ANNUAL FLOOD DISCHARGE ANALYSIS OF RIVER OYAN AT IWAJOWA OYO STATE, NIGERIA

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Abstract

Flood analysis procedure was performed on annual discharge data for River Oyan in Oyo State Nigeria for the period of 1988 to 2010 utilizing five probability distribution models namely: Normal, Log-Normal, Gumbel or Extreme Value Type I, Log-Pearson Type III, Gamma or Pearson Type III and New Model. The models were used to predict flood discharge estimates at 2, 5, 10, 25, 100, and 200 years return periods. The results indicated that the Normal distribution predicted discharge values ranging from 8633.35 m^3/s for two years to 17768.07 m^3/s for 200 years return period, the Log- Normal distribution predicted discharge values ranging from 7894.05 m^3/s for two years to 25113.08 m^3/s for 200 years return period, the Gumbel or Extreme value Type I distribution predicted discharge values ranging from 8056.25 m^3/s for two years to 21557.55 m^3/s for 200 years return period, the Log–Pearson Type III distribution predicted discharge values ranging from 8194.08 m^3/s for two years to 20351.67 m^3/s for 200 years return period, the Gamma or Pearson Type III distribution predicted discharge values ranging from 8285.53 m^3/s for two years to 19317.46 m^3/s for 200 years return period. From the result, Gamma or Pearson Type III, was found most suitable for flood estimation of River Oyan, based on goodness of Fit test using Chi-Square analysis. Future researchers should include more probability distributions; also precision of flood data should be improved by taking data for a longer period of time.

Key words: River Oyan, Flood Discharge, Frequency Distribution, Goodness of Fit.

1. INTRODUCTION

Though flood water is an essential water resource in many countries and flood plains hold many benefits for the society. They can also be the causes of huge losses of lives, livelihoods and property, and can be a hindrance to socioeconomic development. Hydrological process like floods is one of the most destructive natural disasters that occur in most parts of the world and have been identified as the costliest natural hazards having great propensity to destroy human lives and properties (Jacob and Osadolor, 2013).

To manage flood risk successfully, knowledge is needed of both magnitudes of any given flood and an estimate of likelihood of its occurrence. The design and construction of certain projects such as dams and urban drainage systems, the management of water resources and prevention of flood damage requires adequate knowledge of extreme events of high return periods (Tao *et al*., 2002). Thus, the study is aimed at determining the best fit probability distribution model to flood data obtained from River Oyan..

2. FREQUENCY ANALYSIS PRINCIPLES

Normal Distribution

The general formula for the Probability Density Function (PDF) of the normal distribution is given by NIST/SEMATECH (2006) as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\overline{x})^2}{2\sigma^2}\right) \qquad \text{.......... (1)}$$

Where $\bar{x}$ = mean δ = standard deviation, which is evaluated by

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} Xi \qquad \text{.......... (2)}$$

Where, *xi* is the magnitude of the ith event and *N* is the total number of events.

The standard deviation (σ) which is a measure of the dispersion or spread of data set is given by the equation

$$\sigma = \left[\frac{\sum_{i=1}^{N}(x-\overline{x})^2}{N-1}\right]^{½} \qquad \text{.......... (3)}$$

The normal distribution describes many random processes but does not provide satisfactory fit for flood discharge and other hydrologic data (Jacob and Osadolor, 2013).

Log-normal Distribution

The log-normal distribution assumes that the logarithms of the discharge are themselves normally distributed. It is obtained from the normal distribution if the following substitutions are made (Jacob and Osadolor 2013).

$$Y_i = logX_i \qquad \text{.......... (4)}$$

Based on logarithm of each value, the mean and standard deviation becomes:

$$log\bar{x} = \frac{1}{N}\sum_{i=1}^{N} logX_i \qquad \text{.......... (5)}$$

$$\sigma logx = \left[\frac{\sum_{i=1}^{N}(logX_{i-} \; log\,\overline{x})^2}{N-1}\right]^{½} \quad \text{……………………………………………………… (6)}$$

The probability of exceedence is related to the occurrence of particular values by the expression given by:

$$logX = log\bar{X} + K\sigma_{logx} \quad \text{……………………………………………………… (7)}$$

Where, k is the frequency factor.

