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Original Research Paper

Flood Frequency Analysis of the Mahi Basin by Using Log Pearson Type III Probability Distribution



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Abstract

Flood frequency analysis is one of the techniques of examination of peak stream flow frequency and magnitude in the field of flood hydrology, flood geomorphology and hydraulic engineering. In the present study, Log Pearson Type III (LP-III) probability distribution has applied for flood series data of four sites on the Mahi River namely Mataji, Paderdi Badi, Wanakbori and Khanpur and of three sites on its tributaries such as Anas at Chakaliya, Som at Rangeli and Jakham at Dhariawad. The annual maximum series data for the record length of 26-51 years have been used for the present study. The time series plots of the data indicate that two largest ever recorded floods were observed in the year 1973 and 2006 on the Mahi River. The estimated discharges of 100 year return period range between 3676 m³/s and 47632 m³/s. The return period of the largest ever recorded flood on the Mahi River at Wankbori (40663 m³/s) is 127-yr. The recurrence interval of mean annual discharges (Q_m) is between 2.73-yr and 3.95-yr, whereas, the return period of large floods (Q_{lf}) range from 6.24-yr to 9.33-yr. The magnitude-frequency analysis curves represent the reliable estimates of the high floods. The fitted lines are fairly close to the most of the data points. Therefore, it can be reliably and conveniently used to read the recurrence intervals for a given magnitude and vice versa.

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1 INTRODUCTION

Flood frequency analysis is one of the most commonly used techniques by the hydrologists, geomorphologists and hydraulic engineers to estimate the recurrence interval of peak discharge for a given site and is displayed as a flood frequency curve. However, availability of the longest flood series data along with the historic pre-instrumental records are required for the higher accuracy in the estimation of discharges for various return periods (Cunnane, 1989; Merz and Blöschl, 2008a; Merz and Blöschl, 2008b; Gaal *et al.*, 2010 and Elleder *et al.*, 2013). Brazdil *et al.* (2006) studied historic hydrological materials to estimate floods threat in Europe. There are several flood probability distribution models such as the generalized extreme value, Gumbel extreme value type I (GEVI), Log-Normal, Log Pearson type III (LP-III) to enumerate the

magnitude and return period of floods, none of them gained universally recognition and unambiguous for a country (Law and Tasker, 2003). Foster (1924) introduced the Log Pearson Type III (LP-III) frequency distribution for describing the flood data. Griffis and Stedinger (2007, 2009), Phien and Jivajirajah (1984) used LP-III distribution to estimate maximum annual rainfall and discharges. Millington *et al.* (2011) estimated discharges for different return periods by comparing GEV, LP-III and Gumbel probability distribution. A frequency factor based method in flood frequency analysis for random generation of five distributions (Normal, Lognormal, Extreme Value Type I, Pearson Type III and Log Pearson Type III) was presented by Cheng *et al.* (2007).

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Chow *et al.* (1988) stated that a curve produced by the flood frequency analysis have been used in the design of the hydraulic structures. Srikanthan and McMahon (1981) and McMahon and Srikanthan (1981) examined the applicability of LP-III distribution to Australian rivers. Singo *et al.* (2013) suggested that the Log Pearson Type III is the best fit probability model for flood prone Luvuvhu Basin of South Africa. Shen *et al.*, (1980) compared the results of the Log Pearson type III and Gumbel distributions and opine that LP-III distribution is a better description of field data. The United State Water Resources Council (USWRC) in 1967 has recommended Log Pearson Type III (LP-III) probability distribution and subsequently updated in 1975, 1977 and 1981 as the base method of flow frequency analysis in the United States. It has been commonly applied in many parts of the world. Besides, the Institute of Engineers Australia (1987) also recommended that LP-III distribution be fitted to annual peak discharge data by using mean, standard deviation and coefficient of skewness of the logarithms of flow data (Pilgrim, 1987; Kottegoda and Rosso, 1997; Koutrouvelis and Canavos, 2000).

The Normal, Lognormal, Gumbel extreme value and Log Pearson type III probability distributions have been adopted to find flood frequency for different return periods by Jha and Bairagya, (2011) and Kumar *et al.*, (2003) for deltaic region and Middle subzone 1(f) of Ganga Basin respectively. Hire and Patil, (2018) stated

that GEVI probability distribution is best fit for the bedrock Par River in the western India. Bedrock channel morphology of the Par River shows high spatial variability in terms of flood hydraulics and hydrodynamics (Patil *et al.*, 2017). Besides, Hire, (2000) also studied the flood frequency characteristics of the Tapi River by comparing Gumbel Extreme Value Type I and LP-III probability distributions. In case of Indian rivers, analysis reveals that LP-III distribution gives consistent results for estimating peak discharges up to 100-yr recurrence interval (Sakthivadivel and Raghupathy, 1978). Therefore, in view of the basin size and meteorological characteristics of the Mahi Basin Log Pearson type III (LP-III) probability distribution has been applied to the annual maximum series (AMS) data.

