COMPARING THE PERFORMANCE OF DIFFERENT DISTRIBUTION MODELS IN FLOOD PREDICTION: A CASE STUDY OF ZARIA, NIGERIA

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ABSTRACT

This paper sought to compare the performance of different distribution models in flood forecasting using twenty six years rainfall data of the study area (Zaria) as input variables. The study is necessitated following past flooding events in the area.Gumbel, Log Pearson Type III and Chegodayve's distribution models were employed in the modeling with the view of recommending the best fitting curve for the area. Extreme values of rainfall data obtained from Nigerian Meteorological Agency, Aviation Zaria, were used for the analyses.From the result of analyses of the twenty six years rainfall data (1989-2014), using different distribution models to predict rainfall depth that may cause flood in the area when compared to the true meteorological readings of the area, Log – Pearson Type III model produced the greatest correlation coefficient (0.90) as well as least deviation (0.1507). The average annual rainfall (AAR) for the twenty six years return periods for Gumbel, Chegodayve and Log Pearson are 1553.59, 1389.39 and 1161.69mm respectively. Based on the AAR values,Log Pearson's produced AAR that is nearer the meteorological value of 1034.34mm. The error difference for Gumbel and Chegodayve are 15% and 20% respectively in terms of their correlations with respect to Log Pearson's.At any return period (X), based on the model, the rainfall depth can be determined and compared with the available meteorological values, for flood prediction and forecasting in the area. It is recommended that more gauging stations be installedin Zaria so as to have a wider coverage and a model that will simulate the entire catchment.

KEYWORDS: *Probability distribution model, Recurrence interval, Average annual rainfall, Gumbel, Log Pearson, Chegodayve, Meteorological readings.*

INTRODUCTION

A common use of rainfall data is in the assessment of probabilities or return periods of rainfall at given location. Such data can be used in assessing flood discharges through modelling or using some empirical system of equations (Van Campenhout, et al., 2020; Alam et al.,2018; AlHass (2011). These measures have assisted Hydrologists and Civil Engineers in the design of hydraulic structures, such as bridges, culverts and other forms of drainage systems (Monthieth and Scott, 1981). Analysis of rainfall would enhance the management of water resources applications as well as in the effective flood prediction and in the design of water resources facilities,such as reservoir design, flood control work, drainage design, and soil and water conservation planning (Loucks et al.,2017). All these works require the rainfall data as a design basis (Lee, 2005). Bello (1991) and Kabir (1993) observed that some residential structures in some locations of Zaria are old buildings with no formal layout.The probability of Zaria experiencing large scale flood is high due to the low lying nature of the terrain, presence of river and changing weather patterns arising from climate change (Olanrewaju, et al., 2019; Andongma, et al., 2017). The rate of encroachment in Zaria is on the high side, as pressure for development increases. The possibility of flooding is also increasing since River Kubanni is gradually losing its flood plains to urban development (Benedine and Ahmad, 2007). It is hoped that the findings in this paper will help contribute towards solving the problems of flooding in the area. This paper sought to determine the distribution method that will produce the least probability of occurrence within the available rainfall period, as well estimate the average total rainfall depth over 26 years return period and the average annual rainfall (AAR) that correspond with the actual meteorological readings of the study area.

MATERIALS AND METHODS

The Study Area

The study was carried out in Zaria which is located between Latitude 11^{0}11'N and Longitude 738'E on an altitude of about 686m above sea level. The area is situated in the Northern Guinea Savannah ecological zone of Nigeria. It has three distinct seasons; namely the hot dry season from March to May, the warm rainy season from June to September, and a cool dry season from November to February (Oluwasemire and Alabi, 2004). The area has an average relative humidity of 36.0% during the dry season and 78.5% for the wet season. The average evaporation for the year is 1219.7mm/year (Johnson and Reuben, 2009). Rainfall intensities are mostly from 25mm/hr to 125mm/hr. (Adeiza and Lawal, 2004) and are usually higher at the beginning of the rainy seasons. Late afternoon rains are commonly large because of conventional currents which are the major source of air lift and the rains are normally accompanied by lightning and thunderstorm (Iguisi, 1994). As a result of its location, Paladan Region experiences a tropical continental climate with distinct season (Mathias et al 2011). Ashiru and Abdullahi (2012) in their work on flooding in Zaria observed that a total annual precipitation of 1118mm per year occurs in Paladan, this value is approximately equals the meteorological value of 1034.34mm and an average annual rainfall (AAR) of 86.24mm with a peak in August. The map of Zaria showing different locations is shown in Figure 1

