ORIGINAL RESEARCH PAPER

Engineering

FLOOD FREQUENCY ANALYSIS USING GUMBEL EXTREME VALUE DISTRIBUTION METHOD: A CASE STUDY OF THE DIKRONG RIVER, NORTHEAST INDIA

KEY WORDS: Dikrong river, Gumbel's distribution, Design flood

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ABSTRACT

Flood frequency analysis has been carried out for the Dikrong river, an important tributary of the Subansiri river, the latter being a major tributary of the river Brahmaputra located in northeast India. The Dikrong river is subjected to severe flood during monsoon times. As such the frequency analysis has been conducted to relate the magnitude of events to their frequency of occurrence through probability distribution. Gumbel's Extreme Value distribution has been tested and used for consideration for a 30 year discharge data from 1979 to 2008. From the values of discharge against the respective return periods, it has been determined that in a period of 400 years, discharges of 706.268m3/sec, 953.864m3/sec, 1117.795m3/sec, 1478.579m3/sec, 1631.103m3/sec, and 1783.069m3/sec will occur 200 times, 80 times, 40 times, 8 times, 4 times, and 2 times respectively. A discharge of 1934.761m3/sec will occur once in every 400 years.

INTRODUCTION

Flood, one of the most hazardous natural disasters occurring on the earth's surface, results when the flow discharge exceeds the carrying capacity of the river channel, causing the water to overflow the banks of the river. 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). The advantage of this method is that the events of large recurrence interval, which are longer than the record period, can be determined through cautious extrapolation of the fitted distribution based on the model parameters (Pegram and Parak, 2004). Frequency based flood find their application in the estimation of design flood for almost all types of hydraulic structures and for the design of flood control structures. T- year design flood (T = 100 years, 50 years, 20 years, 10 years, or any desired year) is often required or calculated from the best fit distribution; hence probability distribution plays a vital role in designing and proper management of water resources. 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).

STUDY AREA

The Dikrong river, originating in the Lesser Himalayan ranges of Arunachal Pradesh, is a tributary of the Subansiri river which is a major north-bank tributary of the Brahmaputra. The basin area of Dikrong river is bounded by latitudes 26°55'N and 27°20'N and longitudes 95°15'E and 94°0'E (Figure 1). The river is essentially rainfed and as in case of the other tributaries of the Brahmaputra, the Dikrong river basin also witnesses severe floods during monsoon period.

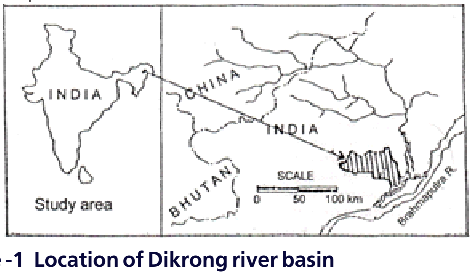

Figure -1 Location of Dikrong river basin

In the present study, an attempt has been made to gather detailed information on the likely flow discharge to be expected in the Dikrong river at various return periods based on the probability approach to the sample of annual flood peaks recorded over a period of 30 years. Such information is also important for designing the flood structure to protect against the expected events. 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 (Solomon and Prince, 2013). Also in case of extreme floods emergency evacuation of people can be carried out well in advance. Similar study can also be carried out on some other study region as the method used for the study is having a constant formula which remains spatially constant (Bhagat, 2017). Such analysis also has much significance in fluvial geomorphology. As an integral part of the study on hydrologic behavior of a river, the analysis of flow characteristics had been carried out not only by the hydrologists but also by geomorphologists interested in the fluvial aspects of a river basin. Pegram and Parak (2004) have applied geomorphological information towards understanding regional maximum flood.

METHOD AND FORMULATION

Gumbel distribution method, which has been applied for flood frequency analysis in the present study, is a statistical method often used for predicting extreme hydrological events such as floods (Haan, 1977). 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 has been taken up because of two reasons:

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. The pre-requisite for application of Gumbel's method is to ascertain if the observed flood data collected in the catchment follows Gumbel's Extreme Value distribution or not which is manifested by linearity of the plots of reduced variate vs peak flood. For this determination, the peak flood data is arranged in descending order in terms of magnitude and the return period for each flood is assigned. 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 reasonable linearity of the plots is observed, then it is reasonable to conclude that the Gumbel's distribution is a good fit for the observed flood data (Solomon and Prince, 2013). In case of the present study, the plot of reduced variate versus peak flood (Figure 2) exhibits reasonable linearity and, as such, Gumbel method has been considered for flood frequency analysis .

 Volume-7 | Issue-11 | November-2018 | PRINT ISSN No 2250-1991

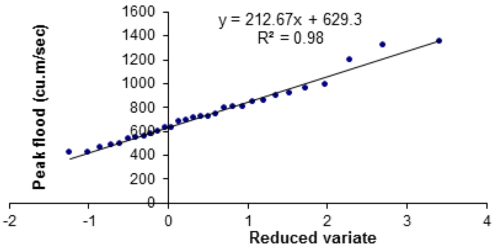

Fig.2 Plot of Reduced variate vs Peak flood

The equation for Gumbel's distribution is given as,'

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

where, X_T = Probable discharge with a return period of T years;
S_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 maximum values of 0.5362 and 1.1124 respectively for 30 years discharge data obtained from Gumbel's Extreme Value distribution table given in Table-1.

