Journal of the Nigerian Association of Mathematical Physics
***Volume 52* (*July & Sept., 2019 Issue*), pp299 – 312**

TREND ANALYSIS, CYCLES AND PERIODICITIES IN ANNUAL MAXIMUM DAILY RAINFALL DISTRIBUTIONS OVER SOUTHERN NIGERIA

[1]Emeribe C.N., [2] Butu A.W. and Laka S.I.

[1]National Centre for Energy and Environment, Energy Commission of Nigeria, University of Benin, Benin, City, Edo State
[2]Department of Geography, Faculty of Arts and Social Sciences, Nigerian Defence Academy, Kaduna, Kaduna State
[3]Department of Geography and Planning, University of Jos, Plateau State

Abstract

The study is aimed at investigating patterns and frequency of annual extreme daily rainfall events over southern Nigeria using the Correlogram method. Maximum daily rainfall data were collected for a period of 1969-2017 for Warri, Benin City, Calabar, Port Harcourt, Ikeja, Ondo, Oshogbo, Enugu and Owerri, while 1986-2017 for Uyo. Maximum daily values were extracted using descriptive statistics of mean, median maximum and minimum. Cycle and periodicity were determined using autocorrelation function white noise and based on asymptotic chi-square approximation. Trend was examined using the Mann-Kendall Test, Spearman's Rho Test and Linear regression test statistics at α =0.10, α <0.1, α <0.05 and α <0.01 levels of significance. Results of correlogram for all the synoptic stations showed evidence of white noise weakly stationary time series, rapid decaying trend and periodicity. The value of Box-Ljung Q statistics for all the stations indicate that the residuals are independent and random, thus it can be concluded that the model provided an adequate fit for the forecast of future maximum daily rainfall in the study area. The autocorrelation plots show, that most residual autocorrelations except those at Lag 3 (Calabar), Lag 2 (Uyo), Lag 8 (Ondo), Lag 13 (Enugu) and Lag 3 (Owerri) fall inside the 95 % confidence bounds indicating the residuals appear to be random. The general trend in annual maximum rainfall distribution over southern Nigeria ranges from absence of trend to strong evidence of statistical trend. In locations like Benin City, Calabar, Enugu, Ikeja, Ondo and Warri, annual maximum values did not show any evidence of statistical significant change at α = 0.1. However, for locations like Port-Harcourt, there is possible to strong evidence of increasing trend, while in Oshogbo, Owerri and Uyo, there is a general strong evidence of increasing trends at α < 0.05. For locations such as Calabar, Port-Harcourt, Uyo, Oshogbo, Enugu, Owerri and Ikeja which show evidence of either double cycles and/or the probability of every year extreme event, and this suggest that these areas are highly vulnerable to extreme meteorological-induced events, in particular urban, river flooding and soil erosion. These patterns are further buttressed by results of annual daily fluctuations around means.

Keywords: Correlogram, Autocorrelation Function, Maximum Daily Rainfall, Cycles and Periodicity

1. Introduction

It has been reported that since 1850, the amount of CO_2 in the atmosphere has increased by more than 40%, and is now higher ~407 ppm1) than it has been in the past 2-25 million years [1]. Similarly, IPCC study showed clearly hat it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was

Corresponding Author**:** Emeribe C.N., Email: emeribe.c@ncee.org.ng, Tel: +2348063581430

caused by increases in carbon dioxide (CO_2) concentrations and other emissions caused by human activity. Since the advent of this warming, there are increased concerns regarding extreme weather events [2]. For example, it has been reported that the severity and frequency of coastal floods is clearly increasing [3,4], largely due to the rise in mean sea level in most global locations [5-7]. Mean sea level rise—e.g., ocean warming and expansion, and glacier and ice sheet melting—has also continue to accelerate since the 21st century [8]. Projections of an increase in flood frequency are robust; however, changes in the most extreme coastal floods will be driven more strongly by the characteristics of storm surge, which is more related to changes in tropical cyclones (TCs) and Extratropical cyclones (ETCs) [9]. A similar study found that many areas in the Northern Hemisphere are expected to have increased risk of wild fire, in particular, the western United States extending northward into Alaska, the northern portions of Canada, the northern part of Africa extending eastward into Saudi Arabia, and into central Asia and northeast part of Russia [10].

Findings by[11] revealed that heavy precipitation and concomitant pluvial (rain-induced) inland flooding have become robust since the 20th century in many regions. The clear physical basis between increasing saturation vapor pressure and increasing temperature gives confidence that the increasing trend in precipitation observed in many locations is influenced by climate change [9].

Like with most countries across the globe, Nigeria have documented evidence of rise in the occurrence of extreme climate events in recent decades ranging from drought in the northern Nigeria to flooding (torrential, river and urban) in the south [12-14]. Many researchers also have found evidences of increasing wet spell in southern Nigeria since 1950s [15-17]. Extreme rainfall events can have severe impacts on the physical environment and social economic life of people, ranging from flooding to soil erosion with associated consequences of access problem to costumers, operational disruption, and access problem to employees, business closure, and damage to farm land, damage to stock, supply chain disruption and damage to inside building leading to loss of lives and property. Depending on the predominant land use type, extreme rainfall may also have implications for human health and surface water pollution. Studies have shown that flooding events are also associated with prevalence of diarrhea and other waterborne diseases as most sources of water are polluted [18-20].In view of the above, it has become necessary to understand the trends and/or develop model for predicting extreme valuesespecially as rainfall in the tropics is marked by occasional sharp variability. Such knowledge is considered a prerequisite for engineering design purposes and creation policy towards adaptation measures to meteorologically induced extreme events. To predict future developments, past statistical trends can be considered along with physically-based climate model projections [21].The aim of the present study is to investigate patterns and frequency of annual extreme daily rainfall events over southern Nigeria using the Correlogram statistical method.

2. Materials and Methods

The study covered selected states in the southern part of Nigeria. Southern Nigeria lies roughly between longitudes 3° and 15° east of the Greenwich meridian and between latitudes 4° and 9° north of the equator (Fig. 1). The synoptic stations are Warri (5.52^0N; 5.73^0E; 6.1m), Benin City (6.32^0N; 5.10^0E; 77.8m), Calabar (4.97^0N; 8.35^0E; 61.9m); Port-Harcourt (11.70^0N; 11.03^0E 414.8m), Uyo (5.50^0N; 7.92^0E; 38.0m), Ikeja (6.58^0N; 3.33^0E; 39.4m), Ondo (7.10^0N; 4.83^0E; 287.3m), Oshogbo (7.80^0N; 4.50^0E; 304m), Enugu (6.47^0N; 7.55^0E; 141.8m), Owerri (5.48^0N; 7.00^0E; 91.0m).

