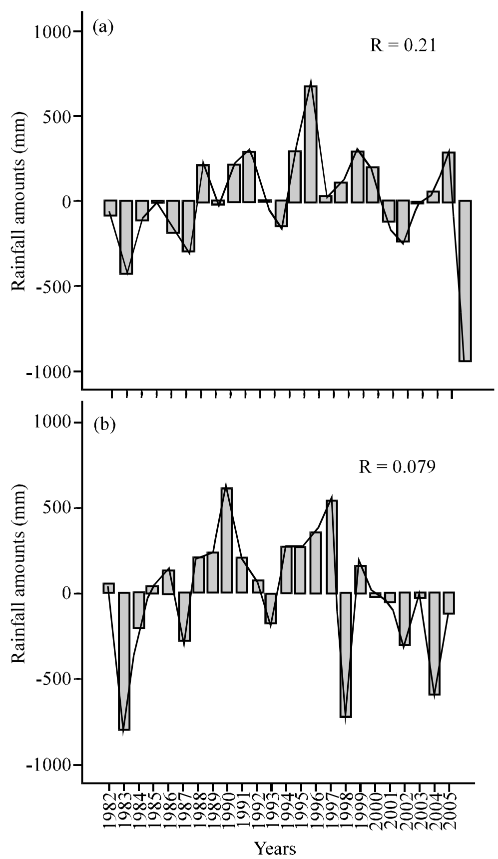

Fig. 10: Trends in rainfall patterns of a) Onitsha and b) Owerri

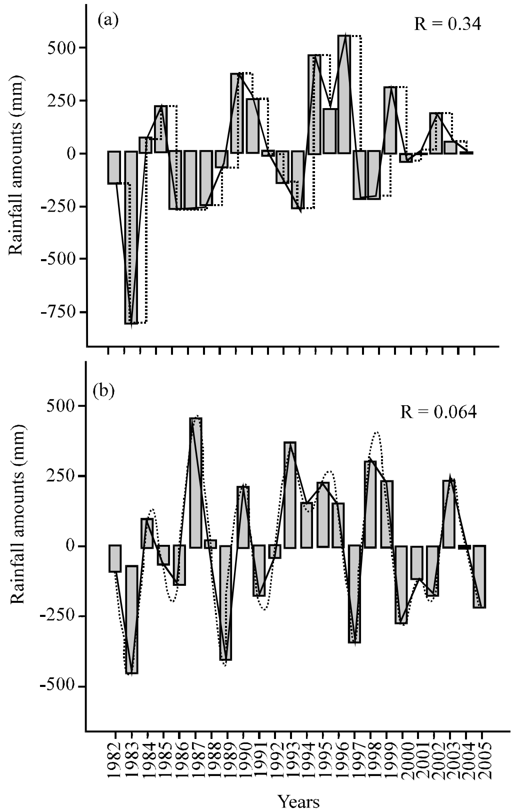

Fig. 11: Trends in rainfall patterns of a) Enugu and b) Port Harcourt

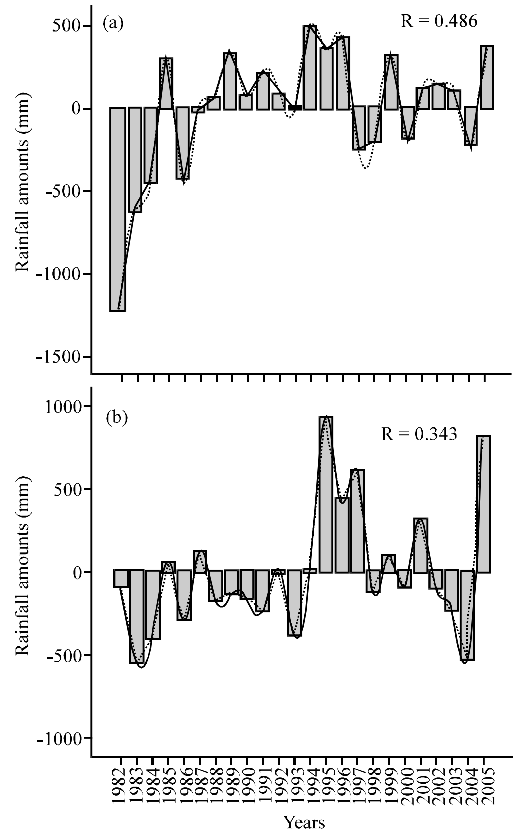

Fig. 12: Trends in rainfall patterns of a) Uyo and b) Calabar

The Figures also revealed trends in inter-annual rainfall patterns as well as the strength and directions of observed trends in rainfall amounts.

In Fig. 10a, b no significant variation was observed however, highest decline in normal rainfall was recorded in 2005 whereas highest rainfall peak was recorded in 1995. In Fig. 10b highest decline from mean rainfall was recorded in 1983.

Other significant years of rainfall decline are 1998 and 2004 while high rainfall peaks were recorded for 1990 and 1997. In Fig. 11a, highest decline in annual rainfall amount was recorded in 1983 while 1998 witnessed abnormally rainfall peak followed by 1995. In Fig. 11b, highest rainfall decline occurred in 1983. Other significant decline was recorded in 1989 and 1997.

Similarly, very high rainfall was recorded in 1987, 1993 and 1999. A general increase in rainfall amount was observed in Fig. 12a up to 1995. Highest deficit on the other hand was recorded in 1982 (Fig. 12a). In Fig. 12b very high rainfall was witnessed in 1995 and 2005 while high decline in rainfall amounts were recorded in 1983 and 1984.

In Fig. 13a, b periods of highest rainfall decline were recorded in 1988 and 2001, respectively while abnormally, rainfall peaks for Ikom and Ogoja were recorded in 1997 and 1990, respectively.

In Fig. 14-17, results of correlogram analysis of the study area are represented. The results reveal periodicities and cycles of rainfall extremes over the study area. A total of 16 lag number was derived for each climatic station. In Fig. 14a, very high rainfall was observed to be cyclic with a periodicity of 4 years. Rainfall deficiencies also showed cyclicity over periodicities of 10 and 11 years. In Fig. 14b, cycle was observed in high rainfall peak with periodicities of 4, 6 and 15 years while cycles in rainfall deficiencies have periodicities of 18 and 14 years. Abnormally high rainfall in Enugu station revealed cycles with periodicities of 5 years (primary peak) and 6 years (secondary peak). Cycles peak deficiency were observed on a periodicities of 14 years (primary peak) and 8 years (secondary peak) (Fig. 15a). In Fig. 15b, abnormally high rainfall was observed to be cyclic with periodicities 3 (primary peak) and 8 (secondary peak) years. Rainfall deficit also showed cycle with periodicities of 4 (primary peak), 7 (primary