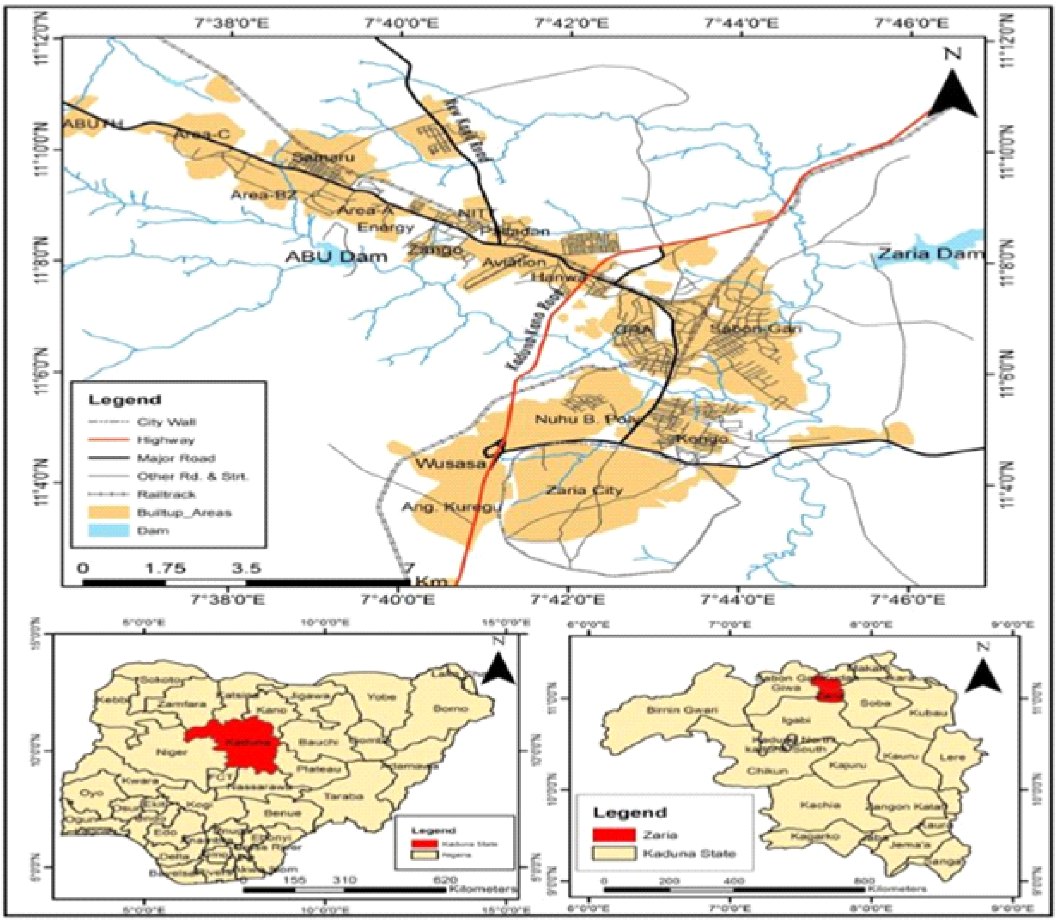

Figure 1: Map of Zaria Area showing the Kubanni River and dam

Source: Satellite Imagery (Lawal et al., 2017).

2.2 Methods

In order to achieve a comprehensive and concise result in this work, different methods of fitting distribution curves were used so as to know the one that best fits the study area. Some of the methods compared are as follows:

1. Gumbel distribution method
2. Log Pearson Type III Distribution
3. Probability plotting method

For each of the above mentioned distributions, the following information was obtained:

1. Estimation of parameters of the distribution.
2. A table of rainfalls of specified exceedence probabilities or return periods with confidence limits.
3. A graphical plot of the data fitted to the distribution.

2.3 Materials

For the execution of this paper, twenty six years rainfall data (1989 - 2014) was used and obtained from Nigerian Meteorological Agency, Aviation Zaria. Most of the analyses were conducted using Microsoft excel.