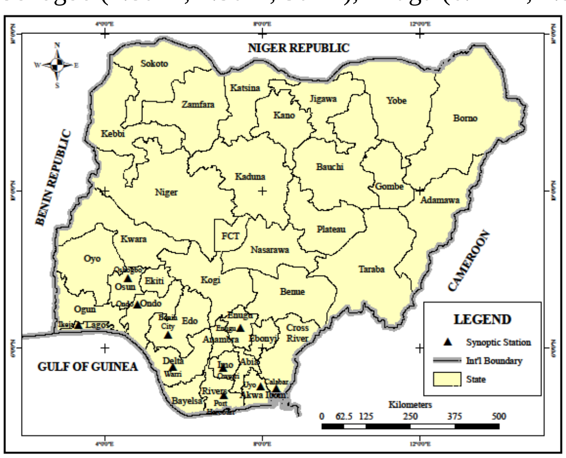

Fig. 1: Study Area

Data Collection

Long term annual daily rainfall data was collected from the Nigerian Meteorological Agency (NIMET), Lagos State. Data were collected for the period 1969-2017. Data was collected for Ten (10) synoptic stations including Warri, Delta State, Benin City, Edo State, Calabar, Cross River, Port Harcourt, Rivers State, Ikeja, Lagos, Ondo, Oshogbo, Osun State, Enugu state and Owerri, Imo State while 1986-2017 for Uyo, Akwa-Ibom. Maximum daily values were extracted using descriptive statistics of mean, median maximum and minimum.

Data analysis

Cycles and Periodicity

Cycles and periodicity in annual maximum daily rainfall was investigated using Correlogram analysis of Autocorrelation function [22, 23] white noise option. Autocorrelation function (ACF) represents the correction between a time series and the same series at a later interval of time [24]. The time interval is called a lag. The statistic is an important diagnostic tool for analysing characteristics time series time series, viz. randomness, the rising or declining trend, oscillation [23,25]. Autocorrelation Equation is according to Barry and Perry, [26] is given as;

$$r_L = \frac{\sum_{i=1}^{N-1} Y_1 Y_2 \ + L \ - \ \frac{1}{N-L}\sum_{i=1}^{N-1} Y_i \sum_{i=L+1}^{N} Y_i}{\sqrt{(\sum_{i=1}^{N-1} Y_i^2 \sum_{i=L+1}^{N} Y_i^2\ )}} \quad (1)$$

Where

$r_L$is the lag-L serial correlation coefficient of the series

Y is the time series and N is the length

When computed, the resulting number can range from +1 to -1. An autocorrelation of +1 represents a perfect positive correlation while a value of -1 represents a perfect negative correlation.

Box-Ljung Q Statistic

For that given lag, the Box-Ljung Q statistic is defined by:

Qk = n*(n+2)*sum(ri2/(n-1)) (2)

For i = 1 to k

When the number of observations is large, then the Q statistic has a Chi-square distribution with k-p-q degrees of freedom, where p and q are the number of autoregressive and moving average parameters, respectively. If the p value of *Box-Ljung Q statistic* is greater than 0.05 then the residuals are independent which we can conclude that the model correct for prediction [27].

Mann-Kendall Test

This tool was used to test whether there is a significant trend in the time series of annual daily rainfall data. The n time series values (X1, X2, X3, ….., Xn) were first replaced by their relative ranks (R1, R2, R3,….., Rn) (starting at 1 for the lowest up to n). The test statistic S is given as:

$$S = \ \sum_{i=1}^{n-1}[\sum_{j=i+1}^{n} sgn(R_{i-}R_{i-})] \quad (3)$$

Where Sgn(x) = 1 for x > 0

Sgn(x) =0 for x = 0

Sgn(x) = -1 for x <0

If the null hypothesis Ho is true, then S is approximately normally distributed with:

μ = 0

σ = n (n – 1) (2n + 5) / 18 (4)

The z-statistic is therefore (critical test statistic values for various significance levels may be obtained from normal probability tables):

$$= |s|/\sigma^{0.5} \quad (5)$$

A positive value of S indicates that there is an increasing trend and vice versa.

Spearman's Rho Test

This was used to determine whether the correlation between two variables is significant. One variable was taken as the time itself (years) and the other as the corresponding time series of rainfall data. Like the Mann-Kendall Test, the n time series values were replaced by their ranks. The test statistic ρs is the correlation coefficient, which is obtained in the same way as the usual sample correlation coefficient, but using ranks. The equation is expressed as;

$$P_s S_{xy\,/}(S_X S_Y)^{0.5} \quad (6)$$

$$where\ S_x = \sum_{i=1}^{n}\left(x_i - \tilde{X}\right)^2 \quad (7)$$

$$S_y = \sum_{i=1}^{n}(y_{i-}\bar{Y})^2 \quad (8)$$

$$S_{xy} = \sum_{i=1}^{n}(x_{i-}\bar{X})^2(y_i - \bar{Y}) \quad (9)$$

and x_i (time), y_i (variable of interest), $\bar{x}$ and $\bar{y}$ refer to the ranks ($\bar{x}$, $\bar{y}$, S_x and S_y have the same value in a trend analysis).

Linear Regression Test

It tests whether there is a linear trend by examining the relationship between time (x) and the variable of interest (y). The regression gradient is estimated by:

$$b = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})2} \qquad (10)$$

and the intercept is estimated as:

$$a = y - bx \qquad (11)$$

The test statistic S is:

$$where \quad \sigma = \sqrt{\frac{12\sum_{i=1}^{n}(y_i-a-bx_i)}{n(n-2)(n^2-1)}} \qquad (12)$$

The test statistic S follows a Student-t distribution with n-2 degrees of freedom under the null hypothesis (critical test statistic values for various significance levels was obtained from Student's t statistic tables).

3. Results

The correlogram results of annual maximum daily rainfall over southern Nigeria are presented in Tables 1-10, while Figures 2 -12 represent the ACF plots of residuals of annual maximum daily rainfall time series. The correlogram for all the synoptic stations showed evidence of white noise weakly stationary time series, rapid decaying trend and periodicity. The shape of the correlogram reveals an alternating positive and negative correlation decaying to zero. Overall, the residual plots can be considered as short term correlation. The value of Box-Ljung Q statictics for all the stations indicate that the residuals are independent and random, thus it can be concluded that the model (ARMA -1,1) provided an adequate fit for the forecast of future maximum daily rainfall. Similarly, the autocorrelation plots show, that most residual autocorrelations except those at Lag 3 (Calabar), Lag 2 (Uyo), Lag 8 (Ondo), Lag 13 (Enugu) and Lag 3 (Owerri) fall within the 95 % confidence bounds indicating the residuals appear to be random.

