Estimation of Design Floods of the Gabharu River, Northeast India, by Flood Frequency analysis

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Abstract: Gabharu river, an important north bank tributary of the river Brahmaputra, is subjected to severe flood during monsoon causing tremendous loss of life and properties. Flood frequency analysis is, therefore, required to understand the nature and magnitude of high discharge in the river. The objective of frequency analysis is to relate the magnitude of events to their frequency of occurrence through probability distribution. In the present study, both Gumbel's Extreme Value distribution and Log Pearson Type III distribution, which are probability distribution methods, have been tested for consideration for 30 year discharge data from 1988 to 2017. The Gumbel's distribution has been found to be unsuitable which could be understood from the lack of linearity between reduced variates (Y_T) and the respective peak flows. Log Pearson type III distribution has been found to be better suited for predicting design flood at different return periods. From the values of discharge against the respective return periods, it has been determined that in a period of 200 years, discharges of 149.66m^3/sec, 288.67m^3/sec, 386.19m^3/sec, 535.67m^3/sec, 669.42m^3/sec, 824.14m^3/sec and 1002.53m^3/sec will occur 100 times, 40 times, 20 times, 8 times, 4 times, and 2 times respectively. A discharge of 1002.53m^3/sec will occur once in every 200 years. The model relationship between expected discharge and return period is given by y= 181.86ln(x) – 11.301.

I. INTRODUCTION

Flood, a common phenomenon worldwide, is considered to be one of the most hazardous natural disasters occurring on the earth's surface. It results when the flow discharge exceeds the carrying capacity of the river channel, causing the water to overflow the banks of the river. Besides, flood may occur due to major infrastructural failures such as dam failure or sudden release of water from reservoir which may be catastrophic in nature. Catastrophic flooding may also be the result of channel diversion or modification due to landslides or earthquake activity.

Almost every year, a lot of resources are invested for flood mitigation and protection using either structural (achieved by river training, storage dams and weirs) and/or non-structural (achieved by means of flood forecasting and rescue operations) measures (Mujere, 2011). However, meteorological forecasts can only provide very short forecasts in an accurate form, which may not allow enough time to reduce the impact of flood events (Madamombe, 2005). Given the above shortcomings of flood forecasting using rainfall data, the applicability of statistical frequency methods to the study of floods has been widely recognized by numerous researchers in the field. Frequency analysis is a procedure for estimating the frequency (or probability) of occurrence of extreme events. Flood frequency analysis (FFA) is most commonly used by engineers and hydrologists worldwide and basically consists of estimating flood peak quantities for a set of non-exceedance probabilities (Bhagat, 2017). Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval (Pegram and Parak, 2004). Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs of the government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains (Tumbare, 2000).

The flood discharge adopted for design of hydraulic structures taking economic and hydrological factors into consideration is known as design flood. The difference between the design return period and the estimated life of the structure should be quite large (Pandey et al., 2018). Although studies have employed several statistical distributions to quantify the likelihood and intensity of floods, none had gained worldwide acceptance and is specific to any country (Law and Tasker, 2003).

River flow characteristics is a subject not only pursued by hydrologists but also by the geomorphologist working on fluvial geomorphology and as such flood frequency analysis is also an important aspect of their study since such phenomenon has a significant bearing on fluvial landscape transformation. Various geomorphic aspects such as relief, drainage network and density, etc. influence to a great extent the occurrence of floods and their associated problems like river bank erosion, channel shifting and sedimentation on river bed and banks.

The present study has been conducted on Gabharu river which experiences severe flood during the monsoon causing tremendous sufferings to the riverine inhabitants. Since mere constructions of earthen embankments are rather temporary measures, therefore, for proper planning and design of water resources projects, it becomes necessary to determine the magnitude and frequency of floods that will occur at area. The present study on flood frequency, therefore, has been undertaken to estimate return periods associated with flood peaks of different magnitudes from recorded historical floods from 1988 to 2017 (30 year period) using statistical methods. Daily maximum discharge data of 30 years were considered from 1988 to 2017 obtained from the measurement taken by the Water Resource Department, Central Assam Investigation Division, Mangaldai, Assam. These were subjected to flood frequency analysis.

