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Flood Frequency Analysis for Jiya Dhol River of Brahmaputra Valley

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Abstract

Flood frequency analysis is an important mathematical modelling technique in determining the return period of the probability of witnessing a particular discharge in a river, especially a peak discharge. Floods as periodic events in a river basin are associated with high discharge. In flood frequency analysis the annual peak discharge in a river is fitted in different probability distributions. Three important statistical methods, most commonly used in flood frequency analysis, are - Gumbel's Extreme Value Distribution, Log Pearson Type III Distribution and Log Normal Distribution. In this paper, 40 years' (i.e., 1973 to 2012) annual peak discharge series of the Jiya Dhol river has been tried to fit in the above mentioned frequency distribution models and the best distribution model(s) for the basin has been identified with the help of D-Index test. The Jiya Dhol river basin is one of the most flooded river basins in the Brahmaputra valley of Assam (India). Floods cause heavy loss of life and property in the flood seasons (i.e., usually the monsoon season) in Lakhimpur and Dhemaji Districts of the north bank of the Brahmaputra valley in Assam. The selection of best probability distribution method in the studied river basin with the recent available records will definitely help the planners and administrators to estimate the major flood events and save life and property accordingly.

Keywords: Flood frequency; Peak Discharge; Return Period.

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1. Introduction

Floods are periodic phenomenon of high discharge and associated over bank flow in a river. These are integral part of the fluvial cycle in a river, these are associated with high stage in a river that overflows the banks and inundates the adjoining areas. Flood frequency analysis is the most important statistical technique in understanding the nature and magnitude of high discharge in a river. This method helps in predicting the recurrence interval of a particular magnitude of peak discharge. The hydraulic and flow behaviour of the river can be examined through flood frequency analysis [1].

The result of frequency distribution depends on the length of the hydrological series. The flood frequency and the magnitude relation is important as the smaller flood events happen relatively frequently whereas the large floods occur rarely but cause the most damage [2]. The USGS recommend the fitting of the logarithm of the annual maximum peak discharge to a Pearson Type III distribution using the method of moments approach for parameter estimation as the standard method. In India, a number of scholars have tried to validate different flood frequency distributions in different river basins [3,4,5,6]. Most of the scholars have tried their best to give the best probability distribution through statistical tests and found different results. D-Index test is one of the most commonly used [7]. Thus, flood frequency analysis of various rivers helps in determining the best distribution for predicting the frequency of floods of a given magnitude.

According to the master plan prepared by Brahmaputra Board, Gumbel's Extreme Value distribution fits best for Jiya Dhol River where as in academic works, where earlier data have been used shows Log Pearson type III distribution as best for the river [8]. Thus, flood frequency analysis of a single river for different time periods may result into different best fitting distribution. So, it should be verified with the longest available data.

In the present study, the best probability distribution in predicting peak discharge of different return periods for the Jiya Dhol river has been tried to find out, in order to use it for the planning and flood management of the river. The 40 years peak discharge data used in this paper, will definitely added to the earlier works on this particular basin. The recent 10 years has a significant role to play in flood frequency analysis of Jiya Dhol river basin.

2. The study area

The Jiya Dhol river is one of the north bank sub-tributaries of the Brahmaputra river that empties in Charikoria river. Basin of the Jiya Dhol river extends from 27°15' N to 27°45' N latitudes and 94°15' E to 94°40' E longitudes, covering an area of 1191.62 sq km, of which 38% (446.6 sq km) lies in Arunachal Pradesh and 62% (746.6 sq km) in Assam (Fig. 1). The upper hilly part of the basin falls in the Outer Himalaya and the Siwaliks comprising of the Tertiary formations. While the middle part of the lies in the piedmont zone characterised by the presence of sand with admixture of cobbles and boulders, where as the lower reaches are characterized by alluvium. Climate of the basin is typically characterised by hot and humid conditions, representing oppressive climate, which is found all along the foothills and piedmont zone, i.e., junction between the Brahmaputra plains

and the Himalaya Mountain. Summer rains occur in the pre-monsoon and monsoon seasons, while the winters are dry.

