Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.3, No.10, 2013

Flood Frequency Analysis of Osse River Using Gumbel's Distribution

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Abstract
This paper shows the result of the study carried out on Osse River with flow measurements carried out at Iguoriakhi. Flood frequency analysis was carried out on the river (Osse river) using Gumbel's distribution which is one of the probability distribution used to model stream flow. This was necessitated by the need to protect lives and property at the downstream of the catchment area. Gumbel's distribution was used to model the annual maximum discharge of the river for a period of 20years (1989 to 2008). The measurement was carried out by Benin Owena River Basin Development Authority .From the trend line equation, R^2 gives a value of 0.954 which shows that Gumbel's distribution is suitable for predicting expected flow in the river. From the Gumbel's distribution using return periods (T) of 2yrs, 5yrs,10yrs, 25yrs, 50yrs, 100yrs, 200yrs and 400yrs; the expected estimated discharges obtained are: 2156.61m^3/s, 2436.24m^3/s, 2621.38m^3/s, 2855.31m^3/s, 3028.85m^3/s, 3201.11m^3/s, 3372.74m^3/s and 3544.05m^3/s respectively. These values are useful for storm management in the area.
Keywords: flood frequency analysis, probability, Gumbel's distribution, return period, flow measurement.

1.0 INTRODUCTION:

Flow discharge which are relatively high and which overflow the natural or manmade banks in any reach of a river maybe called a flood. When the water carrying capacity of a river has been over stretched, the river channels becomes inadequate to carry off the unusual quantity of runoff arising from heavy precipitation causing the river to overflow its banks and inundates the low-lying area. When this happens, water overtop the bank, spread over the flood plain especially low lying regions and come in the activities of man (Reddy 2008).

Apart from the overflows of Rivers, floods maybe caused by the failure of some hydraulic structures such as dams or sudden release of huge amount of water (as in the case of Adamawa state flood in August 2012 cause by water released from Cameron dam), causing considerable damage to lives and properties. The flood later went on and twenty three other states in the country were submerged as a result of this release.

Since man do a lot of it activities on the flood plain, it becomes important for him to protect it against flood. Some of the structures used by man to control flood are leaves, reservoir and channel improvement. For an economic and efficient design of these measures, flood has been estimated with some level of accuracy. Once an estimate of maximum or peak flood which occur in a particular site can be estimated, an ideal solution can then be proffered by a hydraulic Engineer (Haan, 1977).

The flood discharge adopted for the design of hydraulic structures while putting economic and hydrological factor into consideration is known as design flood and as it (design flood increases), the cost of the structure decreases but there will be a reduction in the probability of yearly damage. It is of great importance to select a design flood, which is unlikely to occur during the design life of a hydraulic structure, and as such the difference between the design return period and the estimated life of the structure should be quite large. This is why the return period of hydraulic structure (spillway of dams) is taken very long so as to reduce risk of failure (Izinyon and Igbinoba, 2011).

Annually, a lot of funds are spent on flood effect reduction and protection using either structural (achieved by river training, storage dam, weir, reservoir, drainages and culverts) or non-structural (achieved by flood forecasting, catchment enrichment, channel development and rescue operations) measures. Meteorological data can only provide short forecast in an accurate form, which may allow time to reduce the effects of flood events (Madamombe, 2005). The inaccuracy of meteorological forecast has raised so many false alarms that people no longer take forecast seriously. It is as a result of inaccuracy of flood forecasting using rainfall data that lead to the use of statistical methods (Normal, Extreme Value Type I, Log Normal, Log Pearson Type III e.t.c.) to predict flood.

The use of probability model on the sample of annual flood peak recorded over a given period of time (observation), for a particular watershed, region or catchment is known as Flood Frequency Analysis. From the results of the findings, forecast of the extreme events of large recurrence interval can be ascertained (Pegram and Parak, 2004). Reliable flood frequency estimates are essential for flood plain management, protection of public infrastructure, cost reduction of food related matters to government and private enterprises, for assessing hazards related to the development of flood plains and epidemic control (Tumbere, 2000).