2.4 Descriptions of Log-Pearson Type III method

In the Log-Pearson method of distribution, the mean, standard deviation and skewness co-efficient are the basic variables used for the analysis. These variables were computed from the available rainfall data. Also of importance are the return periods (T_r) and the probability of occurrence (P). The rainfall data were arranged chronologically, in ascending order and then ranked. Formulae used to achieve Log-Pearson Type III analysis for this paper are highlighted below:

i. Probability of occurrence, $P = \frac{1}{T_r}$ i

ii. Return period, $T_r) = \frac{1}{P}$ ii

iii. Mean rainfall, $\bar{x} = \frac{\Sigma x}{N}$ iii

iv. Standard deviation, $\sigma = \sqrt{\frac{\Sigma x^2 - (\frac{(\Sigma x)^2}{N})}{N-1}}$ iv

v. Coefficient of skewness, = $C_s = \frac{N\Sigma(X-\bar{x})}{(N-1)(N-2)\sigma^3}$ v

There are several methods of fitting frequency lines for any distribution. For the purpose of this paper, two methods were adopted, namely the mean and standard deviation method. The frequency line equation for the standard deviation method is given as:

Log $P_T = K\sigma + x?$ vi

P_T is found by taking the antilog of $(K\sigma + x)$

$P_{T = \text{antilog}}(K\sigma + x)$ vii

To obtain the frequency line, P_T is plotted against return period T on a log-normal probability graph.

2.5 Gumbel distribution method

Just like Log- Pearson method of distribution, the Gumbel method also has the mean, standard deviation and skewness co-efficient as the basic variables used for the analysis. These variables were computed from the available rainfall data. Also of importance are the return periods (T_r) and the probability of occurrence (P). Arrangement of rainfall data were done chronologically, in ascending order and then ranked as done in the former. Some of the equations used to achieve Gumbel analysis for this paper are highlighted below:

i. Mean, $\bar{x} = \frac{\sum_{i=1}^{26} X}{N}$ viii

ii. Standard deviation, $\sqrt{\frac{\sum_{i=1}^{26}(x-\bar{x})^2}{(N-1)}}$ ix

iii. Return period, $T = \frac{N+1}{M}$ x

iv. $C_V = \frac{\beta\pi}{(\mu + 0.5772\beta)\sqrt{6}}$ xi

Where: The scale parameter = $\beta = \frac{\sigma\sqrt{6}}{\pi}$ xii

The total rainfall or precipitation at a return T for extreme value distribution is given by Gumbel (1954) as:

$X_T \quad \bar{x} \quad K_T\delta$ xiii

2.6 Probability method

For probability plotting, Chegodayve's and Weibul's frequency distribution methods were considered.

2.6.1 Chegodayve's method

This is basically probabilistic in approach. Some of the equations used for Chegodayve are as follows:

i. Mean, $\bar{x} = \frac{\sum_{i=1}^{26} X}{N}$ xiv

ii. $K_1 = \frac{x_i}{\bar{x}}$ xv

iii. Standard deviation, $\sigma = \sqrt{\frac{\Sigma(K_1-1)^2}{n-1}}$ xvi

iv. coefficient of skewness, $(C_s) = \frac{\Sigma(K_1-1)^3}{(n-1)\sigma^3}$ *xvii*

v. Coefficient of variation $(C_v = \frac{\sigma}{\bar{x}}$ *xviii*

vi. Return period = $\frac{N+0.4}{M-0.3}$ xix

2.6.2 Weibul's method

The mean and the coefficient of variation are calculated as equation **viii** and **xviii** respectively. The standard deviation is calculated as:

i. Standard deviation, $\delta = \sqrt{\frac{\sum_{i=1}^{26}(x-\bar{x})^2}{N}}$ xx

ii. Return period = $\frac{N+1}{M}$ xxi

3. RESULT AND DISCUSSIONS

3.1 Rainfall data

Twenty six (1989-2014) years rainfall data used for the study area was obtained from Nigerian Meteorological Agency, Aviation Zaria. The rainfall data is presented in Table 3.1.

Table 3.1 : Twenty six years (26) rainfall data for Zaria(mm)