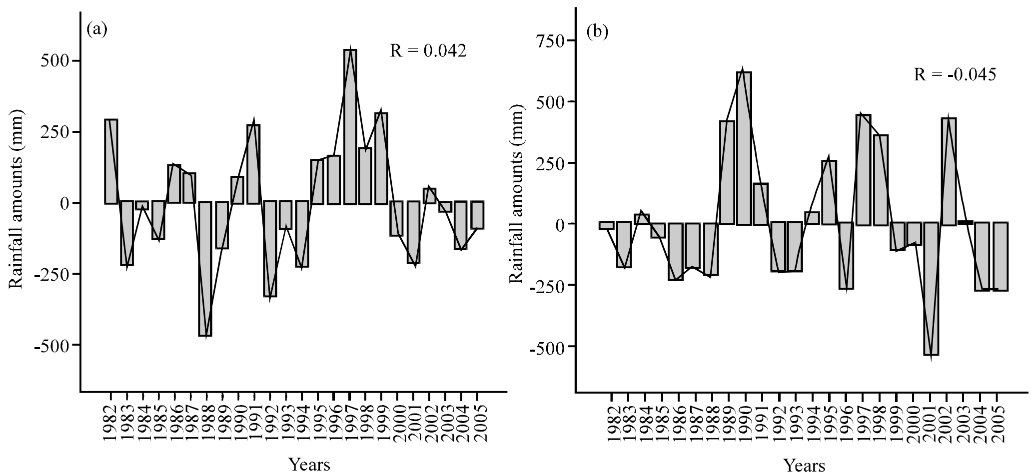

Fig. 13: Trends in rainfall patterns of a) Ikom and b) Ogoja

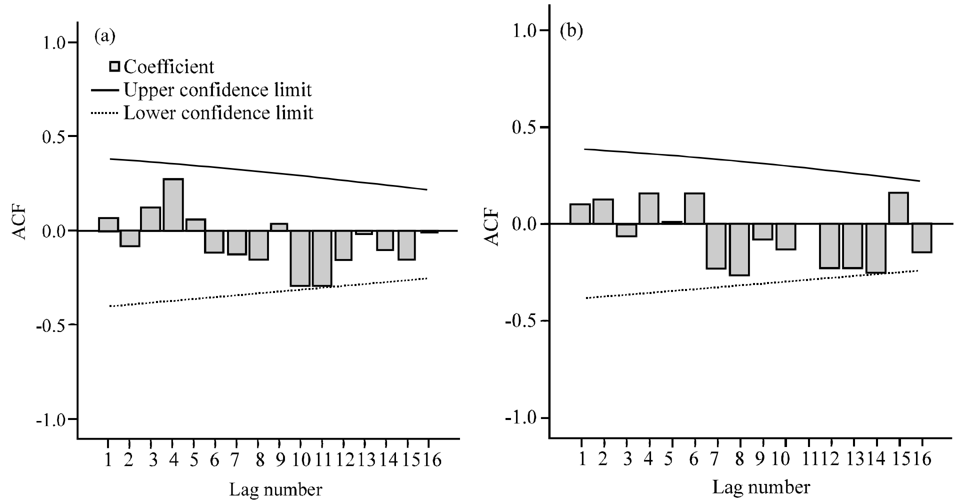

Fig. 14: Correlogram of rainfall of a) Onitsha and b) Owerri

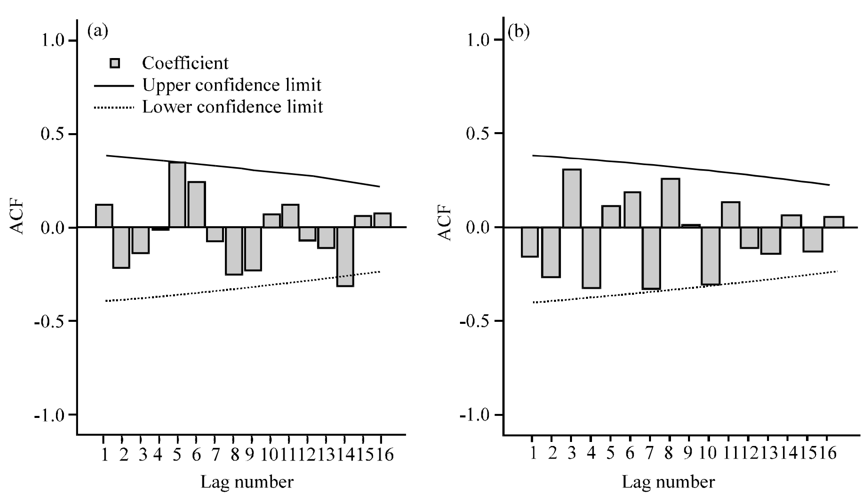

Fig. 15: Correlogram of rainfall of a) Enugu and b) Port-Harcourt

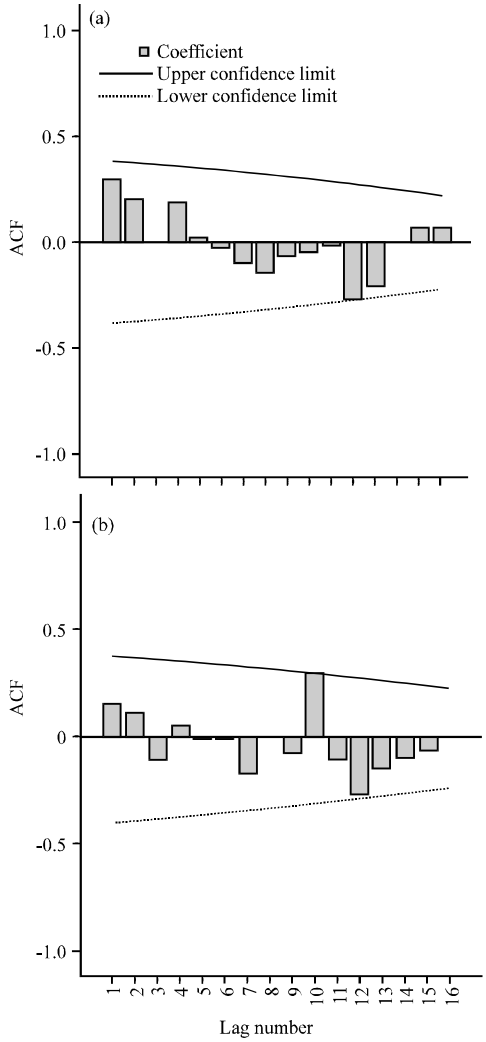

Fig. 16: Correlogram of rainfall of a) Uyo and b) Calabar

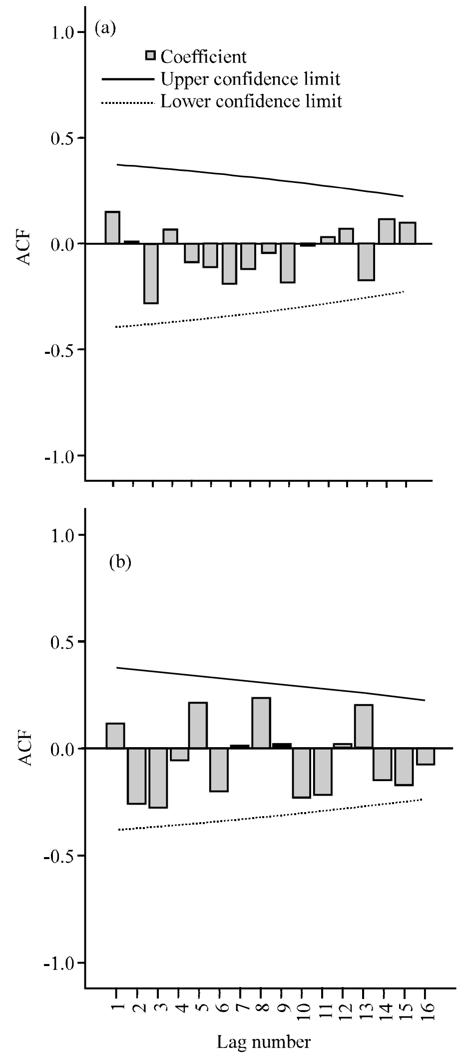

Fig. 17: Correlogram of rainfall of a) Ikom and b) Ogoja

peak) and 10 (primary peak) years. In Fig. 16a, very high rainfall amount was observed to be cyclical over a period of 1 year whereas cycle in rainfall decline was observed with a periodicity of 12 years. In Fig. 16b, periods of extreme high rainfall was observed to be cyclical with a periodicity of 10 years. Cycle in rainfall decline in this station showed a periodicity of 12 years. In Fig. 17a, very peak rainfall amount showed cyclicity with a periodicity of 1 year and deficiency, a periodicity of 3 years. Peak rainfall of Ogoja revealed cycle with a periodicity of 8 years whereas decline has a periodicity of 3 years (Fig. 17b).