In order to ensure safety and economic hydrologic design in the catchment area, the Gumbel distribution, a stochastic generating structure that produce random outcomes was used to model the annual peak discharge data of Osse river at Benin City from 1989 to 2008 obtained from the measurements carried out by the Benin Owena River Basin Development Authority (BORBDA).

The main aim of the paper is to carry out flood frequency analysis of the river catchment using annual peak flow or maximum discharge data obtained from the river from 1989 to 2003. The objectives are:

- Use Gumbel distribution to analyze the annual peak discharge data of Osse River from 1989-2008.
- Predict flood design for return period of 2yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs, 200yrs, and 400yrs.

The results of the analysis generated from the study gives detailed information of likely flow discharge to be expected in the river at the various return periods based on the observed data. This information will be very useful for engineering purposes such as when designing structures in or near the river that may be affected by the flood as well as in designing the flood structure to protect against the expected events. (Izinyon, 2011). This may include the design of dam, bridges and flood control structures which will reduce flood disaster in the catchment or assist considerably in storm water management in the region.

1.1 STUDY AREA

The study area were the flood frequency study was carried out is Benin-Owena, River Basin catchment Area in Edo-State situated within the Western Littoral Hydrological Area HA-6 which is one of the eight hydrological area into which Nigeria is subdivided. The gauge station at which the hydrometric measurements were made is located at Osse River at Iguoriahki. Some important details of the river are list in Table 1.

Table 1: Osse River Gauging Station Details.

Station Location	State	Basin	Latitude	Longitude	Drainage Area (hectares)
Osse River at Iguoriakhi	Edo	Osse	Lat. 6^0 29' N	Log. 5^0 28' E	755

Source: (BORDA, 2010)

2.0 GUMBEL DISTRIBUTION

Gumbel's distribution is one of the statistical approaches that is mostly used to analyze flood data. It is also used to predict hydrological events such as flood. According to Gumbel, the probability of occurrence of an event equal to or longer than value X_o is expressed as (Shaw, 1983):

$$P(X \geq X_O) = 1 - e^{-e^{-y}} \quad (1)$$

Where *y* is another dimensional variable given as;

$$y = \alpha(X - \beta) \quad (2)$$

$$\alpha = \frac{1.28255}{S_x} \quad (3)$$

$$\beta = \bar{x} - 0.45005 S_x \quad (4)$$

$S_x =$ Standard deviation for X

$$y = \frac{1.2825}{S_x}(X - \bar{X}) + 0.577 \quad (5)$$

For any given data, the value of $\bar{x}$ for a given probability (p) is required; therefore Equation (1) is transpose as: $Y_{(p)}$ = value of variate y for a given probability (p) and taking logarithms on both sides to base two, we now have

$$= -\ln[-\ln(1-p)] \quad (6)$$

Using $P = \frac{1}{T}$,

$$Y_{(T)} = -\left[\ln.\ln\frac{T}{T-1}\right] \quad (7)$$

Also, Equation (2) will now become:

$$Y_T = \frac{1.2825}{S_x}[X_T - \bar{X}] + 0.577 \quad (8)$$

Where $X_{(T)}$ = value of X for a return period of T, therefore;

$$X_T = \bar{X} + K.S_x \quad (9)$$

Where;
$$K = \frac{Y_{(T)} - 0.577}{1.2825} \tag{10}$$

K is known as frequency factor. Where N is smaller and it's of finite value, K can be modified as:

$$K = \frac{Y_{(T)} - \bar{Y}_n}{\sigma_n} \tag{11}$$

Where $\bar{Y}_n$ and σ_n are reduced mean and reduced standard deviation having maximum value of 0.577 and 1.2825 respectively. The tables showing these values are referred to as Gumbel's Extreme value distribution.