year	Ja	Fe	Mr	Ap	Ma	Ju	Jul	Au	Se	Oc	No	De	Mi	Max	To	Av
1989	**0.00**	0.00	0.00	21.50	110.10	89.30	146.40	286.70	68.10	53.50	0.00	0.00	0.00	286.700	775.6	64.63
1990	**0.00**	0.00	0.00	2.30	163.20	152.60	197.30	192.90	156.90	3.00	0.00	2.70	0.00	197.300	870.9	72.58
1991	**0.00**	0.00	42.20	75.50	323.10	100.30	350.50	366.50	75.90	30.70	0.00	0.00	0.00	366.500	1364.7	113.7
1992	**0.00**	0.00	0.00	36.60	115.30	81.40	274.80	216.70	242.40	6.20	2.40	0.00	0.00	274.800	975.8	81.32
1993	**0.00**	0.00	1.30	38.90	83.60	88.00	244.30	281.90	199.70	18.80	0.00	0.00	0.00	281.900	956.5	79.71
1994	**0.00**	0.00	0.00	33.70	78.70	137.10	125.50	352.40	205.00	166.60	0.00	0.00	0.00	352.400	1099	91.58
1995	**0.00**	0.00	0.00	59.10	103.00	153.70	233.70	294.30	112.00	32.90	0.00	0.00	0.00	294.300	988.7	82.39
1996	**0.00**	0.00	0.00	8.90	149.60	186.30	184.80	267.00	173.50	59.90	0.00	0.00	0.00	267.000	1030	85.83
1997	**0.00**	0.00	0.00	29.40	176.90	146.80	232.80	355.70	192.30	64.90	0.00	0.00	0.00	355.700	1198.8	99.9
1998	**0.00**	0.00	0.00	33.40	123.30	144.00	184.30	473.10	236.80	71.40	0.00	0.00	0.00	473.100	1266.3	105.5
1999	**0.00**	0.00	6.90	10.50	7.20	229.50	245.70	144.10	268.20	78.00	0.00	0.00	0.00	268.200	990.1	82.51
2000	**0.00**	0.00	0.00	17.68	10.76	157.10	268.00	298.40	177.70	36.30	0.00	0.00	0.00	298.400	965.94	80.5
2001	**0.00**	0.00	0.00	99.80	100.40	189.00	255.70	244.90	312.60	0.00	0.00	0.00	0.00	312.600	1202.4	100.2
2002	**0.00**	0.00	26.40	35.00	10.90	85.90	181.20	210.20	200.10	128.70	0.00	0.00	0.00	210.200	878.4	73.2
2003	**0.00**	0.00	0.00	55.70	107.30	74.50	254.30	407.20	238.20	62.50	0.00	0.00	0.00	407.200	1199.7	99.98
2004	**0.00**	0.00	0.00	34.80	103.90	239.00	284.40	296.90	186.30	23.90	0.00	0.00	0.00	296.900	1169.2	97.43
2005	**0.00**	0.00	0.00	28.10	62.10	179.50	168.60	291.90	85.70	10.70	0.00	0.00	0.00	291.900	826.6	68.88
2006	**0.00**	0.00	0.00	1.50	84.10	125.50	235.80	207.40	356.00	29.20	0.00	0.00	0.00	356.000	1039.5	86.63
2007	**0.00**	0.00	7.00	44.90	239.60	210.20	213.50	457.80	42.90	3.80	0.00	0.00	0.00	457.800	1219.7	101.6
2008	**0.00**	0.00	0.00	36.00	66.00	90.10	120.20	250.70	274.00	16.10	0.00	0.00	0.00	274.000	853.1	71.09
2009	**0.00**	0.00	0.00	14.00	79.60	156.90	191.80	342.70	138.00	55.80	0.00	0.00	0.00	342.700	978.8	81.57
2010	**0.00**	0.00	0.00	41.00	105.90	135.00	219.30	302.40	205.30	83.70	0.00	0.00	0.00	302.400	1092.6	91.05
2011	**0.00**	0.00	0.00	21.00	87.92	120.60	317.00	297.70	181.50	28.50	0.00	0.00	0.00	317.000	1054.22	87.85
2012	**0.00**	0.00	0.00	16.70	270.00	143.70	282.00	396.10	213.10	84.70	0.00	0.00	0.00	396.100	1406.3	117.2
2013	**0.00**	0.00	0.80	92.80	42.80	203.70	308.50	276.00	228.80	11.50	0.00	0.00	0.00	308.500	1164.9	97.08
2014	**0.00**	0.00	0.00	88.70	75.50	171.50	148.60	313.00	226.10	64.70	0.00	0.00	0.00	313.000	1088.1	90.68

Source: Nigerian Metrological Agency, Aviation Zaria

Extreme rainfall values were used for the computations of mean, standard deviation, coefficient of skewness, coefficient of variation, return period and other variables that facilitated the analyses.

3.2 Gumbel distribution analysis

The result of analysis based on Gumbel is presented in Table 3.2. Extreme rainfall data for the study area have been used in the analysis, in chronological descending order.