II. STUDY AREA

The Gabharu river is an important tributary river on the north bank of the Brahmaputra river in the north-eastern part of India. The Gabharu river basin, having an areal extent of 330 sq. km., is a sixth order basin lying partly in the West Kameng district of Arunachal Pradesh and partly in the Sonitpur district of Assam (Figure1). The basin is bounded by latitudes 26^{0}37'30"N and 27^{0}5'N and longitudes 92^{0}25'E and 92^{0}40'E. The Gabharu river, an essentially rain fed river, originates from the west Kameng district of Arunachal Pradesh in the Lesser Himalayan ranges and flows down for about 52 km along a NNW-SSE course through the alluvial plains of Sonitpur district of Assam before meeting the Brahmaputra near Gabharumukh. The river flows over steep gradients in the upper courses and after entering the plains of Assam it flows sluggishly in its entire lower course. Like other tributaries of the Brahmaputra, the river is also subject to severe floods during monsoon period which has, of late, witnessed increasing floods resulting in different types of hazards and as such has become geo-environmentally a very sensitive. Such a disturbing situation with streams and floods has caused serious geomorphic, hydrologic and environmental abnormalities. The increasing trend of sand bar in the river indicates that flash floods occur every year. Such flash floods have their adverse impact on agricultural practices in the basin (Bhattacharjee and Barman, 2015).

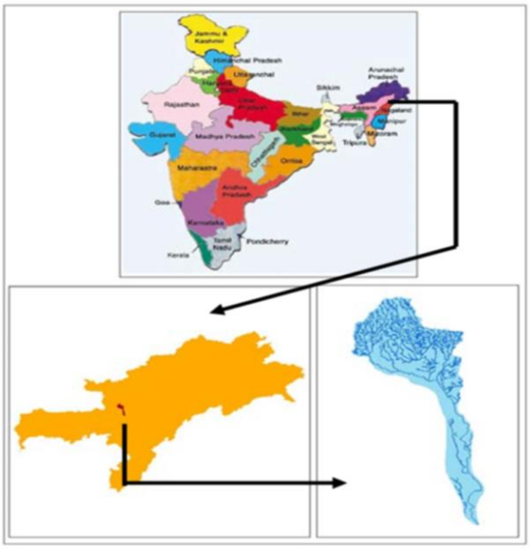


Figure 1: Location Map of the Study Area

III. METHODOLOGY

Both the Gumbel extreme value distribution and Log Pearson Type III distribution have been tested for their suitability in the study area.

<u>Gumbel's distribution</u>:

Gumbel distribution method, which has been frequently applied for flood frequency analysis, is a statistical method often used for predicting extreme hydrological events such as floods (Zelenhasic, 1970; Haan, 1977; Shaw, 1983). Gumbel in 1941 was the first to consider that the annual flood peaks are extreme value of flood in each of the annual series of recorded flood or rainfall. Hence, floods should follow the extreme value distribution (Bharali, 2015).

This methodology can be taken up if the following two conditions are met:

1. According to Mujere (2006), the conditions under which Gumbel's distribution can usually be applied, are as follows:
a) The river is less regulated i.e. not affected by human water demand such as reservoir, diversions and urbanization.
b) Maximum flow data is homogenous and independent.
c) Observed flow data is more than 10 years with good quality.

These conditions match with the present study area.

2. Before applying the Gumbel method, it is also necessary to ascertain whether 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 3. 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 (Solomon and Prince, 2013). The following calculations, however, have shown the lack of linearity (Figure 2) and, therefore, Gumbel's distribution is not applicable here.