3.0 METHODOLOGY

Daily maximum discharge data of Osse river at Iguoriakhi, Benin city from 1989-2008 (20 years flood data) were obtained from the measurement carried out by the Benin Owena River Basin Development Authority (BORBDA) and were subjected to flood frequency analysis applying the Gumbel's distribution. According to Mujere (2006), Gumbel's distribution is usually applied when;

a. The river is less regulated i.e. not affected by human water demand such as reservoir, diversions and urbanization.
b. Maximum flow data are homogenous and independent.
c. Observed flow data was more than 10 years with good quality

The steps to estimate the design flood for any return period using Gumbel's distribution as given by VenTe Chow (1988) is presented below:

Step I: Annual peak flood data for the river was assembled from 1989 -2008.

Step II: From the maximum flood data for n years, the mean $\bar{X}$ and standard deviation σ_x are computed using:

$$\sum_{i=1}^{n} x_i \quad \text{and} \quad \sigma_x = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} \left(x - \bar{x}\right)^2}$$

Step III: From n, the value of $\bar{y}_n$ and σ_n are obtained from Gumbel's Distribution Reduced Extreme Table (shown in Table 4).

Step IV: From the given return period T_r, the reduced variate $Y_{(T)}$, is computed using Equation (7).

Step V: From $\bar{y}_n$, σ_n and $Y_{(T)}$ obtained, the frequency factor, K_T is computed using Equation (11).

Step VI: With the use of Equation (9), the magnitude of flood is computed.

It is of great importance to confirm if the observed flood data collected in the catchment follows Gumbel's distribution or not. In order to achieve this, the observed data is arranged in descending order (the highest coming first) and assigning the return period for each flood; the reduced variate corresponding to each flood is computed using Equation (7). A plot of the reduced variate and magnitude of flood is made on ordinary graph paper. If an eye fits to this plot suggest a straight line, then it is reasonable to conclude that the Gumbel's distribution is a good fit for the observed flood data.

4.0 PRESENTATION OF RESULTS:

The annual peak flow data for Osse River for the period of years obtained from the daily discharge measurement carried out from 1989 – 2008 by Benin Owena River Basin Development Authority are presented in Table 2

Table 2: Annual Peak Flow Data for Osse River (1989 – 2008)

Water Year	Stream Flow Annual Maximum (m^3/s)	Water Year	Stream Flow Annual Maximum (m^3/s)
1989	1980	1999	2150
1990	1982	2000	2210
1991	1948	2001	2211
1992	1836	2002	2365
1993	1842	2003	2310
1994	1978	2004	2442
1995	2009	2005	2547
1996	2010	2006	2539
1997	2101	2007	2661
1998	2136	2008	2650

Table 3: **Computation Table**

Year	Flood Peak (m^3/s)	Flood Peak in Descending order (m^3/s)	Order (m)	$S_x^2 = (n - \overline{x})^2$	Return Period, $T_r = \frac{n+1}{m}$	Reduced Variate, $Y = -\ln\ln\frac{T_r}{T_r - 1}$
1989	1980	2661	1	216829.9225	21	3.02022654
1990	1982	2650	2	206706.6225	10.5	2.301750855
1991	1948	2547	3	123657.7225	7	1.869824714
1992	1836	2539	4	118095.3225	5.25	1.554433319
1993	1842	2442	5	60836.2225	4.2	1.302196935
1994	1978	2365	6	28781.1225	3.5	1.08923964
1995	2009	2310	7	13144.6225	3	0.902720456
1996	2010	2211	8	244.9225	2.625	0.734858987
1997	2101	2210	9	214.6225	2.333333	0.580504824
1998	2136	2150	10	2056.6225	2.1	0.435985403
1999	2150	2136	11	3522.4225	1.909091	0.29849048
2000	2210	2101	12	8901.9225	1.75	0.165702981
2001	2211	2010	13	34354.6225	1.615385	0.035543351
2002	2365	2009	14	34726.3225	1.5	-0.094047828
2003	2310	1982	15	45518.2225	1.4	-0.225351487
2004	2442	1980	16	46375.6225	1.3125	-0.36122375
2005	2547	1978	17	47241.0225	1.235294	-0.505749609
2006	2539	1948	18	61182.0225	1.166667	-0.665729811
2007	2661	1842	19	124856.2225	1.105263	-0.855000373
2008	2650	1836	20	129132.4225	1.05	-1.113344054
SUM		**43907**		**1306378.55**		
AVERAGE		**2195.35**				
S.D				**262.215**		