Table 3.2: Result of Gumbel analysis

Ranking	Year	Extreme value(mm)	Return period	Probality	Deviation	Deviation
(M)		(X)	(T= (N+1)/M)	P =		
1	2012	1406.30	27	3.70	342.62	117388.99
2	1991	1364.70	13.50	7.41	1364.70	1862406.09
3	1998	1266.30	9.00	11.11	1266.30	1603515.69
4	2007	1219.70	6.75	14.81	1219.70	1487668.09
5	2001	1202.40	5.40	22.22	1202.40	1445765.76
6	2003	1199.70	4.50	25.93	1199.70	1439280.09
7	1997	1198.80	3.85	33.33	1198.80	1437121.44
8	2004	1169.20	3.38	37.04	1169.20	1367028.64
9	2013	1164.90	3.00	40.74	1164.90	1356992.01
10	1994	1099.00	2.70	44.44	1099.00	1207801
11	2010	1092.60	2.45	48.15	1092.60	1193774.76
12	2014	1088.10	2.25	44.40	1088.10	1183961.61
13	2011	1054.22	2.08	48.10	1054.22	1111379.81
14	2006	1039.50	1.93	51.80	1039.50	1080560.25
15	1996	1030.00	1.80	55.60	1030.00	1060900.00
16	1999	990.10	1.69	59.30	990.10	980298.01
17	1995	988.70	1.59	63.00	988.70	977527.69
18	2009	978.80	1.50	66.70	978.80	958049.44
19	1992	975.60	1.42	70.40	975.60	951795.36
20	2000	965.94	1.35	74.10	965.94	933040.08
21	1993	956.50	1.29	77.80	956.50	914892.25
22	2002	878.40	1.23	81.50	878.40	771586.56
23	1990	870.90	1.17	85.20	870.90	758466.81
24	2008	853.10	1.13	88.90	853.10	727779.61
25	2005	826.60	1.08	92.60	826.60	683267.56
26	1989	775.60	1.04	96.30	775.60	601555.36
	Total					**28213802.96**

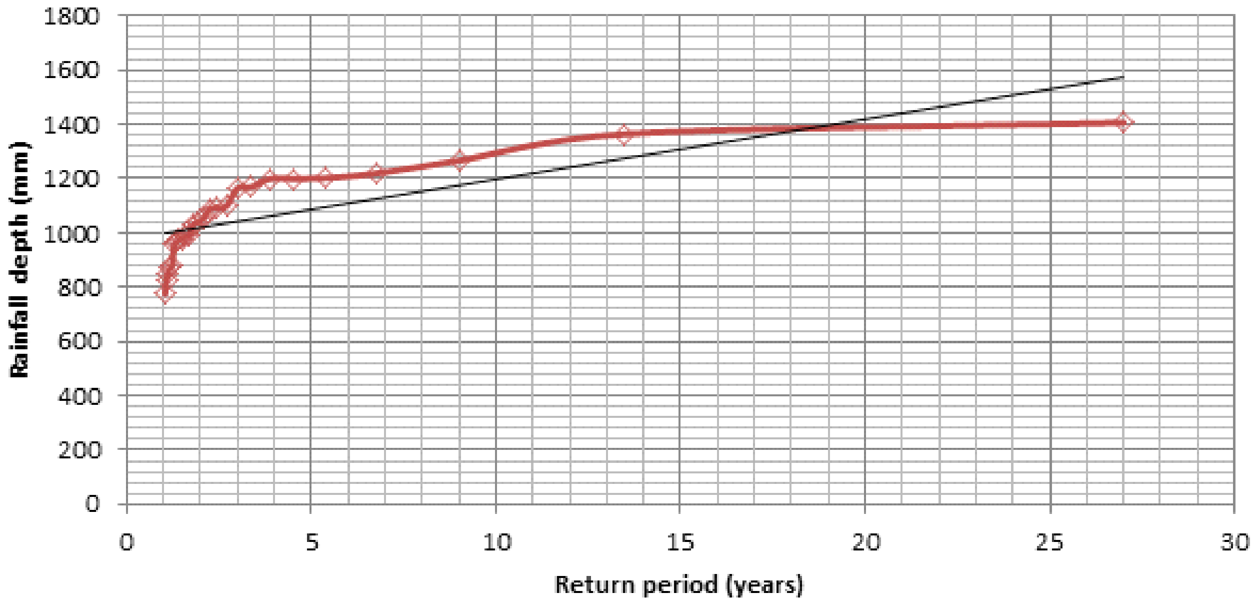

Figure2: Graph of Gumbel

3.3 Chegodayve's analysis

The result of analysis based on Chegodayve's analysis is presented in Table 3.3. Extreme rainfall data for the study area have also been used in the analysis, in chronological descending order.