2 STUDY AREA

The Mahi River originates from Malwa Plateau near the village Mindha in Sardarpur tehsil in Dhar district of Madhya Pradesh at an elevation of 500 m above ASL. It lies between 72°21' to 75°19' E longitudes and 21°46' to 24°30' N latitudes. It is bounded by Aravalli hills on the north and the northwest, by Malwa Plateau on the east, by the Vindhya on the south and by the Gulf of Khambhat on the west (Figure 1). It drains through states of Madhya Pradesh, Rajasthan and Gujarat for a total length of 583 km. The Mahi Basin has total catchment area of 34,842 km². The Som is its principal tributary which joins from right, and the Anas and the Panam join the river from left. The average annual

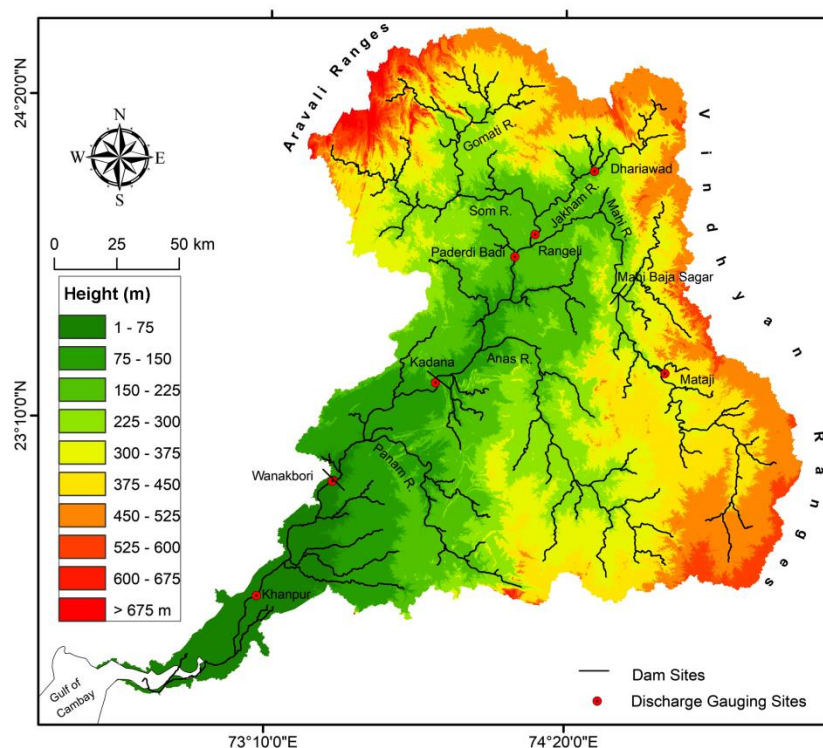


Figure 1. Physiography of the Mahi Basin and discharge gauging sites

rainfall (AAR) of the basin is 889 mm. The southwest monsoon sets in by the middle of June and withdraws by the first week of October. The Mahi Basin receives 97 percent of total rainfall during the monsoon months of which 45% is received in July and August (Figure 2). The rainfall is mainly influenced by the southwest monsoon.

3 DATA AND METHODOLOGY

Annual Maximum Series (AMS) data have been obtained from Central Water Commission (CWC) for the analysis of magnitude and frequency of floods on the Mahi River and its tributaries. The data have been made available for four sites on the Mahi namely, Mataji, Paderdi Badi, Wanakbori and Khanpur and three sites on its tributaries such as Som at Rangeli, Jakham at Dhariawad and Anas at Chakaliya (Figure 1). The data record length for these sites ranges between 26 and 51 years (Table 1).

The fitting the distribution needs of computing the mean (Q_m), standard deviation (σ), and coefficient of skewness (C_s), of the logarithms of the annual peak-flow record in order to describe the mid-point, slope and

curvature of the magnitude frequency curve respectively. Therefore, annual maximum discharge data have been analyzed by applying basic statistical techniques. Besides, time series graph of annual peak discharges for all the stations have been derived for better understanding of spatio-temporal variations in the peak flood discharges.

The expected design flood discharges have been calculated for return periods of 2, 5, 10, 25, 50 and 100 yrs. When three-parameter gamma distribution is used to the logs (either to the base of 10 or natural) of the AMS data, it is called the LP-III distribution (Bedient and Huber, 1989). The discharges of given recurrence intervals were estimated with the help of following equation (equation (1)) (Viessman *et al.*, 1989)

$$\log QT = Q_m \log Q + [K(T) \times \sigma \log Q] \quad (1)$$

where, $\log QT$ is log of discharge of required return period, $Q_m \log Q$ is mean of log of AMS, $\sigma \log Q$ is standard deviation of log of AMS, and $K(T)$ = frequency factor of return period (T). $K(T)$ value is based on skewness coefficient of log of AMS data. The $K(T)$ values were obtained from tables given in the books on Hydrology (Raghunath, 2006).