S.D is Standard Deviation

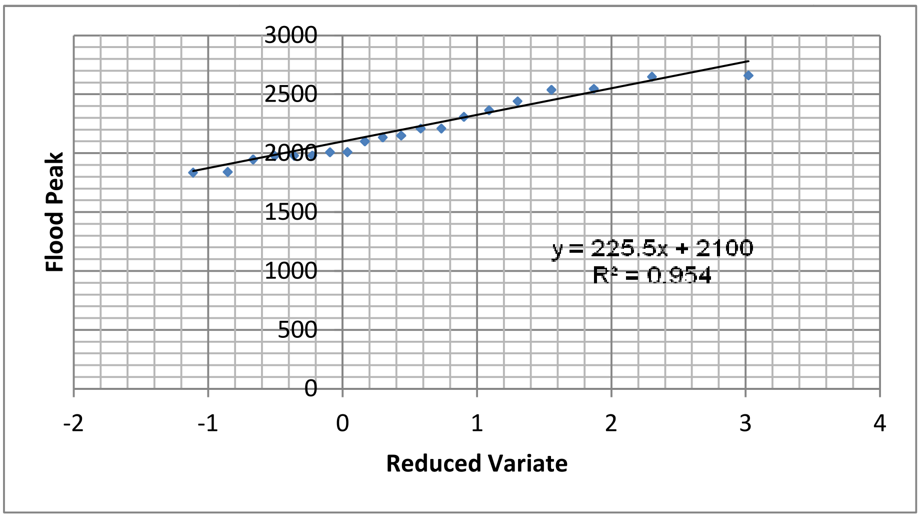

Figure 1: Plot of Osse River Discharge

Table 4: Computation of Expected Flood along Osse River

Return Period (T) in years	Reduced Variate, $Y = -\ln \ln \frac{T_r}{T_r - 1}$	Frequency factor, $K_{(T)} = \frac{Y_T - \overline{Y_n}}{\sigma_n}$	Expected flood, $X_T = \overline{x} + K_T.S_x$
2	0.366512921	-0.147753714	2156.6067
5	1.499939987	0.918669954	2436.239042
10	2.250367327	1.624735214	2621.379944
25	3.198534261	2.516850542	2855.305965
50	3.901938658	3.178672655	3028.84565
100	4.600149227	3.835607978	3201.103946
200	5.295812143	4.490146253	3372.7337
400	5.990213243	5.143497307	3544.052146

Based on the methodology described above, the important parameters needed for the analysis were computed in Table 2 while Table 3 shows the various discharges expected alongside their return periods. The results from the table shows that the expected stream discharge for return periods of 2yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs, 200yrs and 400yrs are 2156.61m^3/s, 2436.24m^3/s, 2621.38m^3/s, 2855.31m^3/s, 3028.85m^3/s, 3201.11m^3/s, 3372.74m^3/s and 3544.05m^3/s respectively.

5.0 CONCLUSION

From the flood frequency analysis carried out for Osse River using 20 years annual peak flow data, figure 1 shows a plot of the flow of the river using the observed data. From the trend line equation, R^2 gives a value of 0.954. The value r = 0.954 shows that the pattern of the scattered is narrow and that Gumbel's distribution is suitable for predicting expected flow in the river. The plot (figure 1) also gives the relationship between the anticipated flow (discharge) and return period as: 225.5x + 2100. From here, other values not shown in chart can be extrapolated. These and other values obtained will be useful in the Engineering design of hydraulic structure such as storm water drains, culverts and reservoirs with a view to protecting lives and properties at the downstream of the river.

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