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Flood Frequency Analysis of River Bako, Niger State, Nigeria

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***Abstract*--Estimation of design flood for River Bako Kpakungu, Minna, Niger State, Nigeria is an important components needed for the construction of hydraulic structures across the River. The unit hydrograph method was used to calculate the peak flow. Three distributions: Normal, Extreme value type (I) and Gamma distributions were applied to 25 (Twenty Five) years annual rainfall data to find the distribution that best fit the rainfall data employed. Among the three distributions used, the Extreme Value Type I (EVTI) was found to have the line of best fit with the regression coefficient of 0.96. Also, the annual maximum rainfall data for 25 years were employed to estimate design flood. For the design flood in the selected -River Bako four different types of land cover were considered and corresponding design flood estimated. The probable maximum precipitation obtained formed the basis for the estimation of Probable Maximum Flood for the return periods of 25, 50 and 100 years. The Probable Maximum Flood (PMF) obtained for the return period of 25, 50 and 100 years were 132.8, 144.2and 154.9 respectively.**

Keywords: Flood frequency analysis, Probable maximum flood, probable maximum precipitation, peak flow, design flood, discharge, River Bako.

1. INTRODUCTION

River Bako is located in Kpakungu, Minna, Niger State, Nigeria. It has been reported to have flooded above the capacity of its channel, taking over roads, lands and houses in the area in August, 2009. The flooding was attributed to occurrence of high rainfall over a period of time in the basin (Niger State Ministry of Environment, 2009). Hence, this paper aimed to estimate the design flood for River Bako in order to avert the problem of flooding that occurred in the area.

Frequency analysis (statistical) method was used to estimate design flood in Bako River basin. Three distributions (Gumbel - Extreme Value Type I, Normal and Gamma distributions) were applied to the annual rainfall data of 25 years used in this analysis. Gumbel (Extreme Value Type I) was found to be the distribution that best fit the rainfall data used in this analysis. Annual maximum rainfall data for 25 years were used to estimate Probable Maximum Precipitation (PMP), which was employed to estimate the Probable Maximum Flood (PMF) for the return period of 25, 50 and 100 years in the basin. According to Kochanek et al, (2011), in their study, discovered that seasonal maxima approach is better to estimate design flood for Polish Rivers and not annual maxima flow due to the homogeneity of the seasonal peak flow datasets but in this paper, annual peak flow was applied to estimate the design flood for Bako River in Niger State due to the location and the weather condition of the area. Yue et al, (1999) applied Gumbel mixed model, bivariate extreme value distribution model with Gumbel marginal to examine joint probability distributions of flood peak and volume as well as flood volumes and duration. They found Gumbel mixed model to be appropriate for representing the joint distribution of peak flood and volumes with flood volumes and duration (Yue et al, 1999). Also, index flood method was used by Kjeldsen et al, (2001) for regional flood frequency analysis in KwaZulu-Natal province in South Africa. They found that General Normal, Person Type 3 and General Pareto distributions were adequate for annual maximum series of flood flow in Region 2 but not for region 1 (Kjeldsen et al, 2001) but this paper used Gumbel distribution; Extreme value type I (EVTI) to estimate design flood for Bako River because it is the model that best fit the rainfall data used.

2. STUDY AREA

Bako River is located in Kpakungu, Minna, Niger State, in the west-Africa sub-continent of the Northern part of Nigeria. It is located between latitude $6^{o}15'$ - $10^{o}43'$N and longitude $7^{o}30'$ - $10^{o}29'$E. It covers the total area of about $114km^2$ and spans through the length of about 17km. The basin is oriented NW-SW with its headwaters originated to the west of Maikunkele town. The basin lies between semi-arid in the north and sub-humid in the south. Its climate is characterized by dry northern-winters and wet northernsummers (Ministry of Land and Survey, 2009). The terrain of the basin is hilly from the source and becomes flat as it gets to Bako River. The Figure 1 shows the location of Bako River basin.