The equation for Gumbel's distribution as well as to the procedure with a return period T is given as,

$$X_T = \bar{X} + K\sigma_X , \quad (1)$$

where, X_T = Probable discharge with a return period of T years;
σ_X = standard deviation of the sample size

$\bar{X}$ = Mean flood;

K = Frequency factor expressed as $K = \frac{Y_T - Y_n}{\sigma_n}$ (2)

where Y_T = Reduced variate; $Y_T = -[Ln.LnT/(T-1)]$ (3)

Y_n and σ_n are expected reduced mean and reduced standard deviations having values of 0.5362 and 1.1124 respectively for 30 years discharge data as computed by Gumbel. The table showing these values (Table 1) with respect to different periods of discharge data is given below.

Table 1: Values of Y_n and σ_n against different periods of discharge

N (Number of years)	Yn	Σn	N	Yn	σn
10	0.4952	0.9497	65	0.5536	1.1803
15	0.5128	1.0206	70	0.5548	1.1854
20	0.5236	1.062	75	0.5559	1.1898
25	0.5309	1.0915	80	0.5569	1.1938
30	0.5362	1.1124	85	0.5578	1.1973
35	0.5403	1.1285	90	0.5589	1.2007
40	0.5436	1.1413	95	0.5593	1.2038
45	0.5463	1.1518	100	0.56	1.2065
50	0.5465	1.1607	200	0.5672	1.2359
55	0.5504	1.1681	500	0.5724	1.2588
60	0.5521	1.1747	1000	0.5745	1.2685

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

Step I: Annual peak flood data for the river was assembled from 1988 to 2017**.**

Step II: From the maximum flood data for *n* years, the mean and standard deviation are computed using:

Step III: From n, the value of Y_n and S_n are obtained from Gumbel's Distribution Reduced Extreme Table.

Step IV: From the given return period T_r, the reduced variate Y_T is computed using Equation (3)

The plot of Y_T vs T_r has been found to be non-linear (Fig. 2) and, therefore, not suitable for estimating design flood with respect to different return periods in the present area .

Log Pearson Type III distribution:

The determinations were carried out based on the following steps (Jagadesh and Jayaram, 2009):
Step 1: Annual peak discharge data for the river was assembled from 1988 to 2017 .
Step 2: The annual peak discharge data was converted to logarithm of base 10 (Table 3).
Step 3: The mean of this data was determined. The standard deviation (S_x) and coefficient of skewness (C_s) were calculated from the formula stated below:

$$S_x = \sqrt{\frac{\sum_1^n (Y-\overline{Y})^2}{n-1}}$$

$$C_s = \frac{n\sum_1^n (Y-\overline{Y})^3}{(n-1)(n-2){S_x}^3}$$

These parameters are calculated to determine estimated peak discharge for a given recurrence interval or exceedence probability for a specific event.

Step 4: Using the general equation stated below, discharges associated with each recurrence interval had been calculated.

$$\text{LogQ} = \text{avg}(\log Q) + [K(Tr,Cs)] \times S_x$$

or, $$Y = \overline{Y} + [K(T_r,C_s)] \times S_x$$

where, K = frequency factor

Frequency Factors K for log-Pearson Type III Distributions for the 2, 5, 10, 25, 50, 100, and 200 recurrence intervals for skewness coefficient value of 0.4556 has been determined for the present study from the frequency factor table (Haan, 1977).

Step 5: The discharges with respect to return periods have been obtained by finding the antilog of the LogQ values (Table 4).

IV. FINDINGS AND DISCUSSION

Gumbel's distribution:

The computation of standard deviation and reduced variate is presented in Table-2.

Table - 2: Computation details of Gumbel's Extreme Value Distribution for the study area

Year	Peak discharge	Decending order	Rank(m)	$Sx^2=(n-\overline{x})^2$	Return period(Tr)	Reduced variate(Y)
1988	419.645	419.645	1	43839.98	31	3.42
1989	351.873	401.172	2	36445.48	15.5	2.71
1990	401.172	371.506	3	25998.66	10.34	2.28
1991	322.868	352.309	4	20176.49	7.75	1.98
1992	371.506	351.873	5	20052.82	6.2	1.74
1993	348.066	348.066	6	18989.11	5.17	1.54
1994	352.309	322.868	7	12679.43	4.43	1.36
1995	249.702	275.111	8	4205	3.88	1.21
1996	203.034	275.111	8	4205	3.88	1.21
1997	253.069	253.069	9	1832.18	3.45	1.07
1998	275.111	249.702	10	1555.27	3.1	0.94
1999	180.13	209.396	11	0.75	2.81	0.82