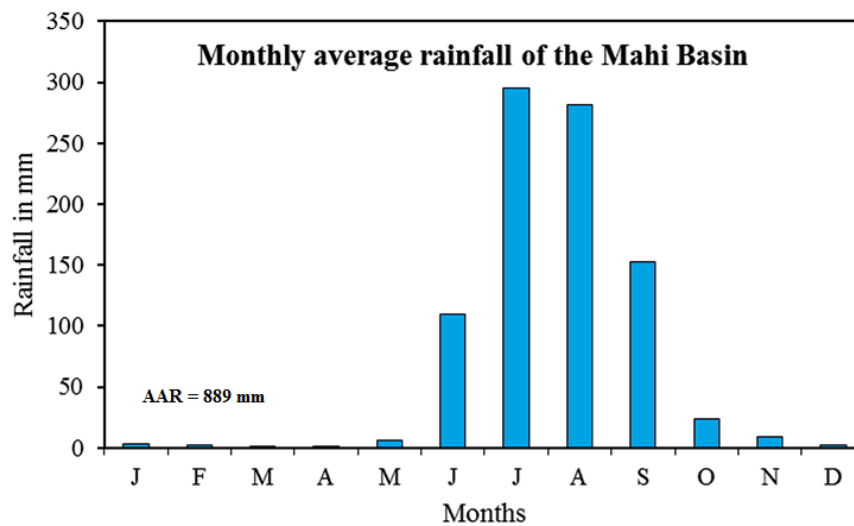


Figure 2. Monthly average rainfall of the Mahi Basin

Table 1. Hydro-geomorphic parameters of the Mahi River and its tributaries

River	Site	Record length (Years)	Elevation of the site (m)	Upstream Area (km ²)	Qmax m ³ /s (Years)
Mahi	Mataji	1982 – 2016 (35)	292	3880	8075 (2005)
Mahi	Paderdi Badi	1978 – 2016 (39)	133	16247	16153 (2006)
Mahi	Wanakbori	1959 – 2009 (51)	52	30665	40663 (1973)
Mahi	Khanpur	1979 – 2016 (38)	11	32510	31062 (2006)
Anas	Chakaliya	1991 – 2016 (26)	219	3121	6956 (2005)
Som	Rangeli	1978 – 2016 (39)	148	8329	5179 (2006)
Jakham	Dhariawad	1990 – 2016 (37)	222	1510	1980 (2006)

Source: Central Water Commission (CWC).

The recurrence interval of given discharges are often estimated graphically or with the help of table of frequency factor (K) (Bedient and Huber, 1989). The recurrence interval of preferred discharges such as Q_m , Q_{lf} and Q_{max} were calculated mathematically. Where, Q_m is the mean annual peak discharge, Q_{lf} is the large flood ((All floods that exceeds mean plus one standard deviation ($>Q_m + 1\sigma$)) and Q_{max} is the observed peak discharge on record (Hire, 2000).

The frequency distribution has been shown graphically on lognormal probability paper by plotting probability against the values of discharge for assured recurrence interval by using (equation (1)). Several formulae have been used to calculate plotting positions, however, of the several formulae in use, the best is due to Gringorten since the outliers fall into line better than other plotting positions (Shaw, 1988). The $F(X)$ values have been calculated as follows (equation (2));

$$P(X) = 1 - F(X) = \frac{r-0.44}{N+0.12} \quad (2)$$

The 95% confidence limits have been placed on frequency curves. A method proposed by Beard (1975) has been adopted to form a reliability band of the confidence limit.

4 RESULT AND DISCUSSION

4.1 Annual Flood Series Analysis

According to Ward (1978) the maximum peak flow recorded in every single year for successions of years at a gauging site is measured as annual maximum series (AMS). The analysis of such annual flood series (AMS) has great significance in the flood hydrology research. Although the aim of the research is flood frequency analysis, time series graph of annual peak discharge for all the site are shown in Figure 3a, 3b and 3c. The time

series plot of Wanakbori indicates that two largest floods were observed in the year 1973 and 2006 with discharge $40663 \text{ m}^3/\text{s}$ and $32557 \text{ m}^3/\text{s}$ respectively. In addition to this, in the year 1994 and 2006, the Mahi Basin experienced major floods after the year 1973 and 1976.