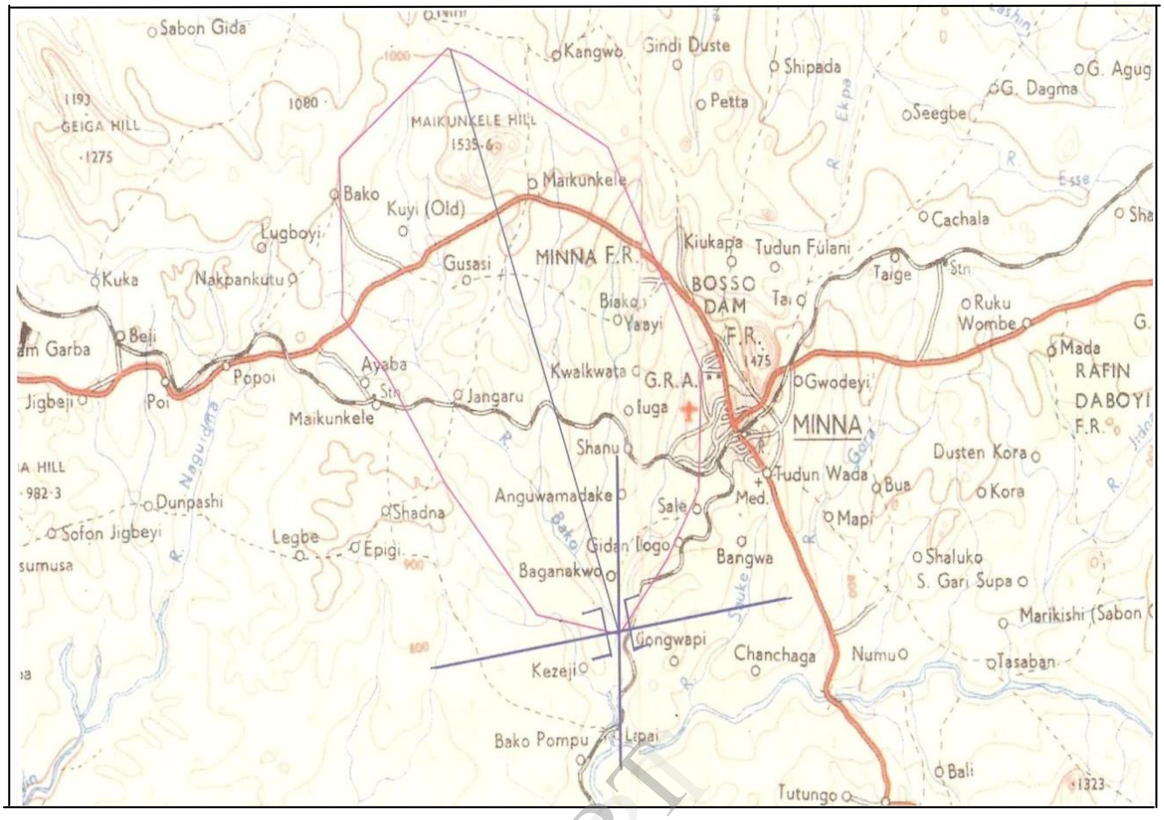

Fig. 1 Location of river Bako basin

3. DATA AND METHODS

3.1 Data Collection:

Twenty Five (25) years rainfall data from 1981-2006 were collected from Upper Niger River Basin Development, Minna, Niger State, Nigeria. Annual maximum rainfall depth were selected and used in this analysis. Double mass curve was used to check for the consistency of the rainfall data and it was found to be consistent.

3.2 Methods

The Catchment was delineated with the aid of AutoCAD software which captures the entire basin of Bako River (see Fig. 1.0).