Table 3.3: Result of Chegodayve's analysis

Ranking	Year	Extreme	Return period	K- factor			
m		X	$T = \frac{N+0.4}{M-0.3}$ (year)	k1	(k1 -1)	(K1-1)^2	(K1 -1)^3
1	2012	1406.30	37.71	1.322109	0.32211	0.103754	0.03342
2	1991	1364.70	15.53	1.283	0.283	0.080089	0.022665
3	1998	1266.30	9.78	1.19049	0.19049	0.036287	0.006912
4	2007	1219.70	7.14	1.14668	0.14668	0.021515	0.003156
5	2001	1202.40	5.62	1.130416	0.13042	0.017008	0.002218
6	2003	1199.70	4.63	1.127878	0.12788	0.016353	0.002091
7	1997	1198.80	3.94	1.127032	0.12703	0.016137	0.00205
8	2004	1169.20	3.43	1.099204	0.0992	0.009841	0.000976
9	2013	1164.90	3.03	1.095161	0.09516	0.009056	0.000862
10	1994	1099.00	2.72	1.033206	0.03321	0.001103	3.66E-05
11	2010	1092.60	2.47	1.027189	0.02719	0.000739	2.01E-05
12	2014	1088.10	2.26	1.022959	0.02296	0.000527	1.21E-05
13	2011	1054.22	2.08	0.991107	-0.0089	7.91E-05	-7E-07
14	2006	1039.50	1.93	0.977268	-0.0227	0.000517	-1.2E-05
15	1996	1030.00	1.80	0.968337	-0.0317	0.001003	-3.2E-05

16	1999	990.10	1.68	0.930826	-0.0692	0.004785	-0.00033
17	1995	988.70	1.58	0.92951	-0.0705	0.004969	-0.00035
18	2009	978.80	1.49	0.920202	-0.0798	0.006368	-0.00051
19	1992	975.60	1.41	0.917194	-0.0828	0.006857	-0.00057
20	2000	965.94	1.34	0.908112	-0.0919	0.008443	-0.00078
21	1993	956.50	1.28	0.899237	-0.1008	0.010153	-0.00102
22	2002	878.40	1.22	0.825813	-0.1742	0.030341	-0.00529
23	1990	870.90	1.16	0.818762	-0.1812	0.032847	-0.00595
24	2008	853.10	1.11	0.802028	-0.198	0.039193	-0.00776
25	2005	826.60	1.07	0.777114	-0.2229	0.049678	-0.01107
26	1989	775.60	1.03	0.729167	-0.2708	0.07335	-0.01987
	Mean:	1063.68					
	Total					0.58099	0.020884