Table 1: Correlogram result over Warri station, Delta state

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.103	0.139	0.549	1	0.459	0.103	0.143
2	0.097	0.137	1.047	2	0.592	0.087	0.143
3	0.041	0.136	1.139	3	0.768	0.024	0.143
4	0.226	0.134	3.971	4	0.410	0.215	0.143
5	-0.204	0.133	6.341	5	0.274	-0.266	0.143
6	-0.147	0.131	7.604	6	0.269	-0.149	0.143
7	-0.018	0.130	7.625	7	0.367	0.049	0.143
8	-0.052	0.128	7.791	8	0.454	-0.078	0.143
9	-0.169	0.127	9.580	9	0.386	-0.051	0.143
10	-0.086	0.125	10.056	10	0.436	-0.036	0.143
11	-0.113	0.123	10.893	11	0.452	-0.177	0.143
12	-0.168	0.122	12.790	12	0.385	-0.137	0.143
13	-0.133	0.120	14.012	13	0.373	-0.057	0.143
14	0.041	0.118	14.131	14	0.440	0.057	0.143
15	0.011	0.117	14.140	15	0.515	0.036	0.143
16	-0.081	0.115	14.639	16	0.551	-0.119	0.143

a. The underlying process assumed is independence (white noise).

b. b. Based on the asymptotic chi-square approximation

Table 2: Correlogram result over, Benin City

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	Df	Sig.[b]		
1	0.066	0.139	0.224	1	0.636	0.066	0.143
2	-0.263	0.137	3.893	2	0.143	-0.268	0.143
3	-0.297	0.136	8.685	3	0.034	-0.279	.143
4	0.051	0.134	8.831	4	0.065	0.009	0.143
5	0.101	0.133	9.416	5	0.094	-0.053	0.143
6	-0.020	0.131	9.438	6	0.150	-0.104	0.143
7	-0.058	0.130	9.640	7	0.210	-0.033	0.143
8	0.044	0.128	9.757	8	0.282	0.036	0.143
9	0.140	0.127	10.976	9	0.277	0.101	0.143
10	-0.155	0.125	12.514	10	0.252	-0.186	0.143
11	-0.125	0.123	13.538	11	0.260	-0.039	0.143
12	0.094	0.122	14.137	12	0.292	0.110	0.143
13	0.079	0.120	14.573	13	0.335	-0.085	0.143
14	-0.064	.0118	14.861	14	0.388	-.089	0.143
15	-0.089	0.117	15.447	15	0.420	-0.003	0.143
16	-0.130	0.115	16.735	16	0.403	-0.201	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

In Fig. 2ahowever, Warri station, largest spike was seen at Lag 4, indicating the presence of cycle with a periodicity of 4years. This pattern suggests that extreme daily rainfall event over Warri is cyclical and will repeat itself every 4years. In Fig. 2b, annual maximum daily rainfall randomly fluctuate around a mean value of 117.5mm. On the whole however, there is a sign of gentle increase in maximum daily rainfall values from 1990s. Figs. 3a and b shows that over Benin City, annual extreme daily rainfall is cyclical with a 9years periodicity. Annual daily maximum rainfall fluctuation around mean value of 87.7mm is better described as stationary in nature. There was sign of steady and gentle decline in maximum daily rainfall amounts starting from the year 1990.

In Fig. 4a annual maximum daily rainfall over Calabar is cyclic in nature with a 3years periodicity. Similarly, secondary cycle with a 7years periodicity suggesting that extreme daily rainfall will repeat itself 3years and 7years, with the former being (3years) most extreme in the station. In Fig. 4b, annual maximum daily rainfall is seen distributed randomly around a mean value of 125.1mm.

Table 3: Correlogram result over Calabar station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	-0.155	0.139	1.245	1	0.264	-0.155	0.143
2	-0.201	0.137	3.400	2	0.183	-0.231	0.143
3	0.334	0.136	9.475	3	0.024	0.282	.143
4	0.024	0.134	9.506	4	0.050	0.086	0.143
5	-0.239	0.133	12.748	5	0.026	-0.129	0.143
6	-0.109	0.131	13.443	6	0.037	-0.285	0.143
7	0.209	0.130	16.032	7	0.025	0.088	0.143
8	-0.205	0.128	18.602	8	0.017	-0.117	0.143
9	-0.005	0.127	18.604	9	0.029	0.161	0.143
10	-0.008	0.125	18.608	10	0.046	-0.215	0.143
11	-0.051	0.123	18.776	11	0.065	-0.035	0.143
12	0.057	0.122	18.999	12	0.089	-0.013	0.143
13	-0.131	0.120	20.198	13	0.090	-0.056	0.143
14	0.018	0.118	20.222	14	0.123	-0.058	0.143
15	-0.020	0.117	20.252	15	0.162	-0.074	0.143
16	-0.014	0.115	20.267	16	0.208	-0.070	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

Table 4: Correlogram result over Port-Harcourt station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.206	0.140	2.163	1	0.141	0.206	0.143
2	-0.133	0.138	3.089	2	.213	-0.183	0.143
3	0.040	0.137	3.174	3	.366	0.119	.143
4	0.224	0.135	5.911	4	.206	0.176	0.143
5	0.022	0.134	5.937	5	.312	-0.060	0.143
6	-0.145	0.132	7.139	6	.308	-0.087	0.143
7	0.079	0.131	7.505	7	.378	0.125	0.143
8	0.151	0.129	8.881	8	.352	0.035	0.143
9	0.120	0.127	9.771	9	.369	0.132	0.143
10	0.010	0.126	9.777	10	.460	0.022	0.143
11	-0.012	0.124	9.787	11	.550	-0.045	0.143
12	0.083	0.122	10.241	12	.595	0.052	0.143
13	0.078	0.121	10.660	13	.639	0.031	0.143
14	0.058	0.119	10.898	14	.694	0.064	0.143
15	-0.059	0.117	11.148	15	.742	-0.065	0.143
16	-0.029	0.115	11.210	16	.796	-0.041	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

In Fig. 5a and b, annual maximum daily rainfall over Port-Harcourt is characterized by a primary and secondary cycles, the primary cycle with a periodicity of 4years, while the secondary cycle is every year extreme event (Lag 1). Annual maximum daily rainfall showed a general rise above a mean value of 96.4. Over Uyo, annual extreme daily rainfall has the largest spike at Lag 1, suggesting a yearly occurrence of extreme daily rainfall event (Fig 6a). However, in Fig 6b, there is a generally gentle decline in annual maximum daily rainfall distribution below a mean value of 102.1mm.