3.2.1 Frequency Analysis (Statistical Method)

Frequency analysis technique was applied to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distribution (SCS, 1993). The probability that a flood will occur in 25, 50 and 100 years in Bako River was determined in relation to return period and it is given by

$$P = \frac{1}{T_r} \tag{1}$$

The reduce variate (y) as relates to return period (T_r) is given below

$$y = \left[-\ln\left(-\ln\left(1 - \frac{1}{T_r} \right) \right) \right] \tag{2}$$

the reduce variate in 25, 50 and 100 years were also determined using reduce variate formula. In addition, the values of reduce variates were substituted into the equation of the model that best fit the data, that is, the equation that has the line of best fit and it gives the flow in 25, 50 and 100 years respectively.

3.2.1.1 Determination of Probable Maximum Precipitation (PMP)

The PMP was obtained based on the principle of Hershfield, (1986). The Mean (x_n) $= \frac{1}{n}\sum_{i=1}^{n} x_i$ and standard deviation (σ) $= \left\{ E\left(x_i - \bar{x}\right)^2 \right\}$ were calculated. Adjustment of mean and standard deviation for Bako River for maximum observed mean and record length was calculated (WMO, 1986). The maximum observed rainfall X_m was calculated using $X_m = X_{av} + K_m\sigma$, where X_{av} is the mean, σ is the standard deviation and K_m is a frequency factor as shown in Fig. 2 below which varies between 5 and 20 depending on the rainfall duration (d) and the mean ($\bar{h}_n$) of annual series.

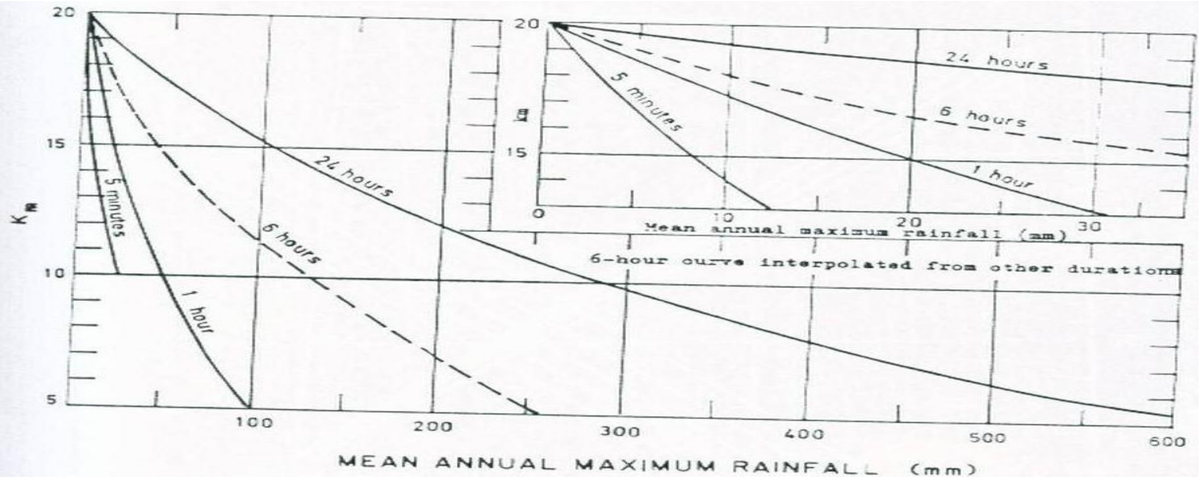

Fig. 2: K_m as a function of rainfall duration and mean of annual series.

The maximum rainfall depth of River Bako based on 24 hourly data was adjusted to true maximum values. Since the annual series data had been computed from fixed observational time intervals (8.00am previous day – 8.00am) instead of hourly data. The adjustment factor is 1.13. That is, PMP = 1.13 $X_{m.}$ Also, Point PMP of River Bako was adjusted to area PMP using Area reduction curve (WMO, 1986).