4.2 Estimation of Discharges for Return Periods

A designed flood has been determined on the basis of observed Q_{max} or historic flood. Therefore, the continuous, long and good quality of record of stream discharges is essential for the more accurate appraisal of recurrence interval of the peak flows. Generally, the AMS data have been more recurrently applied for the analyses. Accordingly, peak flows have been estimated for different return periods such as 2, 5, 10, 25, 50, and 100 yrs. by using Log Pearson type III (LP-III) probability distribution and the estimated discharges are given in (Table 2).

The highest ($47632 \text{ m}^3/\text{s}$) estimated discharge of 100 year return period was for the Wanakbori site on the Mahi River in the Gujarat state. However, the peak discharge of $40663 \text{ m}^3/\text{s}$ magnitude was observed on the Mahi River in the year 1973 generated by heavy to very heavy rainfall due to the low pressure system that crossed the Mahi Basin and centered at Modasa in the Sabarmati Basin adjacent to the Mahi Basin. The minimum estimated discharge is $19861 \text{ m}^3/\text{s}$ for 100 year return period on the Mahi River is for the Paderdi Badi site. Besides, the lowest estimated discharges are observed in case of the Jakham River at Dhariawad which is a tributary of the Som River. This is attributed to less annual rainfall in the upper catchment of the river and controlled discharge due to construction of the Jakham Dam.