Table 5: Correlogram result over Uyo station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.358	0.169	4.487	1	0.034	0.358	0.143
2	0.038	0.166	4.540	2	0.103	-0.103	0.143
3	-0.016	0.163	4.550	3	0.208	0.007	.143
4	0.007	0.160	4.552	4	.336	0.017	0.143
5	-0.098	0.158	4.938	5	.424	-0.126	0.143
6	0.079	0.155	5.197	6	.519	0.189	0.143
7	0.168	0.152	6.426	7	.491	0.080	0.143
8	0.037	0.149	6.489	8	.593	-0.077	0.143
9	-0.059	0.145	6.654	9	.673	-0.026	0.143
10	-0.035	0.142	6.715	10	0.752	-0.020	0.143
11	0.018	0.139	6.731	11	.820	0.060	0.143
12	-0.028	0.136	6.773	12	.872	-0.038	0.143
13	-0.039	0.132	6.859	13	.909	-0.057	0.143
14	-0.075	0.129	7.198	14	.927	-0.083	0.143
15	0.001	0.125	7.198	15	.952	0.079	0.143
16	-0.082	0.121	7.660	16	.958	-0.099	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

In Fig. 7a annual extreme daily rainfall distribution is seen to be cyclical with every year periodicity. In Fig. 7b, distribution was random and fluctuate around a mean value of 106.9mm. From 1980-2000 maximum vales were generally below the mean line. The observed patterns in Calabar, Port-Harcourt, Uyo and Ikeja suggest that these areas are highly vulnerable to extreme daily rainfall event, in particular, urban and river flooding.

Table 6: Correlogram result over Ikeja/Lagos station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.115	0.139	0.691	1	0.406	0.115	0.143
2	-0.080	0.137	1.033	2	0.597	-0.095	0.143
3	0.013	0.136	1.042	3	0.791	0.034	.143
4	-0.072	0.134	1.332	4	0.856	-0.088	0.143
5	-0.141	0.133	2.466	5	0.782	-0.120	0.143
6	0.048	0.131	2.599	6	0.857	0.068	0.143
7	0.087	0.130	3.053	7	.880	0.055	0.143
8	-0.097	0.128	3.624	8	.889	-0.109	0.143
9	0.058	0.127	3.834	9	.922	0.081	0.143
10	-0.111	0.125	4.619	10	0.915	-0.170	0.143
11	-0.208	0.123	7.466	11	0.760	-0.144	0.143
12	-0.117	0.122	8.388	12	0.754	-0.103	0.143
13	-0.015	0.120	8.404	13	0.816	-0.051	0.143
14	0.007	0.118	8.408	14	0.867	0.004	0.143
15	-0.026	0.117	8.456	15	0.904	-0.086	0.143
16	0.002	0.115	8.456	16	0.934	-0.067	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

Ondo station recorded primary and secondary cycles. Primary cycle was observed at Lag 7 while secondary cycle at Lag 8. This pattern suggest that annual extreme daily events will repeat itself every 7 and 8 years (Fig.8a). In Fig. 8b, annual maximum value showed a random pattern similar to observations in other stations, with fluctuation around a mean value of 79.8mm.In Figs. 9a annual extreme daily rainfall distribution over Oshogbo recorded two cycles, the primary being at Lag 9, while second has a periodicity of 2years, suggesting the repeat of extreme daily event every 7years (major extreme event) and 2years (secondary extreme event). In Fig. 9b, daily rainfall distribution was random and fluctuate around a mean value of 65.9mm. Annual maximum daily distribution generally depicts a rising trend above mean.

Table 7: Correlogram result over Ondo station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig[b]		
1	-0.031	0.139	0.049	1	0.825	-0.031	0.143
2	-0.102	0.137	0.598	2	0.742	-0.103	0.143
3	-.124	0.136	1.435	3	0.697	-0.132	.143
4	-0.098	0.134	1.969	4	0.742	-0.122	0.143
5	-0.192	.133	4.067	5	0.540	-0.242	0.143
6	-0.218	.131	6.832	6	0.337	-0.325	0.143
7	0.270	0.130	11.180	7	0.131	0.139	0.143
8	0.191	0.128	13.403	8	0.099	0.102	0.143
9	-0.083	0.127	13.830	9	0.129	-0.158	0.143
10	0.030	0.125	13.888	10	0.178	0.002	0.143
11	0.129	0.123	14.982	11	0.183	0.139	0.143
12	0.010	0.122	14.989	12	0.242	0.094	0.143
13	-0.125	0.120	16.069	13	0.245	0.080	0.143
14	-0.182	0.118	18.438	14	0.188	-0.188	0.143
15	0.126	0.117	19.598	15	0.188	0.038	0.143
16	-0.017	0.115	19.619	16	0.238	0.096	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

Table 8: Correlogram result over Oshogbo station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.008	0.139	0.003	1	0.955	0.008	0.143
2	0.207	0.137	2.283	2	0.319	0.207	0.143
3	-0.001	0.136	2.283	3	0.516	-0.005	.143
4	0.174	0.134	3.972	4	0.410	0.137	0.143
5	-0.023	0.133	4.003	5	0.549	-0.026	0.143
6	0.047	0.131	4.131	6	0.659	-0.013	0.143
7	-0.067	0.130	4.400	7	0.733	-0.061	0.143
8	0.064	0.128	4.648	8	0.794	0.037	0.143
9	0.229	0.127	7.938	9	0.540	0.277	0.143
10	-0.071	0.125	8.258	10	0.604	-0.111	0.143
11	-0.121	0.123	9.214	11	0.602	-0.223	0.143
12	-0.036	0.122	9.301	12	0.677	-0.022	0.143
13	-0.079	0.120	9.739	13	0.715	-0.093	0.143
14	-0.079	0.118	10.189	14	0.748	-0.029	0.143
15	0.011	0.117	10.198	15	0.807	0.119	0.143
16	-0.107	0.115	11.067	16	0.805	-0.055	0.143

a. The underlying process assumed is independence (white noise).
b. b. Based on the asymptotic chi-square approximation

In Fig. 10a and b, annual maximum daily rainfall over Enugu is characterized by a primary and secondary cycles, the primary cycle with a periodicity of 2years, while the secondary cycle will repeat itself every 16years event (Lag 16). Annual maximum daily rainfall showed a random distributionaround a mean value of 93.2. Over Owerri, annual extreme daily rainfall has the largest spike at Lag 3, suggesting a 3years occurrence of extreme daily rainfall event (Fig 11a). However, in Fig 11b, there is a generally gentle decline in annual maximum daily rainfall distribution below a mean value of 105.9mm from 1970-1990 with sign of recovery from the year 2000.