Though the Jiya Dhol river originates in the Arunachal Himalaya, yet it is not fed by snow melt, instead rainfall contributes to its runoff. The Siri, Sido and Sika rivers meet at a place called Trimukh in the Arunachal Himalaya and the combined flow downstream is known as the Jiya Dhol. Hence, the three tributaries contribute most of the runoff and sediment to the Jiya Dhol river. After crossing a gorge near Jiyadhalmukh, it debouches on to the Brahmaputra plains, where the course of the river becomes very broad. In the plains, the river is divided in to several branches which rejoin again downstream. The most important anabranches of the Jiya Dhol, which are well known for causing floods, are Kumatia and Samorajan. At present, a considerable amount of the runoff of Jiya Dhol is carried by the Samorajan river, while the Kumatia receives water from the Jiya Dhol during the monsoon only. Along the southern slope of the foothill many small streams combine together and flow further south in the name of No Noi or Dihingia River. It empties into Smarajan and it is the most important tributary of Jiya Dhol in the plains of Assam. The Kumatia branch of the river meets other small tributaries. On the other hand, Samarajan on entering Ghilamara is called as Sampara. After flowing further down Sampara rejoins the Kumatia branch and retain the name Sampara. Ultimately, it meets Charikoria after crossing many swamps and wetlands.

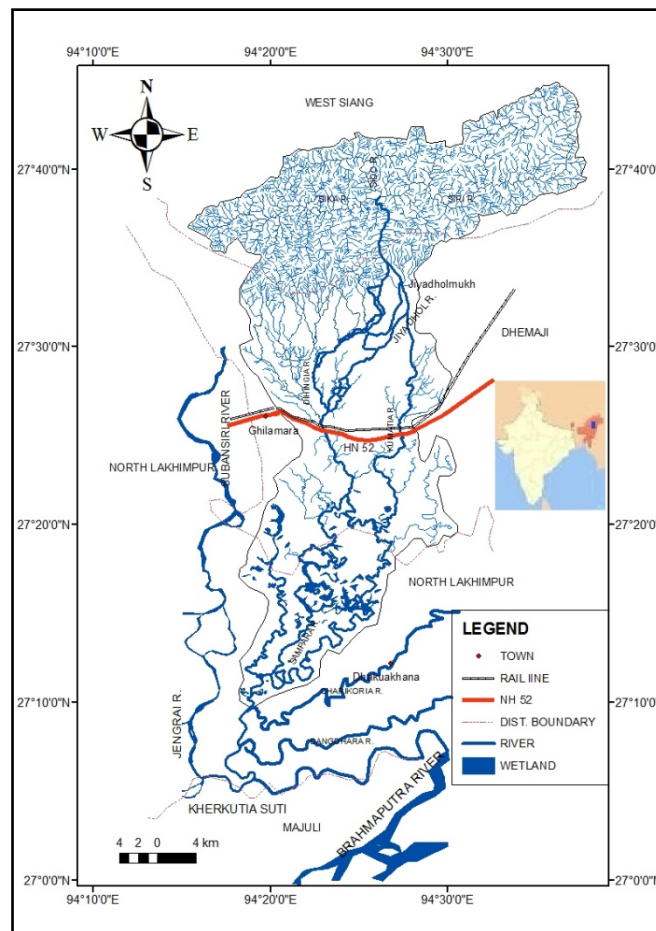


Fig. 1. The Jiya Dhol River Basin

In this paper, the study area is limited to the Jiya Dhol River basin demarcated by the meeting of Sampara and Charikoria. Occurrences of flood in the lower reaches of the basin are basically caused by the river Brahmaputra and its various anabranches. Thus, floods of Jiya Dhol includes floods encountered in the upper part, i.e., on north from the plains of Assam Arunachal Border to the south up to the mosaic of wetlands. So, the discharge at Jiyadhalmukh is very significant in understanding the nature of floods caused by the river.