2000	209.396	203.034	12	52.28	2.58	0.71
2001	203.034	203.034	12	52.28	2.58	0.71
2002	161.12	203.034	12	52.28	2.58	0.71
2003	275.111	180.13	13	908.11	2.38	0.61
2004	84.322	179.329	14	957.03	2.21	0.51
2005	142.514	179.021	15	976.18	2.06	0.41
2006	90.373	161.12	16	2415.23	1.94	0.32
2007	161.12	161.12	16	2415.23	1.94	0.32
2008	160.163	160.163	17	2510.21	1.82	0.23
2009	203.034	142.514	18	4590.19	1.73	0.14
2010	179.021	131.195	19	6252.06	1.63	0.05
2011	179.329	112.096	20	9637.15	1.55	-0.04
2012	131.195	93.561	21	13619.82	1.48	-0.12
2013	112.096	90.373	22	14374.09	1.41	-0.21
2014	93.561	84.322	23	15861.63	1.35	-0.3
2015	78.485	78.485	24	17365.96	1.29	-0.4
2016	56.844	58.755	25	22955.28	1.24	-0.5
2017	58.755	56.844	26	23538	1.19	-0.6
		$\bar{Q}$=210.265				

From the graphical plot of reduced variate and peak flow shown in Figure 2, it is evident that the data do not exhibit reasonable linearity. Therefore, Gumbel's distribution cannot be applied in case of the Gabharu river.

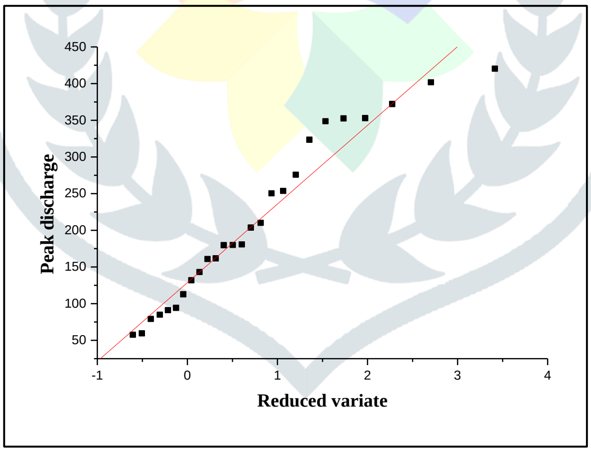


Figure 2: Plot of reduced variate vs peak flood for Gabharu river

As such, Log Pearson Type III distribution has been considered based on the calculations stated below.

<u>Log Pearson Type III</u>

Computation of statistical parameters for Log Pearson Type III distribution is given in Table 3

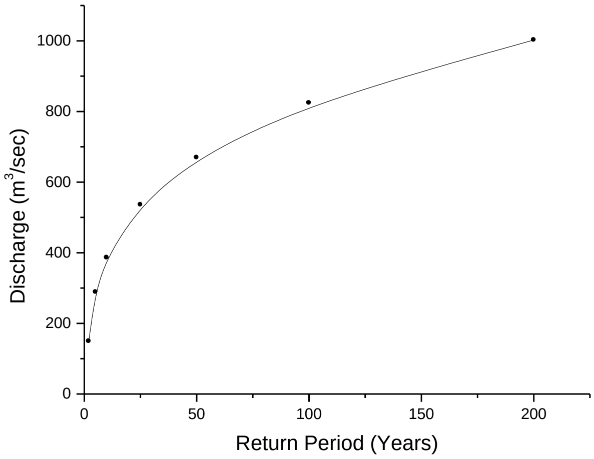
A plot of return period (years) versus discharge (m^3/sec) data (Figure 3) based on Table 4 reveals that Log Pearson Type III distribution is better suited distribution for analyzing discharge in the Gabharu river. The model relationship between expected discharge and return period is given by y= 181.86ln(x) – 11.301. This can be used to calculate expected discharge for return periods not stated beyond stated period of 200 years.