Table 9: Correlogram result over Enugu station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial Autocorrelation	Std. Error
			Value	df	Sig.[b]		
1	0.257	0.139	3.443	1	0.064	0.257	0.143
2	0.120	0.137	4.212	2	0.122	0.058	0.143
3	-0.107	0.136	4.830	3	0.185	-0.162	.143
4	-0.187	0.134	6.781	4	0.148	-0.144	0.143
5	-0.021	0.133	6.806	5	0.235	0.096	0.143
6	-0.082	0.131	7.196	6	0.303	-0.083	0.143
7	-0.173	0.130	8.984	7	0.254	-0.215	0.143
8	-0.017	0.128	9.003	8	0.342	0.082	0.143
9	-0.251	0.127	12.945	9	.0165	-0.255	0.143
10	0.008	0.125	12.949	10	0.227	0.056	0.143
11	-0.165	0.123	14.745	11	0.194	-0.221	0.143
12	-0.150	0.122	16.269	12	0.179	-0.143	0.143
13	-0.149	0.120	17.804	13	0.165	-0.207	0.143
14	-0.204	0.118	20.762	14	0.108	-0.229	0.143
15	0.081	0.117	21.238	15	.129	0.059	0.143
16	0.323	0.115	29.132	16	0.023	0.168	0.143

a. The underlying process assumed is independence (white noise).
b. Based on the asymptotic chi-square approximation

Table 10: Correlogram result over Owerri station

Lag	Autocorrelation	Std. Error[a]	Box-Ljung statistic			Partial	Std. Error
			Value	df	Sig.[b]	Autocorrelation	
1	0.042	0.139	0.091	1	0.763	0.042	0.143
2	0.099	0.137	0.613	2	0.736	0.098	0.143
3	0.287	0.136	5.085	3	0.166	0.282	.143
4	-0.107	0.134	5.722	4	0.221	-0.143	0.143
5	-0.048	0.133	5.854	5	0.321	-0.105	0.143
6	0.135	0.131	6.921	6	0.328	0.096	0.143
7	-0.089	0.130	7.396	7	0.389	-0.012	0.143
8	0.046	0.128	7.523	8	0.481	0.056	0.143
9	0.144	0.127	8.819	9	0.454	0.082	0.143
10	0.038	0.125	8.910	10	0.541	0.077	0.143
11	0.159	0.123	10.572	11	0.480	0.121	0.143
12	-0.036	0.122	10.661	12	0.558	-0.153	0.143
13	0.196	0.120	13.327	13	0.423	.0222	0.143
14	-0.034	0.118	13.407	14	0.495	-0.111	0.143
15	-0.009	0.117	13.413	15	0.570	0.034	0.143
16	0.184	0.115	15.980	16	0.454	0.120	0.143

a. The underlying process assumed is independence (white noise).
b. Based on the asymptotic chi-square approximation

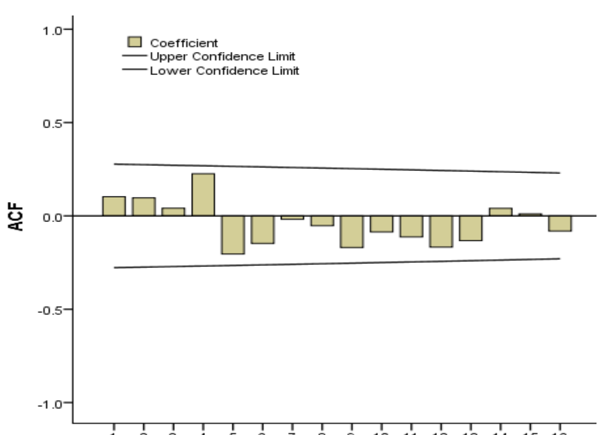

Fig. 2a: Residual ACF plot of Maximum annual daily rainfall over Warri

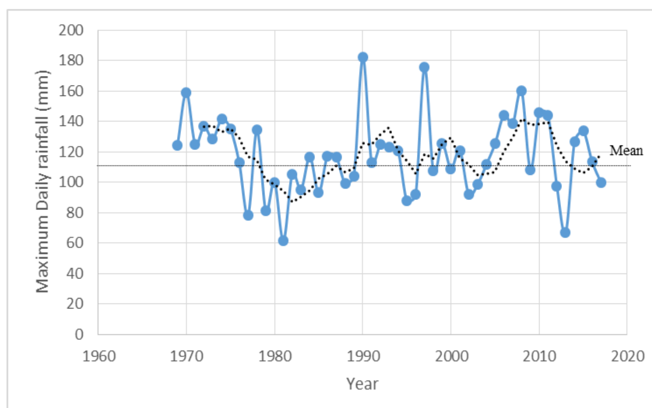

Fig 2b: Fluctuation of Maximum annual daily rainfall over Warri. (4yrs moving Av)

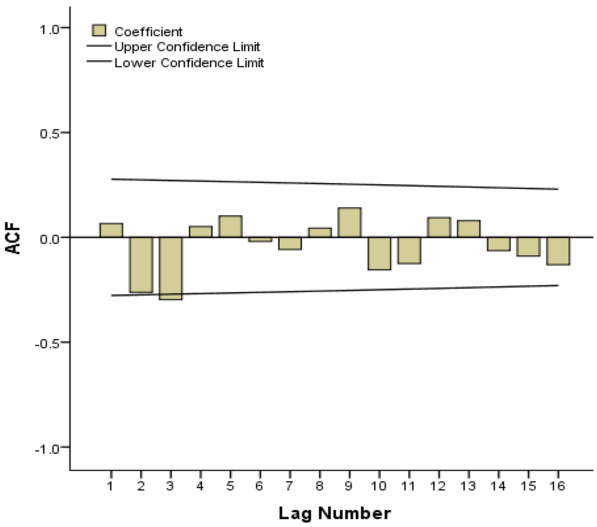

Fig. 3a: Residual ACF plot of Maximum annual daily rainfall over Benin City

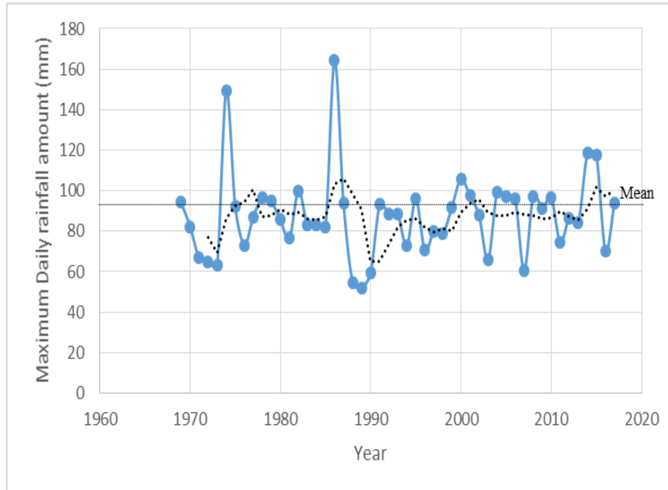

Fig. 3b: Fluctuation of Maximum annual daily rainfall over Benin City. (4yrs moving Av)