3. Material and methodology

The annual peak discharge data of Jiya Dhol River in cumecs, at Jiyadhalmukh station has been collected from Brahmaputra Board, Government of Assam, for a period of 40 years from 1973 to 2012. There are two methods of analyzing the flood peaks. They are the annual maximum series and the partial duration series. The annual floods series analysis is based on the assumption that the peak flows are independent of other events and hence, the highest peak discharge recorded very year is used for analysis. In partial duration series, all flood discharges above a threshold in any year are taken for analysis. In the present paper, the annual peak discharge series of 40 years of Jiya Dhol River has been analysed.

Flood frequency analysis is related with calculation of three interrelated mathematical terms or parameters and they are the probability of exceedence, the relative frequency and the average recurrence interval. The probability of exceedence, is the probability that a flow is greater than, or equal to a particular value. The relative frequency is the probability of the flow being less than a particular value. The average recurrence interval is referred to as the return period with the help of the following formula:

$$\text{The Probability of exceedence,} = P(X)$$

$$\text{The Relative Frequency} = F(X)$$

$$\text{The Average Recurrence Interval} = T(X)$$

Where,

$$P(X) = 1 - F(X) \quad 1$$

$$\text{And} \quad T(X) = 1/P(X) = 1/(1-F(X)) \quad 2$$

There are different methods suggested by scholars to calculate these parameters of flood frequency analysis. One of the earliest methods used in the flood frequency analysis is the Weibull's method and it was first used in 1939. In this method, the annual peak discharge series is ranked in order of magnitude either from the highest to the lowest peak value or *vice versa*, and after that $F(X)$ is calculated by the following formula-

$$F(X) = (N+1)/r, \quad 3$$

here, r = the rank of an individual flood event X within the data series and N = the size of the series.

This distribution is a simple one and it is generally plotted in log paper can be used to compare with the later methods.

In the present study, following methods are used to calculate the above mentioned parameters of Flood Frequency Analysis:

Gumbel's Extreme Value Distribution

It was introduced by E.J. Gumbel in 1941 based on the principle that the distribution of an extreme event is unlimited and hence the most suitable distribution for fitting the extreme values is of double exponential type. He gave the probability of occurrence and exceedence, of an event x_0 as

$$P(x \geq x_0) = 1 - e^{-e^{-y}} \tag{4}$$

here, e = base of natural logarithm

y = a reduced variate, given by

$$y = b(x-a), \quad \text{where, } a = X - 0.45005 \sigma \quad \text{and } b = 1.2825 / \sigma$$

$$\Rightarrow y = (x - X + 0.45 \sigma) / 0.78 \sigma \tag{5}$$

here, x = flood magnitude or the peak discharge with the probability of occurrence P

X = arithmetic mean of all the peak discharge in the series

σ = Standard Deviation of the series

Estimated Peak Discharge is Given by:

$$X_T = X - k \sigma$$

the frequency factor, k of Gumbel's distribution is given by:

$$k = y_T - y_n / \sigma_n$$

where, y_T = the value of peak discharge for a given recurrence interval

y_n = Gumbel's reduced mean and

σ_n = Gumbel's reduced standard deviation

Again the reduce variate for a given return period T_r can be calculated by transposing Equation 4 as

$$y = -\ln(\ln(T_r / (T_r - 1)))$$

$$\Rightarrow y = -(0.834 + 2.303 \log \log T_r) / (T_r - 1)$$

The recurrent interval of an event of magnitude x is given by

$$T = 1/P = 1 / (1 - e^{-e^y})$$

Log Pearson Type III distribution

This distribution is also referred to as the Gamma distribution, which is considered as a standard flood frequency analysis method by many scholars and it is gaining much popularity in India. It has been recommended by the US Water Resource Council due to its flexibility. In this method, the annual peak discharge series is first of all converted to logarithms of base 10 and then the mean, standard deviation and coefficient of skewness are calculated to determine estimated peak discharge for a given recurrence interval or exceedence, probability for a specific event. The estimated discharge of a given period can be evaluated by using the logarithm of the designed flood by

$$Z = Z_{ave} + k \sigma_z \tag{6}$$

Where, Z_{ave} is the mean of the logarithm series and σ_z is the standard deviation and k is the frequency factor, which is the function of recurrence interval and coefficient of skewness and is determined by using frequency factor table for Gamma or Log Pearson Type III distribution [10].