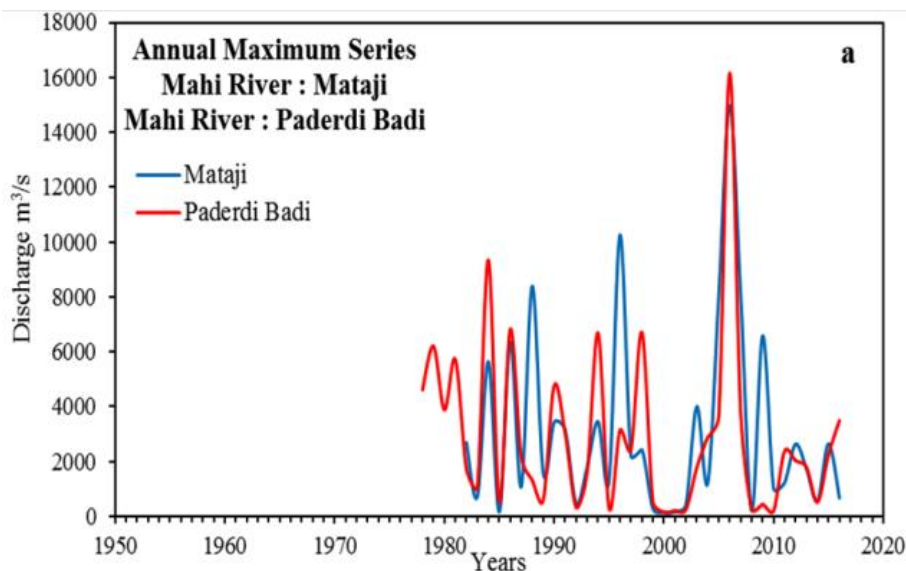


Figure 3a. Annual maximum series, Mahi River at Mataji and Paderdi Badi

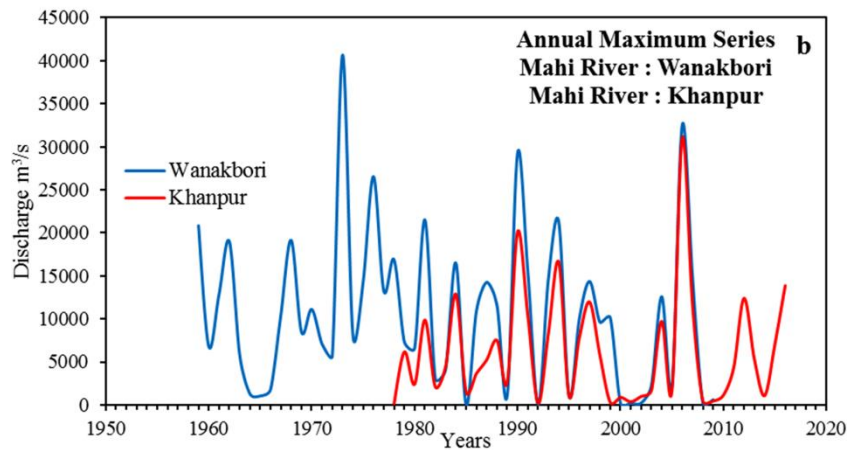


Figure 3b. Annual maximum series, Mahi River at Wanakbori and Khanpur

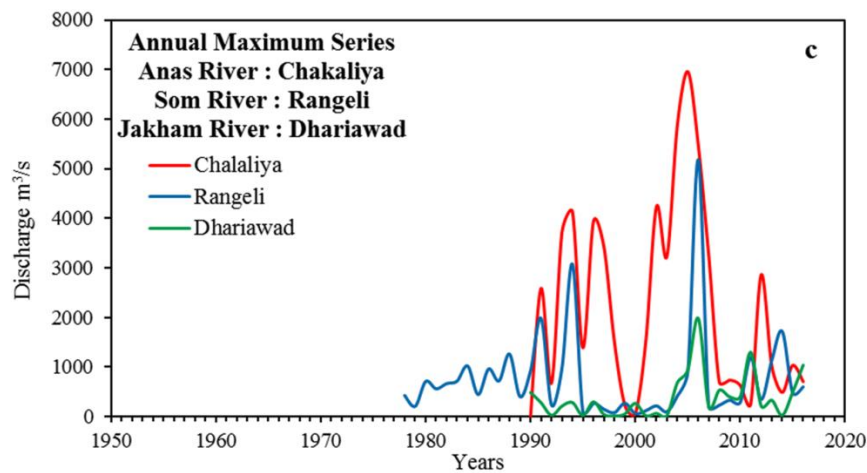


Figure 3c. Annual maximum series, Anas River at Chakaliya, Som River at Rangeli and Jakham River at Dhariawad

Table 2. Estimated discharges in m^3/s for different return periods for different gauging sites on the Mahi River and its tributaries (Based on LP-III distribution)

River	Site	Record length	Estimated Discharges (m^3/s)					
			2 Yr.	5 Yr.	10 Yr.	25 Yr.	50 Yr.	100 Yr.
Mahi	Mataji	35	1748	4672	7464	11910	15823	20174
Mahi	Paderdi Badi	39	1772	4681	7437	11800	15623	19861
Mahi	Wanakbori	51	7329	20723	29641	38784	43873	47632
Mahi	Khanpur	38	3624	10352	16644	26211	34193	42672
Anas	Chakaliya	26	1940	4094	4873	5335	5479	5544
Som	Rangeli	39	450	1074	1708	2823	3920	5283
Jakham	Dhariawad	27	194	632	1111	1949	2744	3676

The estimation of the discharges for different return period has significance in the flood geomorphology, flood hydrology and hydraulic engineering while designing hydraulic structures such as bridges and dams. Therefore, accuracy in the estimation of design flood based on long history of flood is essential. For example, as stated by More (1986), at the

time of construction of Kadana Dam on the Mahi River, the data about peak discharge ($Q_{\max}$) of the large flood of 1927 was not available to estimate the accurate design flood of the Kadana Dam. Therefore, the original project estimate provided for a maximum flood of $23096 \text{ m}^3/\text{s}$. The design flood was revised with the magnitude $31087 \text{ m}^3/\text{s}$ at the time of project clearance in

1966, with 19 spillway gates. However, due to the flood of 1968 with the observed discharge of magnitude $21820 \text{ m}^3/\text{s}$, the design flood was further revised to $36840 \text{ m}^3/\text{s}$ and for this revised flood, 21 spillway gates including one standby were provided. During 1973 due to heavy to very heavy rainfall associated with the low pressure system (LPS), unprecedented flood of the magnitude $32986 \text{ m}^3/\text{s}$ was observed which again forced to revise design flood of Kadana dam and finally maximum probable flood with the magnitude $46871 \text{ m}^3/\text{s}$ was considered in March 1974. To account for this flood the additional spillway is located 2 km away from main spillway on the right bank in the saddle. This example, therefore, suggests the significance of record length and flood frequency analysis for construction of bridges and dams. Therefore, application of flood frequency analysis is inevitable.

4.3 Estimation of Return Period

The estimation of return period is of the great significance for the safety of hydraulic structures. Therefore, an attempt has been made to find out the return period of mean annual peak discharge (Q_m), large flood (Q_{lf}) and actually observed maximum annual peak discharge (Q_{max}) by applying the Log Pearson type III distribution and result have been shown in (Table 3).

The recurrence interval of Q_m is between 2.73-yr and 3.95-yr, whereas, the return period of Q_{lf} ranges from 6.24-yr to 9.33-yr. The magnitude-frequency analysis reveals high return period (127-yr) for the Q_{max} ($40663 \text{ m}^3/\text{s}$) recorded at Wanakbori site in the year 1973. Moreover, the return periods of Q_{max} for all the sites on the tributaries of the Mahi River also shows high recurrence interval as compared to other sites on the Mahi River. The estimates based LP-III indicate that large floods are likely to occur once in 6 to 9 years.

4.4 Magnitude Frequency Curve

The magnitude-frequency analysis graphs of the Log Pearson type III (Figure 4) show that the fitted lines are fairly close to the most of the data points and, therefore, can be reliably and conveniently used to read the recurrence intervals for a given magnitude and vice versa. The graphs also indicate that the return periods of Q_{max} of different stations predicted by LP-III distribution are likely to be quite reliable. However, extrapolation of the lines to estimate the discharges for a higher recurrence interval (200-yr, 500-yr or 1000-yr) is not likely to be accurate and reliable due to short record length.