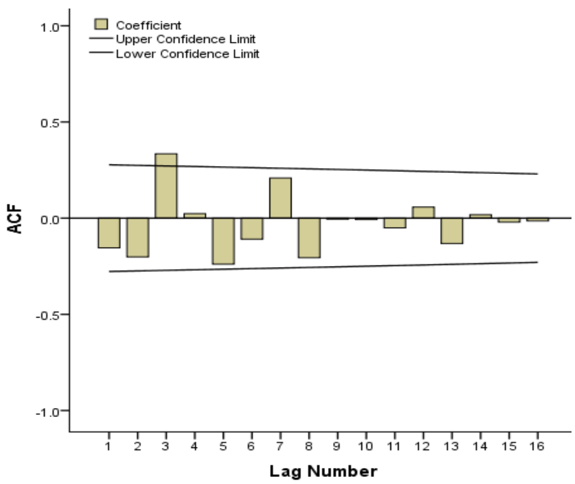

Fig. 4a: Residual ACF plot of Maximum annual daily rainfall over Calabar

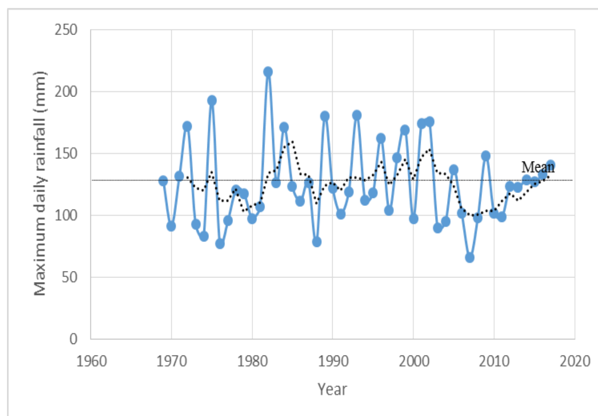

Fig. 4b: Fluctuation of Maximum annual daily rainfall over Calabar. (4yrs moving Av)

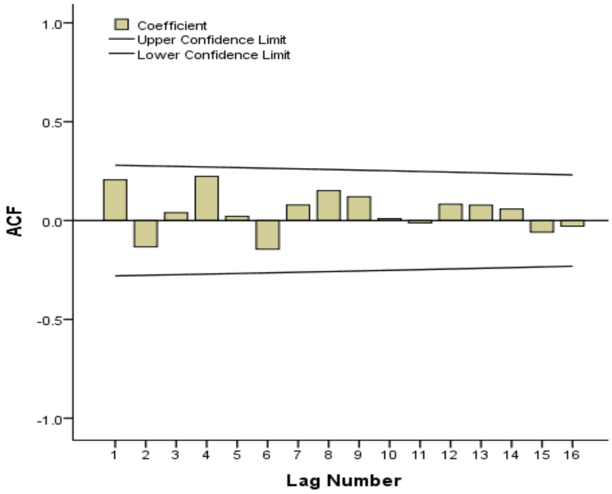

Fig. 5a: Residual ACF plot of Maximum annual daily rainfall over Port-Harcourt

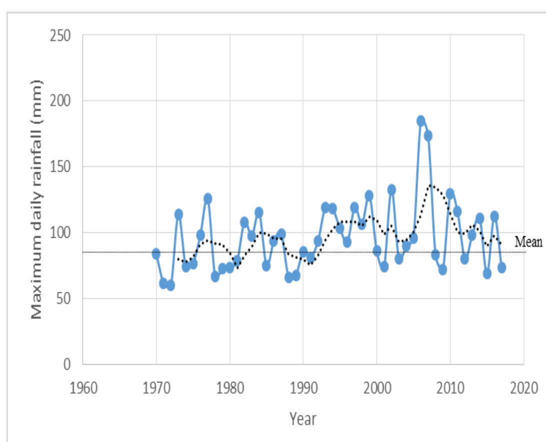

Fig. 5b: Fluctuation of Maximum annual daily rainfall over Port-Harcourt. (4yrs moving Av)

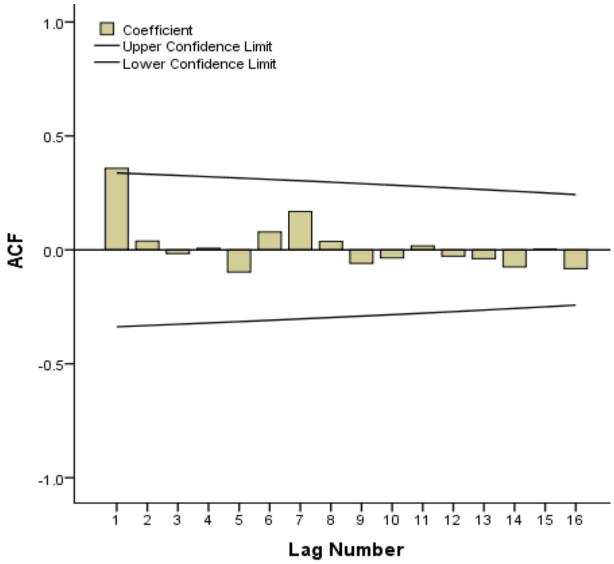

Fig. 6a: Residual ACF plot of Maximum annual daily rainfall over Uyo

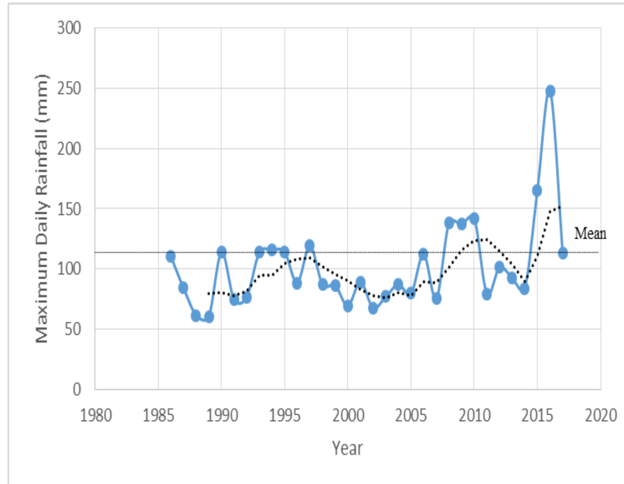

Fig. 6b: Fluctuation of Maximum annual daily rainfall over Uyo (4yrs moving Av)