Extreme value Type 1 distribution or Gumbel distribution

Extreme value Type I or Gumbel distribution is one of the most commonly used distribution in flood frequency. This was first proposed by Gumbel (1958) and was based on the theory of extremes. The distribution is unbounded on both lower and upper ends and negative values are usually not a problem. The probability distribution function is not required and the cumulative distribution function (CDF) can be computed without recourse to tables.

Its probability distribution function (PDF) is given by Jacob and Osadolor (2013) as:

$$f(x) = \exp^{-e^{-\alpha(x-\mu)}} \quad (-\infty < x < \infty) \qquad (8)$$

The parameters are estimated by the equation:

$$\alpha = \frac{\sqrt{6}}{\pi}\sigma \qquad (9)$$

$$u = \bar{x} - 0.5772\alpha \qquad (10)$$

Where $\propto$ is a scale parameter, and u is the mode of distribution.

A reduced variate y is defined as:

$$y = \frac{x-u}{\propto} \qquad (11)$$

For a given return period T, the reduce variate (Y_T) is given as:

$$Y_T = -ln\left[ln\,(\frac{T}{T-1})\right] \quad (12)$$

For the extreme value type 1 distribution, X_T is related to Y_T by the equation given by:

$$X_T = u + \propto y_T \quad (13)$$

The extreme value distributions have been widely used in hydrology and they form the basis for the standardized method of flood frequency analysis in Great Britain.

Log-pearson Type III Distribution

The Log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood for a river at some site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. This technique is the standard technique used by Federal Agencies in the United States. It is calculated using the formula:

$$logx = log\bar{x} + k\sigma_{logx} \quad (14)$$

Where x is the flood discharge value of some specified probability, $log\bar{x}$ is the average of the *log x* discharge values, K is a frequency factor, and σ is the standard deviation of the *log x* values. The frequency factor K is a function of the skewness coefficient and return period and can be found using the frequency factor table. The flood magnitudes for the various return periods are found by solving the general equation. The mean, variance, and standard deviation of the data can be calculated using Equations (15), (16) and (17) below.

$$\text{Mean } log\bar{x} = \frac{\sum(logx_i)}{n} \quad (15)$$

$$\text{Variance} = \frac{[\sum_i^n(logQ - avg(logQ)]^2}{n-1} \quad (16)$$

$$\text{Standard deviation } \sigma_{logx} = \frac{\sqrt{\sum(logx - \log\bar{x})^2}}{n-1} \quad or \quad \sigma logQ = \sqrt{variance} \quad (17)$$

The skewness coefficient C_s can be calculated as follows:

$$C_S = \frac{n\sum(logx - \log\bar{x})^2}{(n-1)(n-2)(\sigma_{logx})^3} \quad (18)$$

Where n is the number of entries, x the flood of some specified probability and σ_{logx} is the standard deviation (Oregon State University FFA) *http://water.oregonstate.edu/streamflow/*

Gamma or Pearson Type III Distribution

This is one of the commonly used distributions in hydrology because of its shape and its well known mathematical properties. It has three parameters and is bound in the left with positive skewness. The three parameters are mean, variance and skewness, but the CDF (cumulative distribution function) can be evaluated using the frequency factor. The frequency factor K is a function of the skewness and the return period. To evaluate the T-yrs flood, the probability distribution function given below by Jacob and Osadolor (2013) is being used.

$$Q_T = \bar{x} + k\sigma \quad (19)$$

Where $\bar{x}$ is the mean and σ is the standard deviation.

Goodness of Fit Test

The chi-squared test, x^2 is one of the versatile and popular statistics available for data analysis and significance testing.It is used to compare differences between observed and expected frequencies. The observed frequencies are those obtained after an observation or experiment has been carried out (data actually collected from field). The expected frequencies are generated on the basis of hypothesis or speculation (Odu and Ihejiamaizu, 2001).

According to Yadav and Lal (1998). Chi-Squared test is used to determine the goodness of fit of distribution of annual peak flow. It is given by