Table 3. Return period of Q_m , Q_{lf} and Q_{max} for different sites on the Mahi River and its tributaries (Based on Log Pearson type III)

River	Site	Record length	$Q \text{ m}^3/\text{s}$	Return period (yr)
Mahi	Mataji	35	$Q_m = 3135$	3.56
			$Q_{lf} = 6568$	7.76
			$Q_{max} = 14972$	36.80
Mahi	Paderdi Badi	39	$Q_m = 2968$	3.59
			$Q_{lf} = 6132$	9.33
			$Q_{max} = 16153$	57.00
Mahi	Wanakbori	51	$Q_m = 10587$	3.95
			$Q_{lf} = 19757$	8.27
			$Q_{max} = 40663$	126.56
Mahi	Khanpur	38	$Q_m = 6448$	3.65
			$Q_{lf} = 13022$	7.42
			$Q_{max} = 31062$	67.41
Anas	Chakaliya	26	$Q_m = 2329$	2.73
			$Q_{lf} = 4275$	6.24
			$Q_{max} = 6956$	101
Som	Rangeli	39	$Q_m = 753$	4.43
			$Q_{lf} = 1697$	6.47
			$Q_{max} = 5179$	104.68
Jakham	Dhariawad	27	$Q_m = 392$	2.74
			$Q_{lf} = 853$	7.59
			$Q_{max} = 1980$	81.97

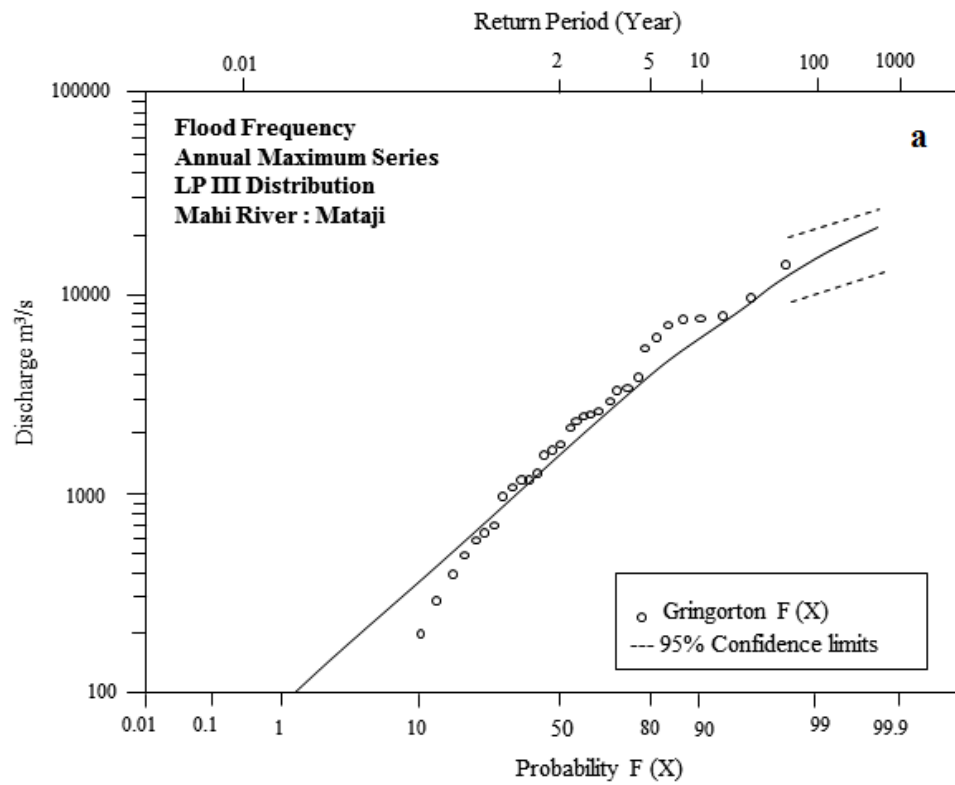


Figure 4a. Flood frequency, annual maximum series, LP III distribution, Mahi River: Mataji