3.2.1.2 Determination of Probable Maximum Flood (PMF)

The PMF was estimated using Soil Conservation Method due to its acceptability for small to medium-sized ungauged basins. The Runoff volume (cu.m or cu. Km) is the amount of water that flows through the hydrometrically closed segment of a drainage basin and is determined by:

$$V_q = \frac{(P-I)^2}{(P+4I)} \quad \text{for P >} \qquad 1.1$$

where P is the Probable Maximum Precipitation (PMP) value for the basin.

Also, the peak discharge due to the event is determined based on the unit hydrograph (UH) concept of the U.S. Soil Conservation Service Method (USSCS) given as:

$$Q_p = \frac{V_q}{T_p} \qquad 1.2$$

where:

The Peak discharge is Q_p, runoff volume (V_q) and the time to peak (T_p) is the time in hours from the beginning of the rising limb to the occurrence of the peak discharge and is given by:

$$(T_p) = 0.5D + T_i \qquad 1.3$$

Catchment lag is the period of time between the centre of the unit storm and peak discharge. It depends upon the storm and catchment characteristics. Based on Snyder's formula Catchment lag is modified by (Linsley and Frazini, 1992) as follows:

$$T_L = C_t \left(\frac{0.386 L_c L}{S^{0.5}} \right)^{0.38} \qquad 1.4$$

where,

L is the distance from station to catchment boundary along the longest stream in km., L_c is the distance from station along stream to a point on the stream nearest to the catchment centroid in km, C_t is a constant between 0.35 and 1.20 depending on catchment and S is the average slope.

The velocity of the river was measured by float method. The time taken (t) by the cork to travel a distance (L) of 30m and the peak discharge was determined by multiplying the area with the velocity of the river. Float method cannot be used in a large river (Arora, 2007).

Three distributions were selected on the basis of their ability to fit the plotted data from runoff namely: Normal, Gumbel (Extreme Value Type 1), and Gamma distributions. The distribution that best fitted to the recorded runoff among the trials shall be adopted for this work.

Since the value of variate for a given return period (x_T) determined by Gumbel's method can have errors, an estimate of the confidence limits of the estimate is desirable. The confidence interval indicates the limits about the calculated value between which the true value can lie with a specified probability based on sampling errors only. For a confidence probability (c), the confidence interval of the variate (x_T) is bounded by values x_1 and x_2 given by:

$$x_{1/2} = x_T \pm f(c)S_e \qquad 1.5$$

where $f(c)$ is the function of the confidence probability c determined by using Table 1.

Table 1: Confidence Probability function of Normal Variate

c (%)	50	68	80	90	95	99
$f(c)$	0.674	1.00	1.282	1.645	1.96	2.58

(Submramanya, 2006)

S_e is the probable error which is $b\dfrac{\sigma_n - 1}{\sqrt{N}}$ 1.6a

b is the $\sqrt{1+3K+1.1K^2}$ 1.6b

k is the frequency factor and is given by: $k = \dfrac{y-\bar{y}_n}{S_n}$ 1.6c

where $\sigma_n - 1$ is the standard deviation of the sample, N is the sample size, y is the reduce variate, $\bar{y}_n$ and S_n are reduced mean and reduced standard deviation. The equation 1.6a to 1.6c will be used to check the degree of error.

4.0 RESULTS AND DISCUSSION

4.1 *Estimation of Probable Maximum Precipitation*

The Mean ($\bar{x}$) = **90** and Standard Deviation (σ) = **77.70** obtained from rainfall data of 25 years**.**

Adjustment of mean for length of record for 25years = 101% and adjustment of standard deviation length of record for 25years (σ_n) = 70.75%.