$$x^2 = \sum \frac{(b-c)^2}{c} \tag{20}$$

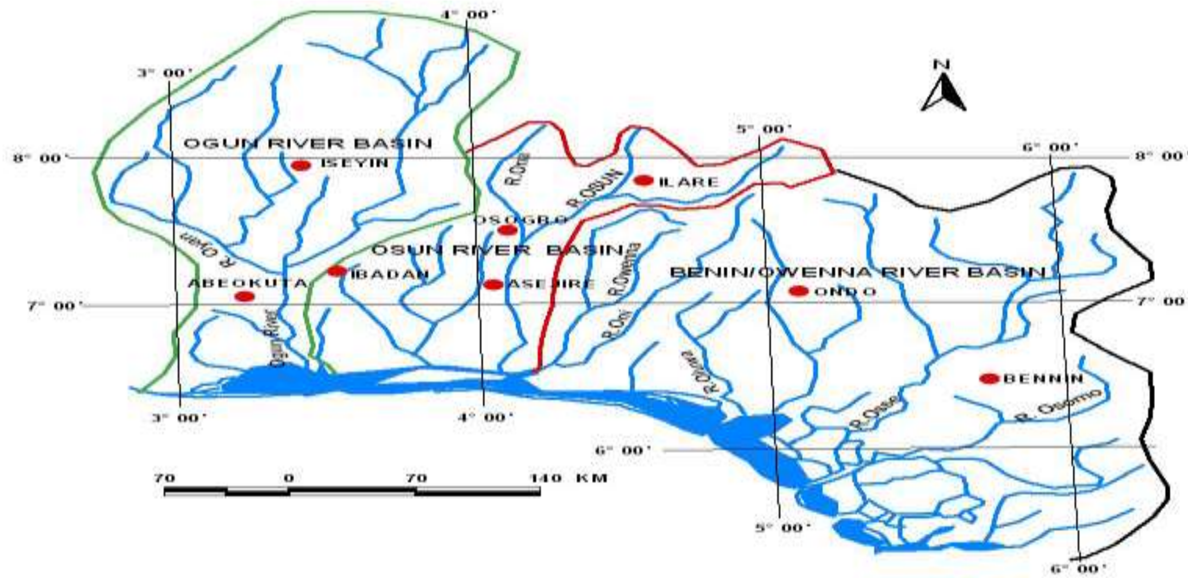
b = Number of observed frequencies, c= Expected frequencies

In a Chi-Square test, a critical value x_0^2 of x^2 for a significance level $\propto$, so that $x^2 < x_0^2$, Null hypothesis of good fit is accepted. For $x^2 \geq x_0^2$, Null hypothesis of good fit is rejected. The value of $x_0^2$is usually obtained for a given number of degree of freedom (NDF) at a particular level of significance $\propto$ usually taken as 5%from standard statistics text book.

3. METHODOLOGY

The Study Area

River Oyan also known as River Awayne at Iwajowa village is located in the Southwestern Nigeria in Oyo State. It is located at an elevation of 30.4 meters above sea level in Africa/middle east; having coordinates $7^0 55' 59''$N and $3^0 2' 59''$E in DMS (Degree Minutes Seconds). The River has a link with the Ogun River which geographically lies between latitudes 6º 26' N and 9º 10'N and longitudes 2º 28'E and 4º 8'E. The rivers linking the Ogun River are the Oyan, Ofiki and Opeki Rivers. Two seasons are distinguishable in the region; a dry season from November to March and a wet season between April and October estimated at between 1600 and 1900 mm. (OORBDA, 1980). A map showing River Oyan is shown in Figure 1 below



Source: (ORBDA, 2011) ***Figure 1:*** *Map showing River Opeki*

Data Collection/ Analysis

Discharge data of River Oyan for a period 23 years from 1988 to 2010 was obtained from the OORBD (Ogun-Oshun River Basin Development). The collected data was subjected to FFA (flood frequency analysis), utilizing the four probability distribution models

The mean, variance, standard deviation, and skew coefficient to each of the models were calculated where applicable.

Estimates of the recurrence interval (T) was obtained using Equation (12) and the Weibull formula as $T = \frac{n+1}{m}$ (21)

where, n = number of years of record and m = rank obtained by arranging the annual flood series in descending order of magnitude with the maximum being assigned the rank of 1.

Test for goodness of fit was determined by using the Chi-Square test. The Z value for the different T (yrs) for normal distribution and its discharge were calculated using the equations below.

$$f(z) = 1 - \frac{1}{T} \tag{22}$$

$$Q = \bar{x} + Z\sigma \tag{23}$$

Where Z is the standard normal variate and corresponds to the frequency factor, $\bar{\mathbf{x}}$ is the mean and $\boldsymbol{\sigma}$ is the standard deviation.