In Fig. 10-13, the extents of deviation (very high or decline in rainfall amounts) from normal rainfall was presented for each climatic station. The patterns of high and rainfall decline range from moderate to severe. Although, no significant trends was observed in the pattern of rainfall fluctuations in all the stations except for Uyo, a general increase in annual rainfall amount was observed in almost all the stations from 1980's towards the end of the 20th century while fluctuation in rainfall decline showed no significant trends. The gradual decline or steady slope in rainfall trends up to the end of the 20th century for some climatic stations (Fig. 2, 3, 4 and 6) may suggest a changing rainfall pattern with the wake 21st century. Similarly even when rainfall of Port-Harcourt (Fig. 5), Calabar (Fig. 7), Ikom (Fig. 8), showed slight variations since 1980-1990, gradual rise in rainfall amounts was observed towards the end of the 20th century followed by a gradual decline or steady slope in the trend line of rainfall amounts. From the graphs of Autocorrelation Function (Fig. 14-17), cycles and periodicities in rainfall extremes were revealed. Generally, cycles and periods of very high rainfall over the study area tend to vary from one station to another. A sequence of 4 years (Onitsha) 4, 6 and 15 years (Owerri), 5 years (Enugu), 3 years (Port-Harcourt), 1 year (Uyo), 10 years (Calabar), 1 year (Ikom) and 8 year (Ogoja) periodicities in cycles of high rainfall were determined in the study area. Cycles in rainfall deficiencies on the other hand yielded a periodicities sequence of 10 and 11 years (Onitsha), 8 and 14 years (Owerri), 14 years (Enugu), 4, 7 and 10 years (Port-Harcourt), 12 years (Uyo), 12 years (Calabar), 3 years (Ikom), 3 years (Ogoja). From the sequence of periodicities of cycles for rainfall deficiencies over southeastern Nigerian, similarities was observed between Uyo and Calabar and between Ikom and Ogoja. Accordingly, Winstanley (1973a, b) and Nicholson (1980) have reported similar periodicities and varying amplitudes in peak rainfall for various regions in the tropics. The observed marked variations in periodicities of cycles of rainfall peaks may be attributed to the varying human and environmental factors influencing rainfall formation and amount in the study area.

CONCLUSION

With changing climate and rainfall pattern, coupled with increasing pressure on water resources, there is a growing concern that many areas in West Africa will face serious water problems. Since, the water resources of the Southeastern Nigeria depend mainly on rainfall which is highly variable and increasingly unpredictable, the need to understand the character of rainfall in the region both in terms of seasonal and spatial dimensions is crucial. The present study attempts to investigate the characteristics of periodicities and cycles in the annual rainfall (1982-2005) over Southeastern Nigeria with a view to predicting rainfall extremes. The study has demonstrated that there has been a general increase in rainfall amounts in all the stations from the early 1980's to the 20th century followed by a gradual decline or steady slope in the line of rainfall trend. The correlogram analysis yielded a sequence which is in consistent with results for various regions in the tropics. This more so because rainfall in tropical climate of which the study area is a part is essentially depends on the interaction of two major air masses viz the Tropical continental (cT) and Tropical maritime (mT) and they both meet at the Inter-Tropical Discontinuity (ITD).

Thus, rainfall pattern in the study area is a good reflection of the seasonal variations of the surface location of the Inter-Tropical Discontinuity (ITD). The study showed that very high rainfalls were mostly recorded between mid 90's and late 1990's. Finally, the results of the study provides a historical insights in to the rainfall patterns of the study area and can provide information that can be helpful in formulating polices for mitigating flooding and stream flow drought in the region.

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