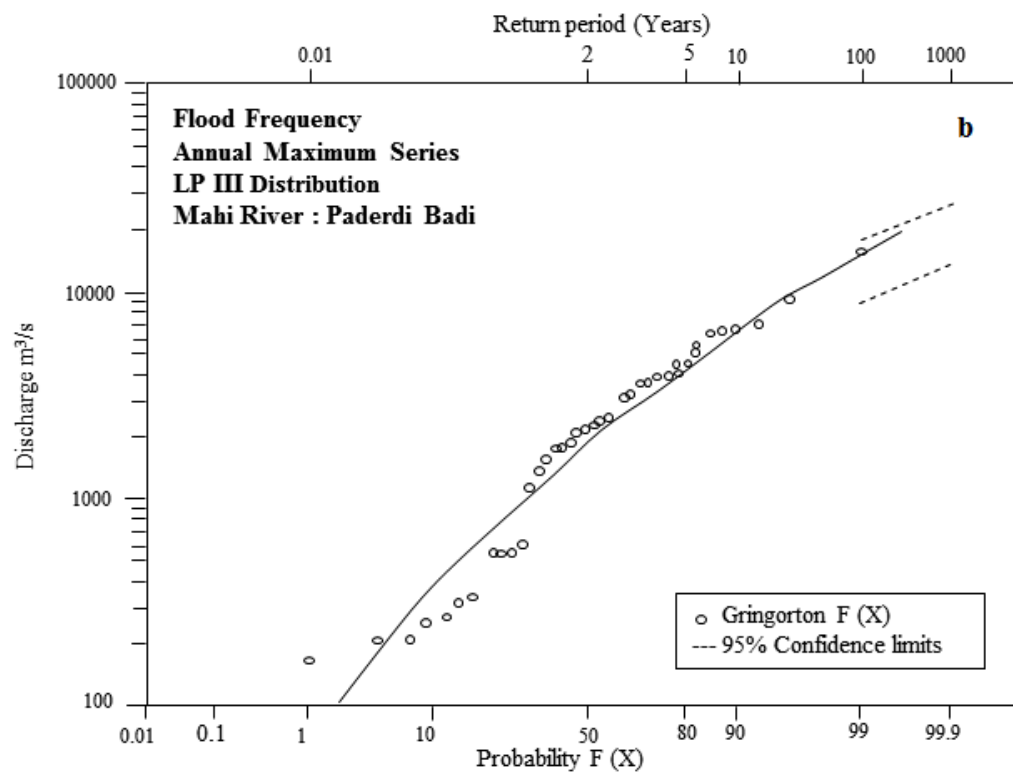


Figure 4b. Flood frequency, annual maximum series, LP III distribution, Mahi River: Paderdi Badi

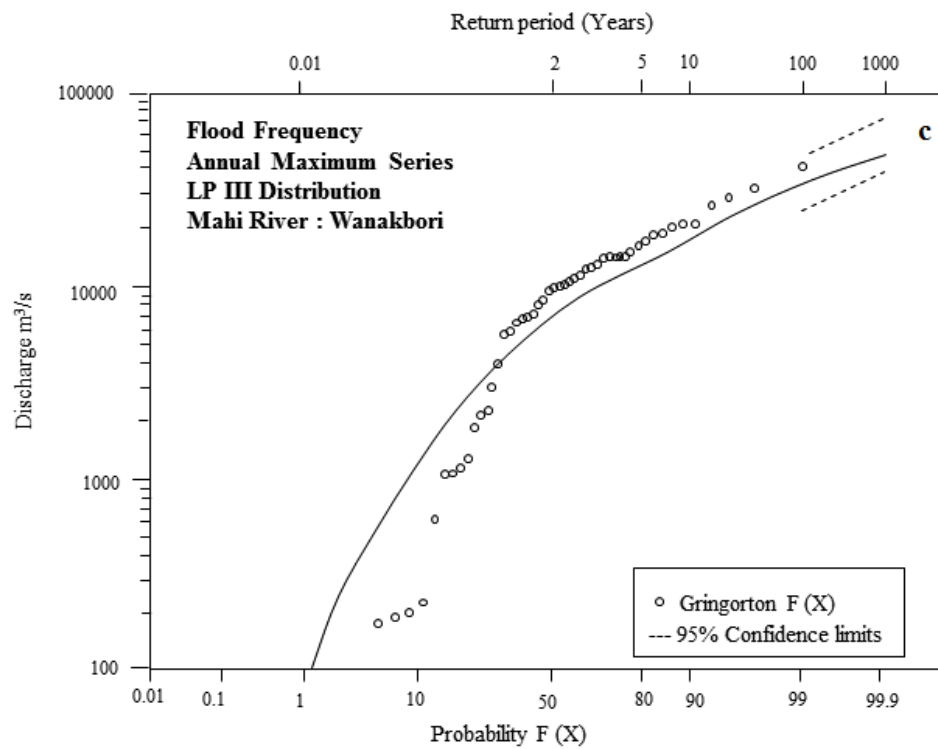


Figure 4c. Flood frequency, annual maximum series, LP III distribution, Mahi River: Wanakbori