Estimated T (yrs.) flood were transformed to the original equation by computing its exponent as

$$Q_T = 10^{Y_T} \tag{24}$$

4. RESULTS AND DISCUSSIONS

Arranging the annual flood series in descending order of magnitude with the maximum being assigned the rank of 1 as shown below

Table 1: Data for Normal Distribution

RANK	X or Q (m^2/s)	RANK	X or Q (m^2/s)
1	18478.99	14	7672.36
2	12527.98	15	7468.16
3	12343.67	16	6971.8
4	1128.61	17	6833.15
5	11696.65	18	5441.85
6	10961.25	19	5219.9
7	10190.19	20	4827.1
8	10126.45	21	4162.25
9	9594.27	22	3484.69
10	9649.36	23	2987.79
11	9444.95	Mean $\bar{x}$	8633.351
12	8597.1	STDEV σ	3513.355
13	7758.55		

The Z value for the different T (yrs) is calculated using the formula below.

$$\boldsymbol{f(z) = 1 - \frac{1}{T}}$$ ………………………………………………………………………… (22)

Obtaining Z from the normal distribution table, thus Table 5 below

Table 2: Z values for Normal Distribution (interpolated from normal table)

T (yrs)	$F(z) = 1 - \frac{1}{T}$	Z
2	0.5	0.0
5	0.8	0.85
10	0.9	1.30
25	0.96	1.80
50	0.98	2.10
100	0.99	2.33
200	0.995	2.60

Upon substituting of the value of $\bar{x}$ and σ in the equation below for the different values of Z, the estimated discharges Q are obtained in Table 6 below.

$$Q = \bar{x} + Z\sigma \quad \text{……………………………………………………………………………… (23)}$$

Table 3: Application of Normal Distribution to the observed data

T (yrs)	Z	σ	$Z\sigma$	$\bar{x}$	$Q = \bar{x} + Z\sigma$ (m^2/s)
2	0.0	3513.355	0.0	8633.351	8633.35
5	0.85	3513.355	2986.352	8633.351	11619.70
10	1.30	3513.355	4567.362	8633.351	13200.71
25	1.80	3513.355	6324.039	8633.351	14957.39
50	2.10	3513.355	7378.046	8633.351	16011.39
100	2.33	3513.355	8186.117	8633.351	16819.47
200	2.60	3513.355	9134.723	8633.351	17768.07

Table 4: Data for Log- normal Distribution

Rank	X OR Q (m^2/s)	Log X	Rank	X OR Q (m^2/s)	Log X
1	18478.99	4.2666	14	7672.36	3.8849
2	12527.98	4.0978	15	7468.16	3.8732
3	12343.67	4.0914	16	6971.8	3.8433
4	12128.61	4.0838	17	6833.15	3.8346
5	11696.65	4.0680	18	5441.85	3.73367
6	10961.25	4.0398	19	5219.9	3.7176
7	10190.19	4.0081	20	4827.1	3.6836
8	10126.45	4.0054	21	4162.25	3.6193
9	9594.27	3.9820	22	3484.69	3.5421
10	9649.36	3.9844	23	2987.79	3.4753
11	9444.95	3.9751	Mean log $\bar{x}$		3.8973
12	8597.1	3.9343	STDEV $\sigma log x$		0.1951
13	7758.55	3.8897			

The Log-Normal Distribution has a positive skewness because it is bounded on the left by zero. $C_S = 0$. Thus the K values for zero skew co-efficient are given in Table 8 below.

Table 5: k value for Log-Normal Distribution (interpolated from table).

T (yrs) Recurrence interval	K_T (C_S = 0)
2	0.000
5	0.842
10	1.282
25	1.751
50	2.054
100	2.326
200	2.576

Applying Equation (7) to the log parameters of the observed data for the different values of return period T (yrs), and the relevant K values obtained from Table 5, we obtain Table 6 as shown below

Table 6: Application of Log-Normal Distribution to the observed data

T (yrs)	K_T	$\sigma log x$	$K_T \sigma log x$	$log \bar{x}$	$Y_T = log \bar{x}$ +K$\sigma log x$	Q = 10^{Y_T} (m^2/s)
2	0	0.1951	0	3.8973	3.8793	7894.05
5	0.842	0.1951	0.1642	3.8973	4.0615	11521.26
10	1.282	0.1951	0.2501	3.8973	4.1474	14041.06
25	1.751	0.1951	0.3416	3.8973	4.2389	17334.05
50	2.054	0.1951	0.4007	3.8973	4.2980	19860.95
100	2.326	0.1951	0.4538	3.8973	4.3511	22443.99
200	2.576	0.1951	0.5026	3.8973	4.3999	25113.08