4.1.1 *Maximum Observed Rainfall Calculation* (x_m)

Maximum observed rainfall is: (x_m) = **1,338.5,** which was adjusted based on 24 hourly data using adjustment factor 1.13(x_m), hence, PMP = **1,513mm.** Area reduction curve was used to convert point to Area precipitation (Hershfield, 1986). The Catchment Area = 114km^2. Percentage of Probable Maximum Precipitation or 25km^2, therefore, Area Rainfall = **96mm**

4.2 *Frequency Analysis*

The probability that a magnitude of flood will occur in 25, 50 and 100 years are 0.04, 0.02 and 0.01 respectively. From the formula that relate Reduce Variate to Return Period which is y = (-ln(-ln(1-1/T)), the reduce variate for 25, 50 and 100 years are 3.19853, 3.90194 and 4.60015 respectively. Substituting the values of reduce variate into the equation of the model that best fit the data, the flow for 25, 50 and 100 years are 127.805, 136.077 and 144.288mm respectively, which means the maximum flow of 144.288mm was used to design the Probable Maximum Flood.

4.2.1 *Confidence Limits*

Using Gumbel's method to estimate the flood discharge with a return period of 25, 50 and 100 years with the confidence limit of 80% and 95% for these estimates are given in Table 2 below:

Table 2: Confidence Limits for 25, 50 and 100 years.

	Confidence limits at 25	Confidence limits at 50	Confidence limits at 100
The reduce variate,	y_{25} = 3.19853	y_{50} = 3.90194	y_{100} = 4.60015
Frequency factor,	k_{25} = 2.4440	k_{50} = 2.8892	k_{100} = 3.3487
T_r flood estimation,	x_{25}=132.80m^3/s	x_{50} = 144.22m^3/s	x_{100} = 154.90m^3/s
	b = 3.27	b = 3.73	b = 4.21
Probable error,	S_e = 13.63	S_e = 10.10	S_e = 8.78
For 80% conf. Prob. f(c),	x_1 = 150.28m^3/s	x_1 = 157.17m^3/s	x_1 = 166.16m^3/s
	x_2 = 115.33 m^3/s	x_2 = 131.27 m^3/s	x_2 = 149.64m^3/s
For 95% conf. Prob. f(c),	x_1 = 159.51m^3/s	x_1 = 164.02 m^3/s	x_1 = 172.11 m^3/s
	x_2 = 106.09m^3/s	x_2 = 124.42m^3/s	x_2 = 137.70m^3/s

Thus the estimated discharge for the return periods of 25, 50 and 100 are 150.28 m^3/s, 157.17m^3/s and 166.16m^3/s and they have 80% probability of lying between 150.30m^3/s and 115.00m^3/s, 157m^3/s and 131m^3/s, 166m^3/s and 150m^3/s respectively. Also the estimated discharge for the return periods of 25, 50 and 100 are 150.28 m^3/s, 157.17m^3/s and 166.16m^3/s and they have 95% probability of lying between 160.00 and 106.00m^3/s, 164.00 and 124m^3/s, 172 and 137m^3/s respectively.

4.4.1 Determination of Volume of Runoff (V_q)

The volume of runoff were determined for different land use, using the value obtained from the Probable Maximum Precipitation = **96mm**. The table 3 shows the volume of runoff (V_q) for different land use for moderate and slow infiltration. The value obtained from PMP was used to estimate PMF.

Table 3: Volume of Runoff (V_q) for different land use

Land Description	**Moderate Infiltration**	**Slow Infiltration**
(i) Cultivated Land with Conservation Treatment	V_{q1} = **0.4 mm^3**	V_{q2} = 1.**11mm^3**
(ii) Cultivated Land without Conservation Treatment	V_{q3} =**1.5mm**^{3}	V_{q4} = **2.70mm^3**
(iii)Pasture or Range Land with Good Condition	V_{q5} = **0.032mm^3**	V_{q6} = **0.70mm^3**
(iv) Paved Surface	V_{q6} =**55mm^3**	V_{q7} = **69mm^3**

4.4.2 *Determination of Peak Discharge (Q_p)*

The peak discharge for different land use were calculated using the slope of the catchment (S), the catchment lag and the time to peak (T_p) which were calculated to be **0.043**, **5.53 hours,** and **17.5 hours** respectively. Table 4 shows the values for peak discharge (Q_p) for different land use for moderate and slow infiltration. The values obtained from PMP, volume of runoff and time to peak for different land use for moderate and slow infiltration were used to estimate the peak discharge.