Log Normal Distribution

In log normal distribution, the series is normally distributed with mean and standard deviation and the coefficient of skewness is assumed to be zero. The estimated peak discharge is given by-

$$Z = Z_{ave} + K_0 \sigma_z \tag{7}$$

Where, Z_{ave} is the mean of the logarithm series and σ_z is the standard deviation and K_0 is the frequency factor corresponding to a particular return period with coefficient of skewness as zero as per determined by the table [10].

D-Index Test

D-Index Test is performed to find out the best method for estimating peak discharge in Jiya Dhol River Valley among the above mentioned three methods. D-Index is given by

$$D\text{-Index} = 1/Q \sum_{i=1}^4 |x - x^*|$$

Where, Q is the mean of the annual peak discharge series, x is the ith highest recorded discharge and x* is ith the highest estimated discharge. The distribution with lowest value of D-Index will be considered as the best distribution for estimating peak discharge for a given return period.

4. Results

During the monsoon period the average discharge of the river is 215 cumecs per day. The Danger Level (DL) is marked at a stage of 124.39 m above mean sea level. The highest annual peak discharge ever recorded for the river Jiya Dhol at Jiyadholmukh was 1020.47 cumecs on 29th June, 2004, with water level at 127.03 m. whereas, the lowest annual peak discharge of 232.755 cumecs was recorded on 21st August, 2010. The annual peak discharge in the river from 1973 to 2012 is given in Figure 2. The graph shows a negative trend of annual peak discharge mainly because of the lower values of discharge in the recent 8 years.

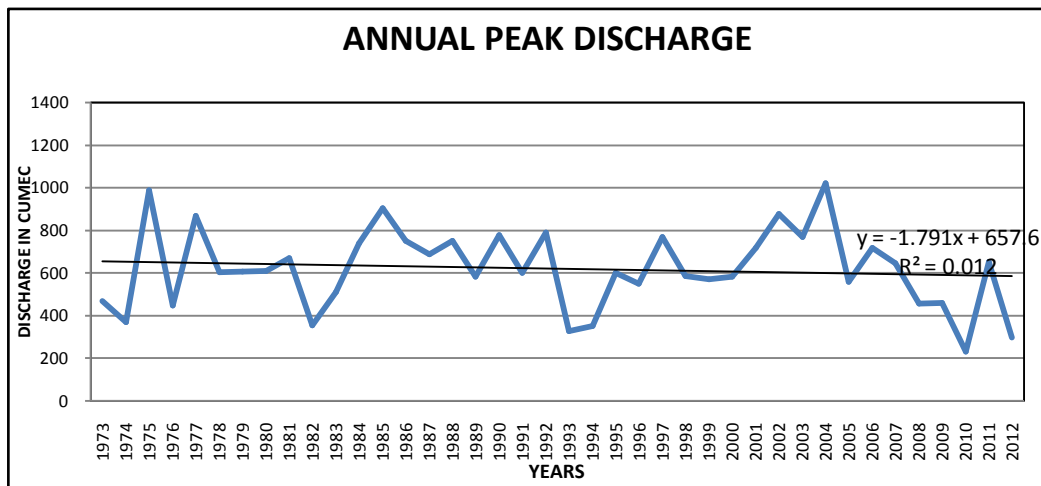


Fig. 2. Annual Peak Discharge, 1973 to 2012

From the annual peak discharge series the Gumbel’s Extreme Value Distribution, Log Pearson Type III Distribution and Log Normal Distributions have been prepared. The peak discharge for 2, 5, 10, 25, 50, 100 and 200 years return period are estimated separately by the three methods in Tables 1, 2 and 3. The values have also been plotted in the log graph as shown in Figures 1, 2 and 3.