The estimated T (yrs) flood was transformed to the original equation by computing its exponent as $\boldsymbol{Q_T} = \boldsymbol{10^{Y_T}}$ ………………………………………………………………... (24)

Table 7: Data for Extreme Value Type 1 Distribution

Rank	X or Q (m^2/s)	Rank	X or Q (m^2/s)
1	18478.99	13	7758.55
2	12527.98	14	7672.36
3	12343.67	15	7468.16
4	12128.61	16	6971.8
5	11696.65	17	6833.15
6	10961.25	18	5441.85
7	10190.19	19	5219.9
8	10126.45	20	4827.1
9	9594.27	21	4162.25

10	9649.36	22	3484.69
11	9444.95	23	2987.79
12	8597.1		
Mean $\bar{x}$			8633.351
STDEV σ			3513.355

From Equation (9), $\boldsymbol{\alpha} = \frac{\sqrt{6}}{\pi}\boldsymbol{\sigma} = 2738.99$

Equation (10) $\boldsymbol{\mu} = \bar{\boldsymbol{x}} - 0.5772\boldsymbol{\alpha} = 7052.41$

Using Equation (12), the Y_T for the various recurrence intervals is given below.

Table 8: Y_T value for Extreme Value Type 1 Distribution

T (yrs) Recurrence Interval	$Y_T = -ln\left[ln\left(\frac{T}{T-1}\right)\right]$
2	0.3665
5	1.4999
10	2.2504
25	3.1985
50	3.9019
100	4.6001
200	5.2958

Upon substitution of the value of $\boldsymbol{\alpha}$ ***and*** $\boldsymbol{\mu}$ in Equation (13), for the different value of Y_T, the estimated discharge Q_T, are obtained in Table 9 below.

Table 9: Application of Extreme Value Type 1 Distribution to the observed data

T (yrs)	Y_T	α	αY_T	μ	$Q_T = \mu + \alpha Y_T$ (m^2/s)
2	0.3665	2738.99	1003.84	7054.41	8056.25
5	1.4999	2738.99	4108.21	7054.41	11160.62
10	2.2504	2738.99	6163.82	7054.41	13216.23
25	3.1985	2738.99	8760.65	7054.41	15813.06
50	3.9019	2738.99	10687.27	7054.41	17739.68
100	4.6001	2738.99	12599.63	7054.41	19652.04
200	5.2958	2738.99	14505.14	7054.41	21557.55

Table 10: Data for Log-Pearson Type III distribution

Rank	X OR Q (m^2/s)	Log X	Rank	X OR Q (m^2/s)	Log X
1	18478.99	4.2666	14	7672.36	3.8849
2	12527.98	4.0978	15	7468.16	3.8732
3	12343.67	4.0914	16	6971.8	3.8433
4	12128.61	4.0838	17	6833.15	3.8346

5	11696.65	4.0680	18	5441.85	3.73367
6	10961.25	4.0398	19	5219.9	3.7176
7	10190.19	4.0081	20	4827.1	3.6836
8	10126.45	4.0054	21	4162.25	3.6193
9	9594.27	3.9820	22	3484.69	3.5421
10	9649.36	3.9844	23	2987.79	3.4753
11	9444.95	3.9751	Mean log $\bar{x}$		3.8973
12	8597.1	3.9343	STDEV $\sigma log x$		0.1951
13	7758.55	3.8897			

Table 11: K value for Log-Pearson Type III Distribution (interpolated from table)

T (yrs) Recurrence Interval	K_T (C_S = -0.5157)
2	0.083
5	0.856
10	1.216
25	1.567
50	1.777
100	1.955
200	2.108

Applying Equation (14) to the log parameters of the observed data for the different values of return period T (yrs) and the relevant K values obtained from Table 11, Table 12 is obtained as shown below.