Table 4: Determination of Peak Discharge (Q_p) for different land use

Land Description	Moderate Infiltration	Slow Infiltration
(i) Cultivated Land with Conservation Treatment	Q_{p1} = **6.39 m^3/s**	Q_{p2} = **17.50 m^3/s**
(ii) Cultivated Land without Conservation Treatment	Q_{p3} = **23.89 m^3/s**	Q_{P4} = **15.43 m^3/s**
(iii)Pasture or Range Land with good condition	Q_{p5} = **0.50m^3/s**	Q_{p6} = **11.11m^3/s**
(iv)Paved Surface	Q_{p7} = **36.37m^3/s**	Q_{p8} = **45.63m^3/s**

4.4.3 *Synthetic Unit Hydrograph Diagram*

Synthetic unit hydrograph diagram was drawn to show the plot of (Q/Qp) discharge/peak discharge against time/peak time (T/Tp).

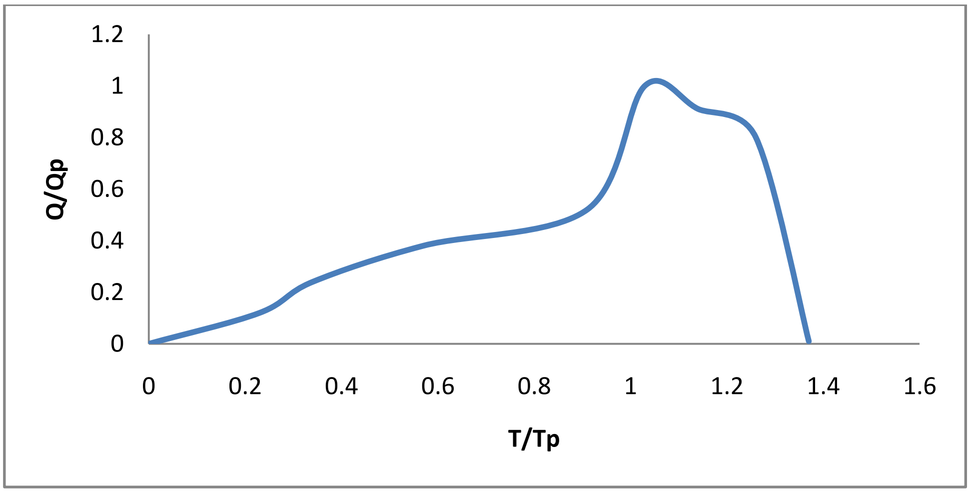

Fig. 3 shows the value of Q/Q_p against T/T_p

4.5 *Field discharge of the river* (***Q_f***)

The velocity of Bako River when it was not full was 1.06m/s, and the area was measured to be 102.5m^2. The field discharge of the Bako River (Q_f) was 108.65m^3/s.

4.6 *Fitting Runoff Record to a Distribution*

The graphs showed the plot of reduce variate against flow for Normal, Extreme value type 1 and Gamma distributions. The best fit (least square method) for the respective distributions are: Y = log (flow) = -20.13 xs+90.19 for normal distribution; Y = log (flow) = 11.76 xs+90.19 for extreme value type 1 distribution; and Y = log (flow) = -436.3 xs+124.5 for Gamma distribution. The regression coefficients obtained are 0.9329, 0.9578 and 0.9329 for Normal, Extreme value type 1 and Gamma distributions respectively. Based on this, the Extreme value type 1 distribution is the one that has the line of best fit. Therefore to estimate the probable maximum flood of river Bako at Kpakungun, Extreme value type 1 distribution was applied. Fig. 4 shows flow against reduce variate of Normal distribution with the equation of regression coefficient of $x = \mu + \sigma y$.