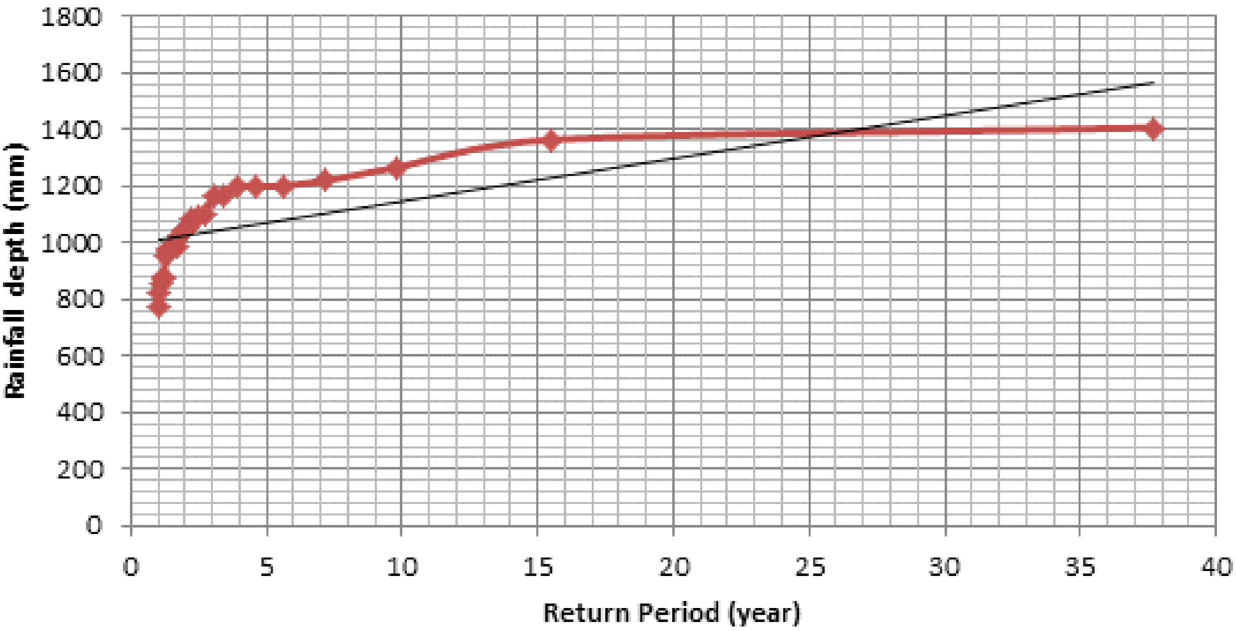

Figure3: Graph of Chegodayve

3.4 Log-Pearson Type III analysis

The result of analysis based on Log – Pearson Type III analysis is presented in Table 3.4 The rainfall depth at a particular return period, P_T of focus is calculated by taking the antilog of $(K\sigma + \bar{x})$. From the graph the rainfall depth is 680mm

Table 3.4: Result of Log – Pearson Type III analysis

Rankin g	Year	Ext. value(mm	Return period		Deviations					
M		Xr	T= N+1/M	X=LogXr	X^2	(X- x̄)		K	(Kσ + x̄)	Anti(K + x̄)
1	2012	1406.3	27	3.14808	9.91	6.89	327.08	-2	2.890993	778.0240017
2	1991	1364.7	13.5	3.13504	9.83	9.83	949.86	-1.7	2.911833	816.2687187
3	1998	1266.3	9	3.10254	9.63	9.56	873.72	-1.3	2.93565	862.2824137
4	2007	1219.7	6.75	3.08625	9.52	9.52	862.80	-1.2	2.943236	877.4779731
5	2001	1202.4	5.4	3.08005	9.49	9.49	854.67	-1.1	2.950371	892.0129737
6	2003	1199.7	4.5	3.07907	9.48	9.48	851.97	-1	2.95744	906.65004
7	1997	1198.8	3.857143	3.07875	9.48	9.48	851.97	-0.9	2.964541	921.5977714
8	2004	1169.2	3.375	3.06789	9.41	9.41	833.23	-0.8	2.968069	929.1140545
9	2013	1164.9	3	3.06629	9.4	9.4	830'58	-0.7	2.975284	944.6777732
10	1994	1099	2.7	3.041	9.25	9.25	791.45	-0.4	2.994543	987.5128165
11	2010	1092.6	2.454545	3.03846	9.23	9.23	786.33	-0.3	2.999047	997.8078713
12	2014	1088.1	2.25	3.03667	9.22	9.22	783.78	-0.3	3.003425	1007.917271
13	2011	1054.22	2.076923	3.02293	9.14	9.14	763.55	-0.2	3.011609	1027.092321
14	2006	1039.5	1.928571	3.01682	9.1	9.1	753.57	-0.1	3.015722	1036.863794
15	1996	1030	1.8	3.01284	9.08	9.08	748.61	-0	3.019894	1046.872346
16	1999	990.1	1.6875	2.99568	8.97	8.97	721.73	0.03	3.024099	1057.058352
17	1995	988.7	1.588235	2.99506	8.97	8.97	721.73	0.1	3.028278	1067.278162
18	2009	978.8	1.5	2.99069	8.94	8.94	714.52	0.21	3.036216	1086.967139
19	1992	975.6	1.421053	2.98927	8.94	8.94	714.52	0.41	3.049204	1119.964212
20	2000	965.94	1.35	2.98495	8.91	8.91	707.35	0.48	3.05406	1132.557934
21	1993	956.5	1.285714	2.98068	8.88	8.88	700.23	0.55	3.058724	1144.78532
22	2002	878.4	1.227273	2.94369	8.67	8.67	651.71	0.87	3.079757	1201.591555
23	1990	870.9	1.173913	2.93997	8.64	8.64	644.97	0.96	3.085576	1217.8013

24	2008	853.1	1.125	2.931	8.59	8.59	633.84	1.08	3.093847	1241.216077
25	2005	826.6	1.08	2.9173	8.51	8.51	616.30	1.47	3.119584	1316.993685
26	1989	775.6	1.038462	2.88964	8.35	8.35	582.18	1.67	3.13291	1358.032719
	Mean:	3.02195								
	Total						18441.67	-4		
	σ	0.06643								