Table 3: Statistical parameters for Log Pearson Type III distribution

Year	Peak discharge(Q)	Y	Rank	Return period(Tr)	1/Tr
1988	419.645	2.62	1	31	0.03
1989	351.873	2.55	5	6.2	0.16
1990	401.172	2.6	2	15.5	0.06
1991	322.868	2.51	7	4.43	0.23
1992	371.506	2.57	3	10.34	0.09
1993	348.066	2.54	6	5.17	0.19
1994	352.309	2.55	4	7.75	0.13
1995	249.702	2.39	10	3.1	0.32
1996	203.034	2.31	12	2.58	0.39
1997	253.069	2.4	9	3.45	0.29
1998	275.111	2.44	8	3.88	0.26
1999	180.13	2.26	13	2.38	0.42
2000	209.396	2.32	11	2.81	0.35
2001	203.034	2.31	12	2.58	0.39
2002	161.12	2.21	16	1.94	0.52
2003	275.111	2.44	8	3.88	0.26
2004	84.322	1.93	23	1.35	0.74
2005	142.514	2.15	18	1.73	0.58
2006	90.373	1.96	22	1.41	0.71
2007	161.12	2.21	16	1.94	0.52
2008	160.163	2.2	17	1.82	0.55
2009	203.034	2.31	12	2.58	0.39
2010	179.021	2.25	15	2.06	0.48
2011	179.329	2.25	14	2.21	0.45
2012	131.195	2.12	19	1.63	0.61
2013	112.096	2.05	20	1.55	0.64
2014	93.561	1.97	21	1.48	0.68
2015	78.485	1.89	24	1.29	0.78
2016	56.844	1.75	26	1.19	0.84
2017	58.755	1.76	25	1.24	0.81
	AvgQ=210.265	$\bar{Y}$ =2.261			

Table 4: Discharges with respect to return periods

Return Period (Years)	Probability of Exceedence (%)	Frequency Factor C_s = 0.4556	Discharge (m^3/sec)
2	50	-0.348	149.66
5	20	0.808	288.67
10	10	1.320	386.19
25	4	1.896	535.67
50	2	2.288	669.42
100	1	2.654	824.14
200	0.5	2.999	1002.53



: **Figure 3:** Log-Pearson Probability fit to Gabharu river flow

V. CONCLUSIONS

From the flood frequency analysis carried out in the Gabharu river the following conclusions are drawn:

1. Gumbel's E V distribution, although a frequently used method, however has been found to be inappropriate in the present work which has been proved by the non-linearity of the bivariate plots of peak flow versus reduced variate.

2. Log Pearson Type III distribution has been found to be better suited to forecast the return periods for different discharges.

3. The probability distribution function was applied to return periods (T_r) of 2 yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs and 200 years. The estimated discharges obtained are 149.66m^3/sec, 288.67m^3/sec, 386.19m^3/sec, 535.67m^3/sec, 669.42m^3/sec, 824.14m^3/sec and 1002.53m^3/sec respectively. These values are the design floods useful for hydraulic design of structures in the catchment area and for storm water management.

4. From the values of discharge against the respective return periods, it can be said that in a period of 200 years, discharges of 149.66m^3/sec, 288.67m^3/sec, 386.19m^3/sec, 535.67m^3/sec, 669.42m^3/sec, 824.14m^3/sec and 1002.53m^3/sec will occur 100 times, 40 times, 20 times, 8 times, 4 times, and two times respectively. A discharge of 1002.53m^3/sec will occur once in every 200 years.

5. If found necessary, the data on peak discharges corresponding to respective return periods not stated in the given Table 4 can be generated and extrapolated from the relation $y= 181.86\ln(x) – 11.301$ which has been obtained on the basis of the plotted data. The values of design floods thus obtained will be useful in the engineering design of hydraulic structure such as storm water drains, culverts and reservoirs which could be extremely helpful for protecting lives and properties of the riverine dwellers.

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