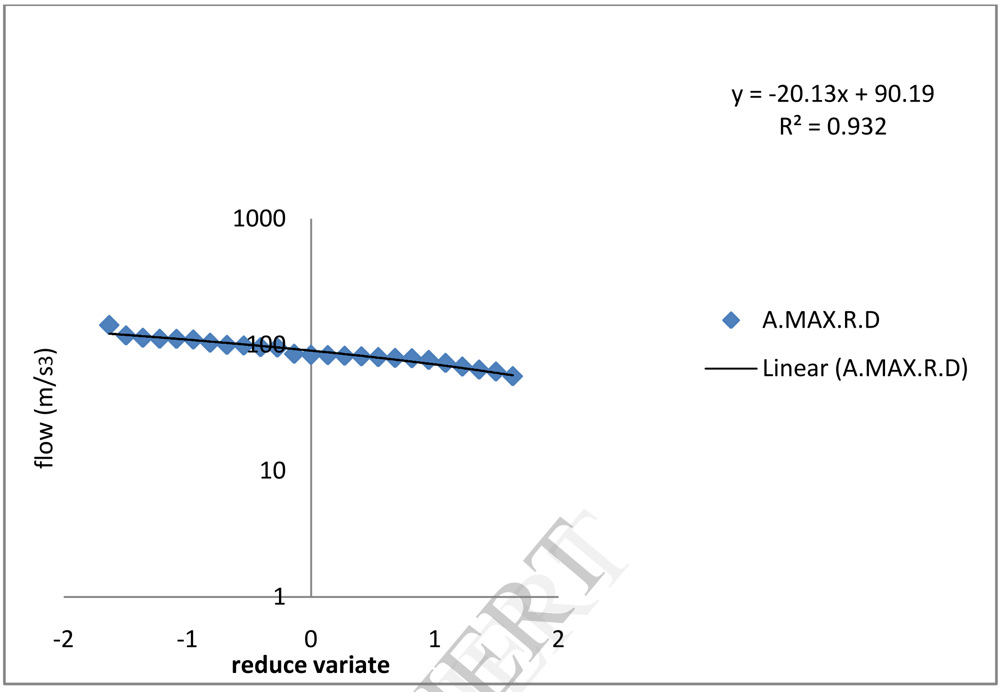

Fig 4: Fitting Runoff Record to a Normal Distribution

Fig. 5 shows flow against reduce variate of Extreme value type 1 distribution with the equation of regression coefficient of $x_1 = u + \alpha y_1$.