Table 1. Estimation of the Peak Discharge by Gumble's Extreme Value Distribution

T	$T/(T-1)$	$\log\log T/(T-1)$	$Y_T = -0.834 + 2.303 \log\log T / T-1$	$K = (Y_T - Y_{ave}) / \sigma$	$X_T = X + K\sigma$
2	2	-0.52139	0.366762	-0.16401	590.2674
5	1.25	-0.7576	0.910756	0.260161	669.443
10	1.111111	-0.95424	1.36362	0.613271	735.355
25	1.041667	-1.23472	2.009566	1.116933	829.369
50	1.020408	-1.46001	2.528404	1.521485	904.8834
100	1.010101	-1.69461	3.068676	1.942749	983.5172
200	1.005025	-1.93693	3.626752	2.377896	1064.742

Table 2. Estimation of Peak Discharge by Log Pearson Type III Distribution

T	Coefficient of Skewness, C_{sy}	$K=f(t, C_{sy})$	Z_T	$Q = \text{antilog } Z_T$
2		0.132	2.790407	617.1733
5		0.856	2.895817	786.7145
10		1.166	2.940951	872.8734
25	-0816	1.448	2.982009	959.4199
50		1.606	3.005013	1011.609
100		1.733	3.023503	1055.609
200		1.837	3.038645	1093.062

Table 3: Estimation of Peak Discharge by Log Normal Distribution

T	Coefficient of Skewness, C_{sy}	K_0	Z_T	Q
2		0	2.771189	590.4577
5		0.842	2.893779	783.0308
10		1.282	2.95784	907.4864
25	0	1.751	3.026124	1061.998
50		2.054	3.070239	1175.543
100		2.326	3.10984	1287.776
200		2.576	3.146239	1400.357