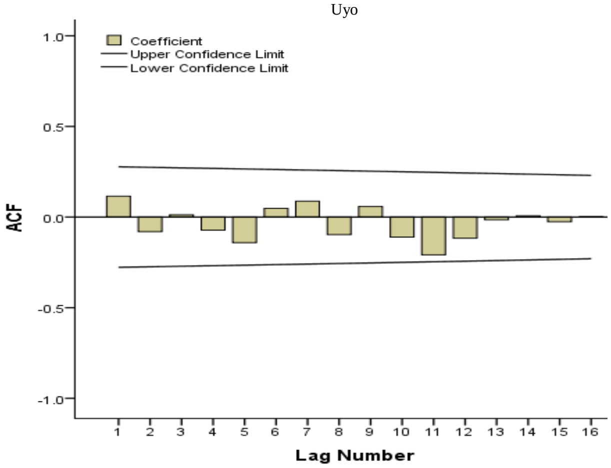

Fig. 7a: Residual ACF plot of Maximum annual daily rainfall over Ikeja

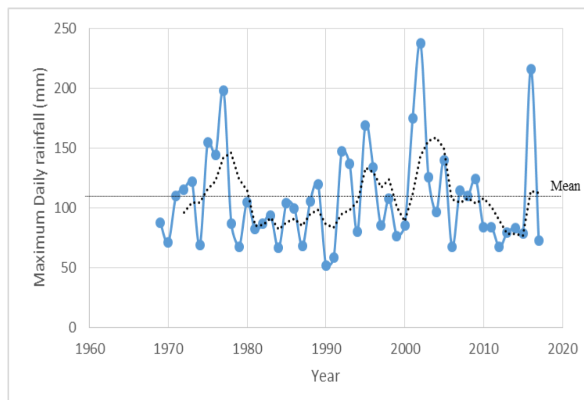

Fig. 7b: Fluctuation of Maximum annual daily rainfall over Ikeja (4yrs moving Av)

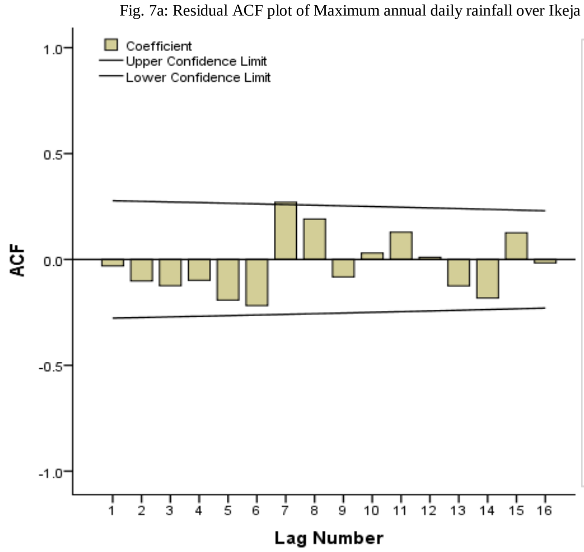

Fig. 8a: Residual ACF plot of Maximum annual daily rainfall over Ondo

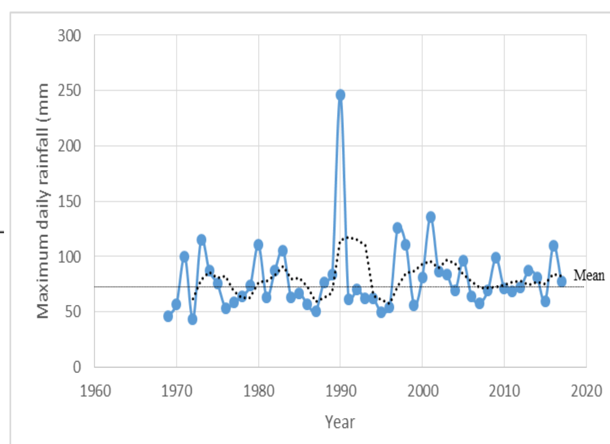

Fig. 8b: Fluctuation of Maximum annual daily rainfall over Ondo (4yrs moving Av)

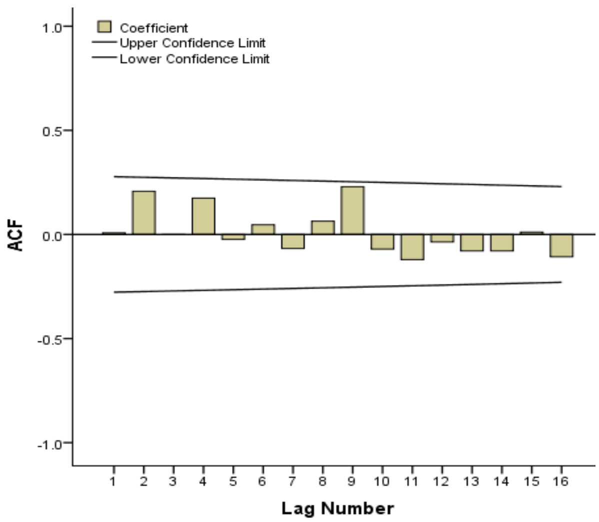

Fig. 9a: Residual ACF plot of Maximum annual daily rainfall over Oshogbo

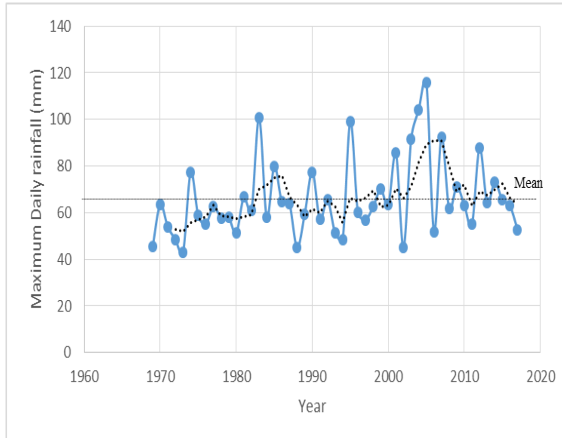

Fig. 9b: Fluctuation of Maximum annual daily rainfall over Oshogbo (4yrs moving Av)

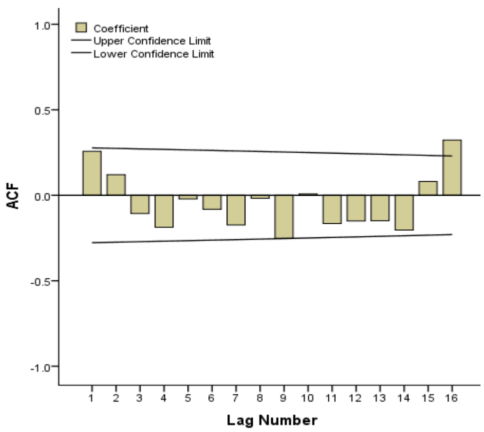

Fig. 10a: Residual ACF plot of Maximum annual daily rainfall over Enug

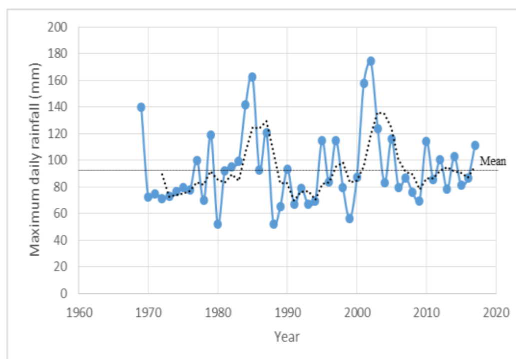

Fig. 10b: Fluctuation of Maximum annual daily rainfall over Enugu (4yrs moving Av)