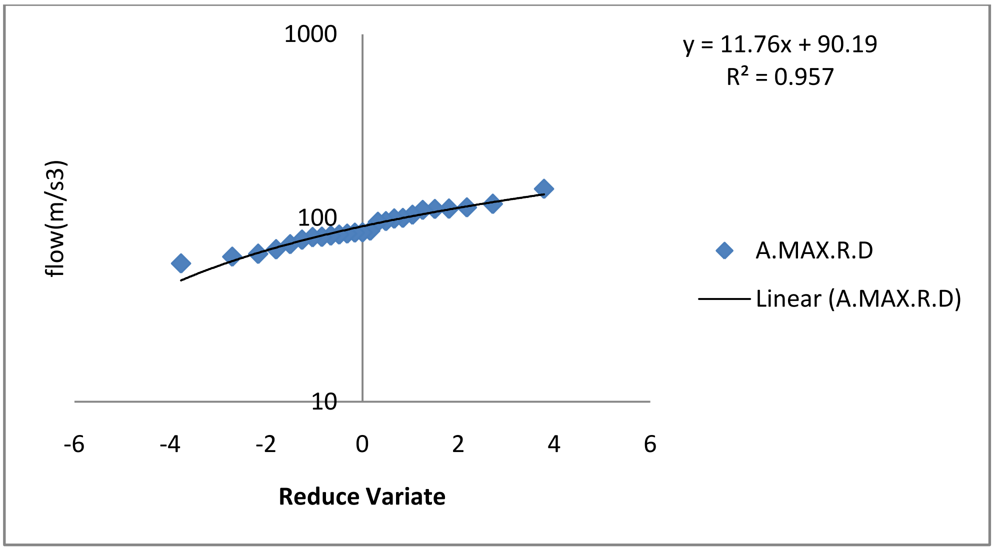

Fig 5: Fitting Runoff Record to an Extreme Value Type 1 Distribution

Fig. 6 shows flow against reduce variate of Gamma distribution with the equation of regression coefficient of $x = \beta y$.

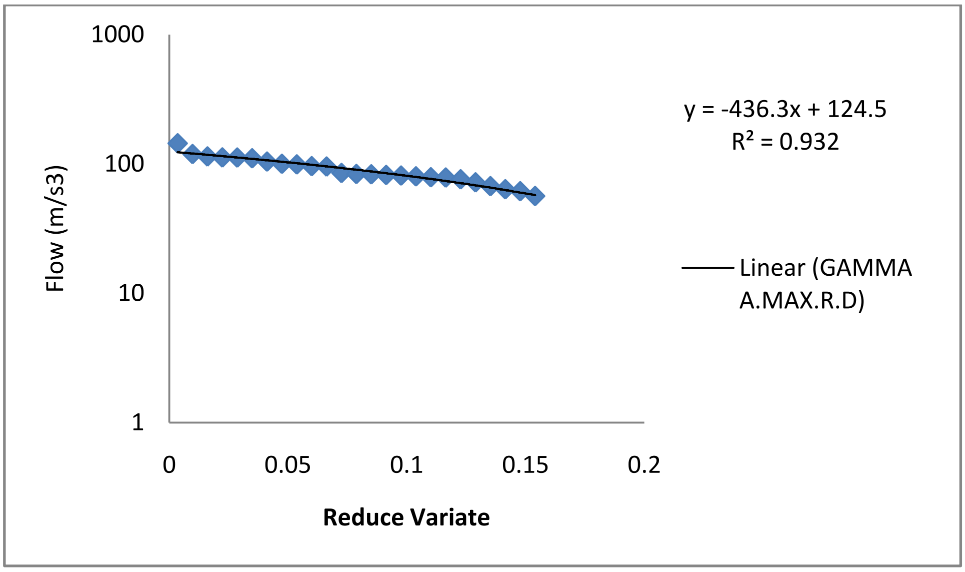

Fig 6: Fitting Runoff Record to a Gamma Distribution

4.7 *Flood Estimation for different Return Period (x_T)*

For 25 years return period (T_r), $x_T = 132.80 m^3/s$. For 50 years return period (T_r), $x_T = 144.22 m^3/s$ and for 100 years return period (T_r), $x_T = 154.90 m^3/s$.

5.0 CONCLUSIONS

The catchment area of the River Bako was delineated and 114 square kilometres is suggested for future study of the basin. The Probable Maximum Precipitation for the annual maximum rainfall series was also determined and estimated to be 96mm. The maximum annual series for twenty five years rainfall data was fitted to Gumbel (Extreme Value Type 1), Normal, and Gamma distributions. Gumbel (Extreme Value Type 1) was found to be the best probability distribution model for River Bako at Kpakungu, Minna with R^2 of 0.957. The probability that a flood of 25, 50 and 100 years occurring in 25, 10 and 15 years and are 64%, 18.29% and 13.99% respectively. The field discharge of the river was 108.65m^3/s. The PMF derived especially that of 25 years return period, which is 132.80m^3/s was found to be adequate for the length of record used. Channel improvement should be done by increasing the free board. Gauge station should be established and the use of discharge recording equipment should be encouraged in the Bako River. River banks should be well protected against erosion and excessive practise of land use should be discouraged to reduce deforestation.

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