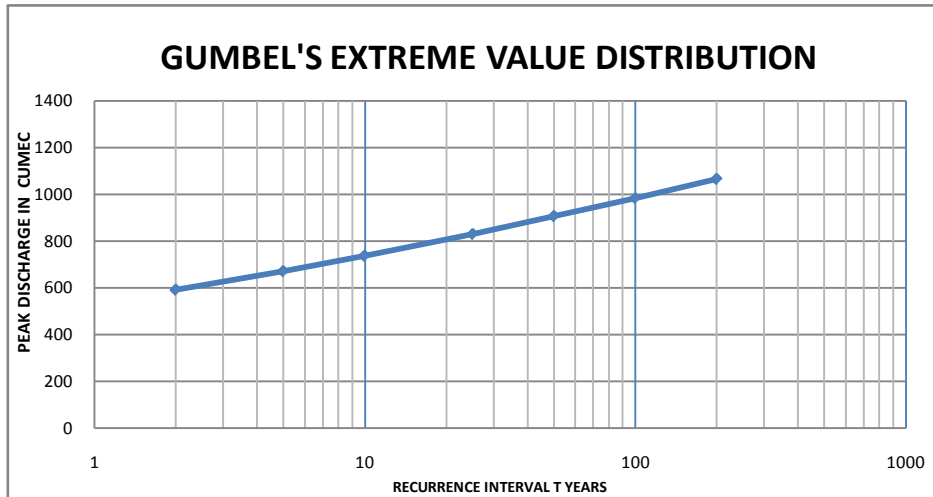


Fig. 3. Gumbel's Extreme Value Distribution

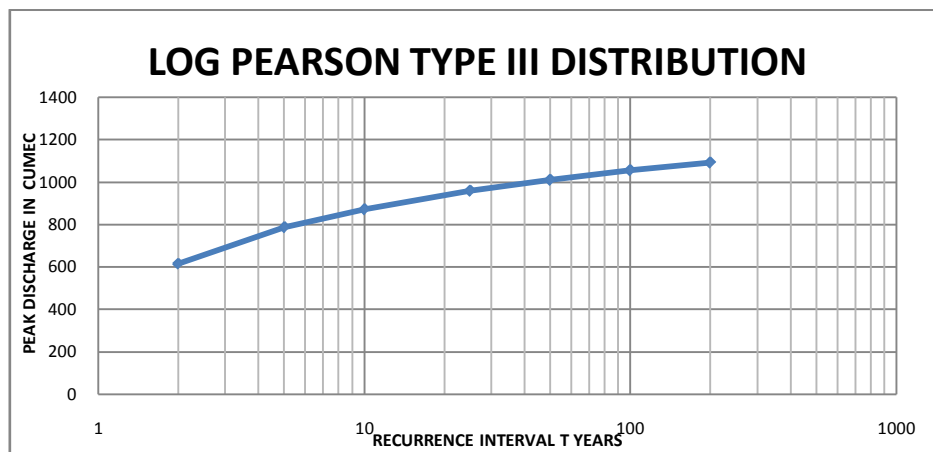


Fig. 4. Log Pearson Type III Distribution

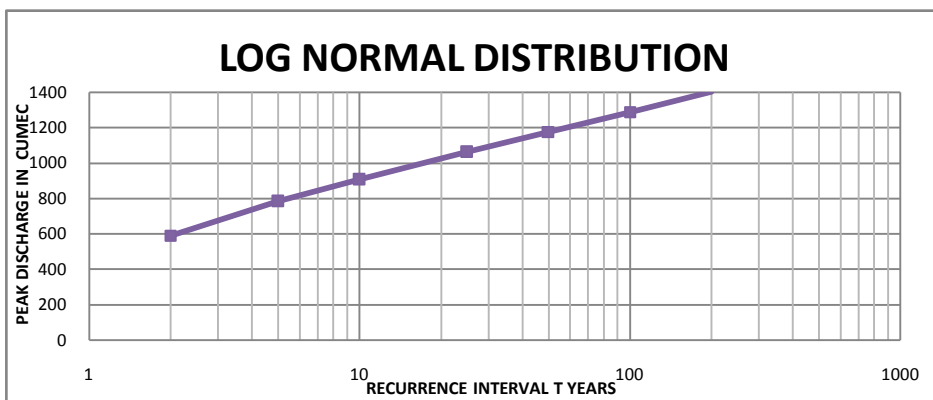


Fig 5. Log Normal Distribution

It is clear from the Tables and Figures 1, 2 and 3 that the Gumbel's Extreme Value Distribution gives lower values of peak discharge as compared to other two distributions, except for 2 years return period. On the other hand, Log Normal Distribution gives higher values for 10, 25, 50, 100 and 200 years compared to other two distributions except for 2 and 5 years return period. The Gumbel's Extreme Value Distribution shows a curve in which the middle portion is curved inward whereas the Log Pearson Type III Distribution gives a curve which is bulging outward. On the other hand, the Log Normal Distribution gives a straight curve.

To test the best probability distribution for estimating the peak discharge, D-Index values for each distribution have been calculated. The D-Indices are calculated using recorded peak discharge and estimated peak discharge for 2, 5, 10 and 25 years return period for all the three distributions. The lowest value of D-Index statistically means the lowest deviation from the recorded data. In this paper, the lowest value of D-Index is derived for the Log Pearson Type III Distribution.

Table 4. D-Index Test

Type of Distribution	D-Index Value
Gumbel's Extreme Value Distribution	0.78
Log Pearson Type III Distribution	0.24
Log Normal Distribution	1.028

5. Conclusion

Log Pearson Type III Distribution is the best probability distribution method for estimating the peak discharge in the Jiya Dhol River basin of the Brahmaputra Valley, Assam. But Gumbel's Extreme Value Distribution can also be used as it gives a lower value. Thus, both Log Pearson Type III and Gumbel's Extreme Value Distributions are good for estimating high discharge and flood events in the Jiya Dhol River.

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