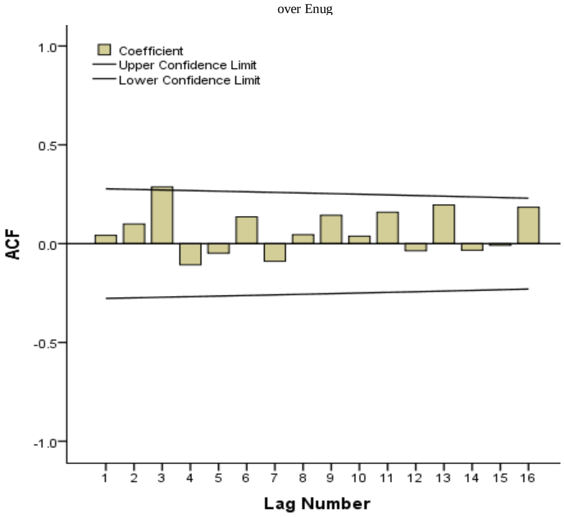

Fig. 11a: Residual ACF plot of Maximum annual daily rainfall over Owerri

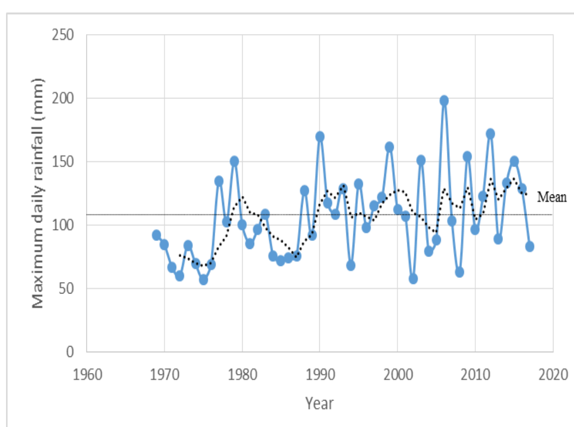

Fig. 11b: Fluctuation of Maximum annual daily rainfall over Owerri (4yrs moving Av)

Table 11: Trend Analysis for hydro-climatological variables over Kainji Dam hydropower station (1985-2017)

Synoptic Station	Mann-Kendal z-test	Significance level	Spearman's Rho z-test	Significance level	Linear Regression t-test	Significance level
Warri Station	0.121	α =0.10	0.003	α =0.10	0.04	α =0.10
Benin City	1.772	α =0.10	1.29	α =0.10	0.513	α =0.10
Calabar	0.58	α =0.10	0.602	α =0.10	-0.115	α =0.10
Port-Harcourt	1.955	α <0.1	1.87	α <0.1	2.13	α<0.05
Uyo	2.011	α<0.05	1.92	α<0.1	2.62	α<0.05
Ikeja	-0.35	α =0.10	-0.31	α =0.10	0.291	α =0.10
Ondo	1.198	α =0.10	1.24	α =0.10	0.548	α =0.10
Oshogbo	2.23	α<0.05	2.23	α<0.05	2.10	α<0.05
Enugu	1.18	α =0.10	1.23	α =0.10	0.68	α =0.10
Owerri	2.78	α<0.01	2.79	α<0.01	2.97	α<0.01

α =0.10, no evidence of statistical sig trend, α <0.1, possible evidence of statistical sig trend; α<0.05, strong evidence of statistical sign trend; α<0.01, very strong evidence of statistical sig trend

The general trend in annual maximum rainfall distribution over southern Nigeria ranges from absence of trend to strong evidence of statistical trend. In locations like Benin City, Calabar, Enugu, Ikeja, Ondo and Warri, annual maximum values did not show any evidence of statistical significant change at α = 0.1. However, for locations like Port-Harcourt, there is possible to strong evidence of increasing trend, while in Oshogbo, Owerri and Uyo, there is a general strong evidence of increasing trends at α<0.05.

4. Discussion

Results of correlogram for locations like Calabar, Port-Harcourt, Uyo, Oshogbo, Enugu, Owerri and Ikeja which show proofs of either double cycles and/or the probability of every year extreme event, suggest that these areas are highly vulnerable to extreme daily rainfall event, in particular, urban and river flooding and soil erosion. These patterns are further buttressed by results of annual daily fluctuations around means. For locations like Port-Harcourt, Uyo, Oshogbo, Owerri there is possible to strong evidence of rising extreme values. These observed pattern of rising maximum daily rainfall Nigeria have implications for the design and development of climate change adaption and mitigation measures especially in the areas of flood pre-preparedness, prevention, control and formulation of policy on pre and post disaster management. Similarly, the observed evidence of increasing rainfall will also have implication for economic development in these region as small and medium scale business owners may be impacted via access problem to costumers, operational disruption, and access problem to employees, business closure, and damage to farm land, damage to stock, supply chain disruption and damage to inside building. Flooding arising from extreme rainfall can also have implication on health and surface water pollution. Studies have reported that flooding events maybe accompanied with prevalence of diarrhea and other waterborne diseases as most sources of water are polluted [18-20]. Soil erosion in stations like Owerri, Port-Harcourt and Uyo have also been reported by authors pointing to increasing rainfall extremes and effect of rainfall erosivity in the development of soil erosion[28-30]. In Imo state for example [31] have shown that the average depth of gullies existing in Ideato North and South L.G.A ranges between 15-35 m, with a cross-sectional area of about 80metres in some places and covering a distance of about 3 km. According to [32], the erosion rate in Orlu zone between 1984-2008 has progressed from 6.58 km^2 to 31.07 km^2 and it is projected to reach 34.07 km2 by 2018. The problem associated with the observed trend patterns and AFC results for most stations in the southern Nigeria will be execrated due to land modification, rapid urban expansion and renewal leading to encroachment of adjacent rural areas for removal of soil for projects in the municipality, Land use for sand- mining, flat topography and soil types of these locations and problem of solid waste management.

5. Conclusion

The study analysed annual maximum daily rainfall frequency trend over Southern Nigeria using the Correlogram and Box –Ljung Q statistics. The finding of the study shows that the general trend in annual maximum rainfall distribution over southern Nigeria, ranges from absence of trend in locations like Benin City, Calabar, Enugu, Ikeja, Ondo and Warri, indicating that annual maximum values did not show any evidence of statistical significant change at α = 0.1, to strong evidence of statistical trend in locations like Port Harcourt, which indicates a possible to strong evidence of increasing trend, as well as locations like Oshogbo, Owerri and Uyo, where there is a general strong evidence of increasing trends at α<0.05. These observed pattern of rising maximum daily rainfall Nigeria have implications for the design and development of climate change adaption and mitigation measures especially in the areas of flood pre-preparedness, prevention, control and formulation of policy on pre and post disaster management. The study provides evidence that there has been a generally gentle decline in annual maximum daily rainfall distribution below a mean value of 105.9mm from 1970-1990 with sign of recovery from the year 2000.

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