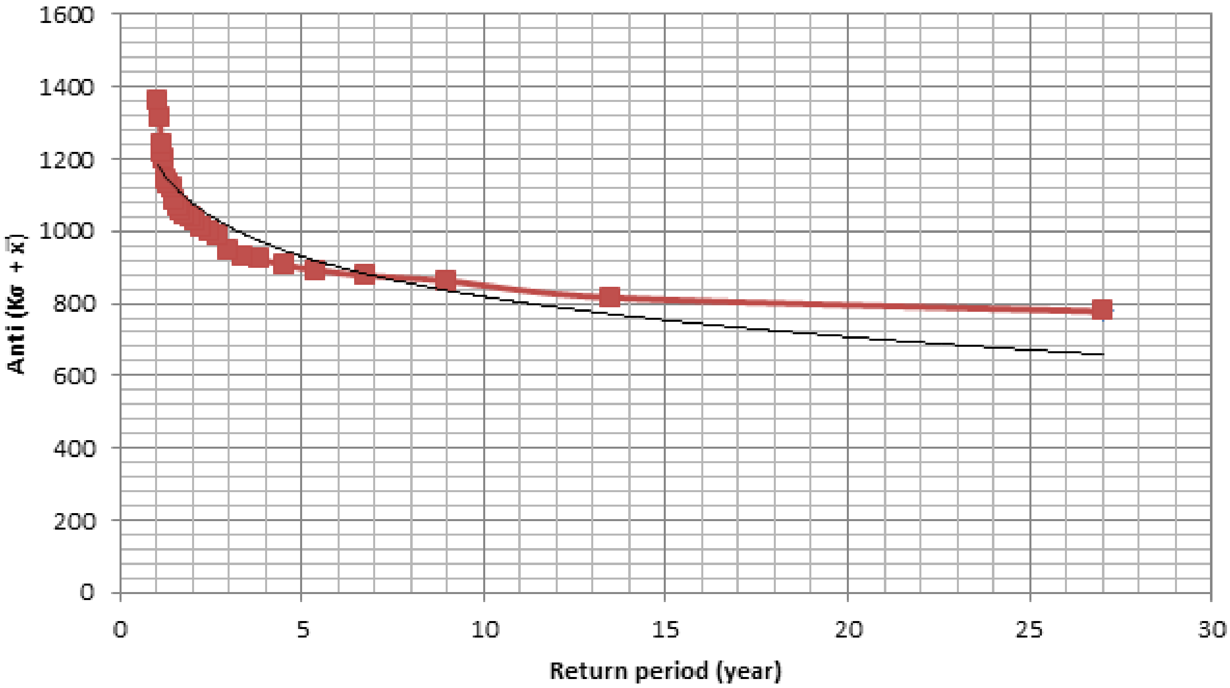

Figure 4: Graph of Log Pearson Type III

4. DISCUSSIONS OF RESULT

The deviations for the results of analyses of Log Person, Chegodayve and Gumbel are 0.1507, 0.1524 and 162.15 respectively. Result of Log Person Type III indicates least deviation (0.1507) when compared with others. The rainfall model for the three distributions is presented in Table 4.1. Log Pearson' distribution appears to be the suitable model for rainfall amount for the study area with the greatest correlation coefficient (0.90) closer to 1.0. At any return period (x) , the rainfall depth can be determined and compared with the available meteorological values, for flood prediction and forecasting in the area as presented in Table 4.1

Table 4.1: Established model for the study area

	Distribution models		
	Gumbel	Chegodayve	Log Pearson
Rainfall Model () in (mm)	$Y = 22.271x + 974.54$	$Y = 15.188x + 994.5$	$Y = -8.23\ln(x) + 1188.5$
Correlation	R = 0.75	0.70	R = 0.90
Rainfall for Twenty six years teturn period,	1553.59	1389.39	1161.69
Least deviation	162.15	0.1524	0.1507
Meteorological value for Twenty six years return period (mm)	1034.34		

5. CONCLUSION

From the result of analysis of twenty six years rainfall data (1989-2014) of Zaria, using different distribution models to predict rainfall depth that may cause flood in the area when compared to the true meteorological readings of the area. Log – Pearson Type III model produced the highest correlation coefficient (0.90) as well as least deviation (0.1507). This will no doubt help in flood prediction in the area when used. The average annual rainfall (AAR) for the twenty six years return periods for Gumbel, Chegodayve and Log Pearson are 1553.59, 1389.39 and 1161.69mm respectively. Based on the AAR values, Log Pearson's produced AAR that is nearer the meteorological value of 1034.34mm. The error difference for Gumbel and Chegodayve are 15% and 20% respectively in terms of their correlations with respect to Log-Pearson's. It is recommended that more gauging stations be made available in Zaria so as to have a wider coverage and a model that will reflect the entire catchment.

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