Table 12: Application of Log-Pearson Type III Distribution to the observed data

T (yrs)	K_T	$\sigma log x$	$K_T \sigma log x$	$log \bar{x}$	$Y_T = log\bar{x} + K\sigma log x$	Q = 10^{Y_T} (m^2/s)
2	0.083	0.1951	0.0162	3.8973	3.9135	8194.08
5	0.856	0.1951	0.1670	3.8973	4.0643	11595.78
10	1.216	0.1951	0.2372	3.8973	4.1345	13630.13
25	1.567	0.1951	0.3057	3.8973	4.203	15958.79
50	1.777	0.1951	0.3467	3.8973	4.244	17538.81
100	1.955	0.1951	0.3814	3.8973	4.2787	18997.66
200	2.108	0.1951	0.4113	3.8973	4.3086	20351.67

Table 13: Data for Gamma Distribution

Rank	X or Q (m^2/s)	Rank	X or Q (m^2/s)
1	18478.99	13	7758.55
2	12527.98	14	7672.36
3	12343.67	15	7468.16
4	12128.61	16	6971.8
5	11696.65	17	6833.15
6	10961.25	18	5441.85

7	10190.19	19	5219.9
8	10126.45	20	4827.1
9	9594.27	21	4162.25
10	9649.36	22	3484.69
11	9444.95	23	2987.79
12	8597.1		
Mean $\bar{x}$			8633.351
STDEV σ			3513.355
Skew C_S			0.6567

Table 14: K value for Gamma or Pearson Type III Distribution (interpolated from table)

T (yrs) Recurrence Interval	K_T (C_S = 0.6567)
2	-0.099
5	0.800
10	1.328
25	1.939
50	2.311
100	2.686
200	3.041

Applying Equation (19) to the parameters of the observed data for the different values of return period (T), and the relevant K values obtained from Table 14, Table 15 is obtained as shown below.

Table 15: Application of Gamma Distribution to the observed data

T (yrs)	Z	σ	$K\sigma$	$\bar{x}$	$Q_T = \bar{x} + K\sigma$ (m^2/s)
2	-0.099	3513.355	-347.82	8633.351	8285.53
5	0.800	3513.355	2810.68	8633.351	11444.03
10	1.328	3513.355	4665.74	8633.351	13299.09
25	1.939	3513.355	6812.39	8633.351	15445.74
50	2.311	3513.355	8119.36	8633.351	16752.71
100	2.686	3513.355	9436.87	8633.351	18070.22
200	3.041	3513.355	10684.11	8633.351	19317.46

Table 19: Summary of Flood Estimates Obtained from the Different Probability Distributions.

	Flood Discharge Estimates (m^3/s)				
T (yrs)	Normal	Log-Normal	Gumbel	Log-Pearson Type III	Gamma
2	8633.35	7894.05	8056.25	8194.08	8285.53
5	11619.70	11521.26	11160.62	11595.78	11444.03
10	13200.71	14041.06	13216.23	13630.13	13299.09
25	14957.39	17334.05	15813.06	15958.79	15445.74
50	16011.39	19860.95	17739.68	17538.81	16752.71
100	16819.47	22443.99	19652.04	18997.66	18070.22
200	17768.07	25113.08	21557.55	20351.67	19317.46

Table 20: Chi-Square test of Fit for various Distribution

Distribution	Chi-Square χ^2 for 5% Level NDF=22, χ^2_0=33.92
Normal	69.000
Log-Normal	284.000
Gumbel' Extreme Value Type I	12.000
Log-Pearson Type III	506.000
Gamma or Pearson Type III	11.000

5. Conclusion and Recommendation

This study presents the Estimation of flood discharge at River Oyan using flow data recorded between 1988 and 2010 and subjecting same to five probability distribution models namely; Normal, Log-Normal, Gumbel or Extreme Value Type I, Log-Pearson Type III, and Gamma or Pearson Type III. From the study the following conclusions were drawn

I. The estimated discharge values were within the same range for all the five distributions at lower return periods. But for higher return periods, the results gave higher magnitudes.

II. The log-normal probability distribution recorded the highest estimated flow discharge value of 25113.08 m^3/s at 200 years return periods.

III. For safer prediction, Gumbel's Extreme Value Type I and Gamma or Pearson Type III, are best fit models which can be utilized for flood frequency analysis of River Oyan..

6.2 Recommendations

The extent of flood devastation in Nigeria is wide spread especially in riverine areas and the effects are felt all around the nation. This study was conducted under major constraint due to paucity of hydrological data. Therefore, the following recommendations are made;

I. Adequate flow gauging stations should be established and maintained for river network in Nigeria.
II. Proper record keeping should be adopted as this will help provide long term flow data needed to carryout reliable hydrological studies for design and operation of hydraulic structures.
III. Although, Gamma or Pearson Type III model is recommended as the best probability distribution for the River based on its goodness of fit, Further research on probability distribution for extreme rainfall for River Oyan is suggested.

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