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

n (Number of years)	Yn	σ_n	n	Y_n	σ_n
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

Daily maximum discharge data were considered from 1979 to 2008 (30 years flood data) obtained from the measurement carried out by the Department of Water Resources, Jamuguri, Assam and were subjected to flood frequency analysis applying the Gumbel's distribution.

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 1979 -2008.

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

using: $\sum_{i=1}^{n}\bar{x}$ and $\sigma_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x-\overline{x})^2}$

Step III: The values of Y_n and S_n, obtained from Gumbel's Extreme Value Distribution Table

(Table- 1), are 0.5362 and 1.1124 respectively.

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

Step V: From Y_n, σ_n, and Y_T, the flood frequency factor K is computed using Equation (2).

Step VI: With use of Equation (1), the magnitude of flood is computed.

RESULTS

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

Table – 2 Computation details of Gumbel's Extreme Value Distribution

Year	Flood Peak (m^3/s)	Flood Peak in descending order (m^3/s)	Order (expressed as 'm')	$Sx^2 = (n-\bar{X})^2$	Return Period $Tr = \frac{N+1}{m}$ (N: no. of years)	Reduced Variate $YT = -\ln.\ln\frac{Tr}{Tr-1}$
1979	533.67	1344.54	1	361446.25	31	3.417
1980	552.28	1315.90	2	327829.53	15.5	2.707
1981	1199.24	1199.24	3	207848.46	10.33	2.285
1982	724.90	992.48	4	62072.73	7.75	1.979
1983	1344.54	957.42	5	45831.96	6.2	1.738
1984	1315.90	912.02	6	28454.29	5.166	1.536
1985	489.27	895.96	7	23294.08	4.428	1.363
1986	597.66	855.97	8	12686.42	3.875	1.209
1987	579.64	844.81	9	10296.97	3.444	1.070
1988	460.36	800.48	10	3265.44	3.1	0.943
1989	685.70	799.01	11	3099.59	2.818	0.825
1990	855.97	791.74	12	2342.95	2.583	0.714
1991	423.69	739.82	13	12.36	2.384	0.609
1992	895.96	724.3	14	362.37	2.214	0.509
1993	992.48	718.09	15	637.36	2.066	0.413
1994	739.82	709.65	16	1134.75	1.937	0.320
1995	791.74	685.70	17	3321.91	1.823	0.229
1996	678.27	678.27	18	4233.58	1.722	0.140
1997	912.02	625.23	19	13949.03	1631	0.052
1998	844.81	624.91	20	14024.72	1.55	-0.035
1999	799.01	597.66	21	21221.49	1.476	-0.123
2000	709.65	579.64	22	26796.38	1.409	-0.212
2001	800.48	552.28	23	36502.39	1.348	-0.303
2002	718.09	544.21	24	39651.16	1.291	-0.397
2003	424.46	533.67	25	43959.83	1.24	-0.496
2004	479.31	489.27	26	64549.53	1.192	-0.601
2005	625.23	479.31	27	69709.73	1.148	-0.716
2006	544.21	460.36	28	80075.42	1.107	-0.848

2007	624.91	424.46	29	101681.90	1.069	-1.008
2008	957.42	423.69	30	102173.56	1.033	-1.233
SUM		**22300.09**		**1712466.00**		
AVG.		**743.336**				
STD.DEV.				**243.003**		

Table – 3 Computation of expected floods at different return periods along Dikrong river

Return Period (Tr) in years	Reduced Variate (YT) YT = $-\ln.\ln\frac{Tr}{Tr-1}$	Frequency Factor (K) K = $(Y_T-Y_n)/\sigma_n$	Expected Flood $X_T = \overline{X} + K.S_x$ (in m^3/sec)
2	0.366513	-0.152541	706.268
5	1.499940	0.866361	953.864
10	2.250367	1.540963	1117.795
50	3.901939	3.025655	1478.579
100	4.600149	3.653316	1631.103
200	5.295812	4.278687	1783.069
400	5.990213	4.902924	1934.761

CONCLUSIONS

Gumbel's E V distribution, a frequently used method, has been found to be appropriate in the present work which has been proved by the linearity of the bivariate plots of peak flow versus reduced variate. From the trendline equation, the R^2 gives a value of 0.98 indicating that the pattern of scatter is narrow thereby implying the suitability of Gumbel distribution method in the present study area. The probability distribution function was applied to return periods (T_r) of 2yrs, 5yrs, 10yrs, 50yrs, 100yrs, 200yrs, and 400yrs The estimated discharges obtained are 706.268m^3/sec, 953.864m^3/sec, 1117.795m^3/sec, 1478.579m^3/sec, 1631.103m^3/sec, 1783.069m^3/sec, and 1934.761m^3/sec respectively. These values are the design floods useful for hydraulic design of structures in the catchment area and for storm water management. Therefore, from the values of discharge against the respective return periods, it can be said that in a period of 400 years, discharges of 706.268m^3/sec, 953.864m^3/sec, 1117.795m^3/sec, 1478.579m^3/sec, 1631.103m^3/ sec, 1783.069m^3/ sec will occur 200 times, 80 times, 40 times, 8 times, 4 times, 2 times respectively. A discharge of 1934.761m^3/sec will occur once in every 400 years.

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