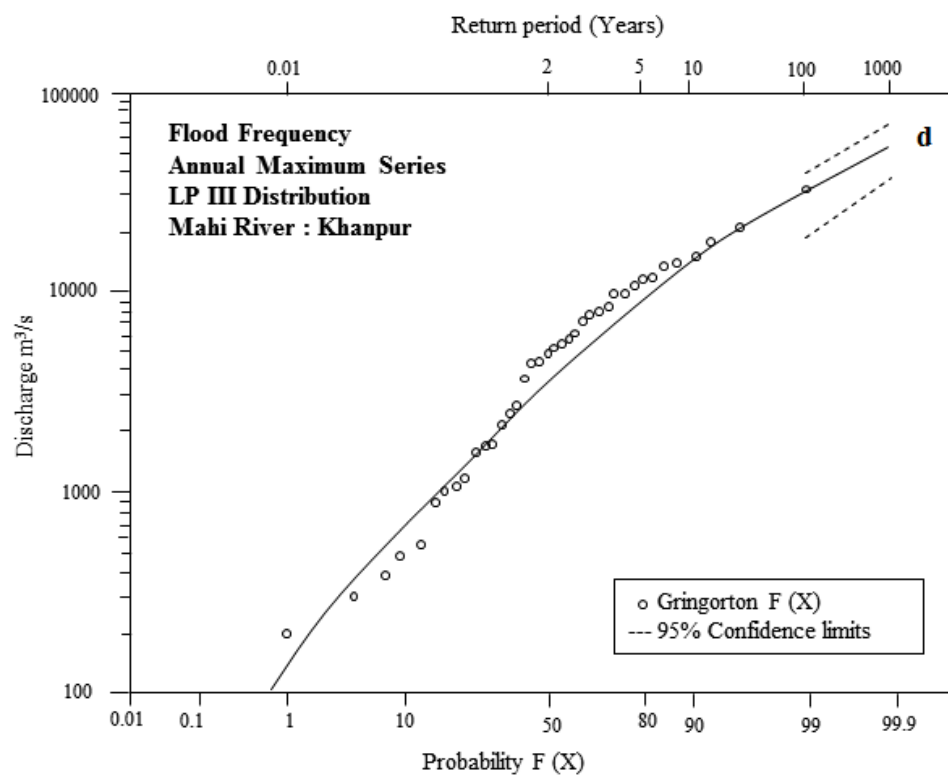


Figure 4d. Flood frequency, annual maximum series, LP III distribution, Mahi River: Khanpur

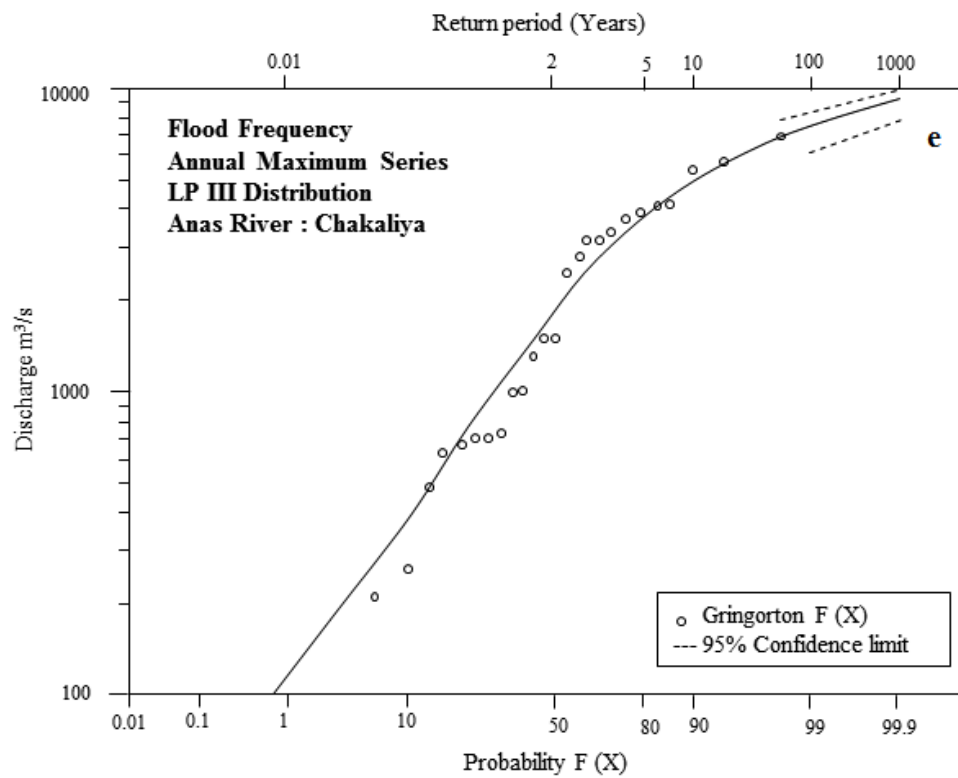


Figure 4e. Flood frequency, annual maximum series, LP III distribution, Anas River: Chakaliya

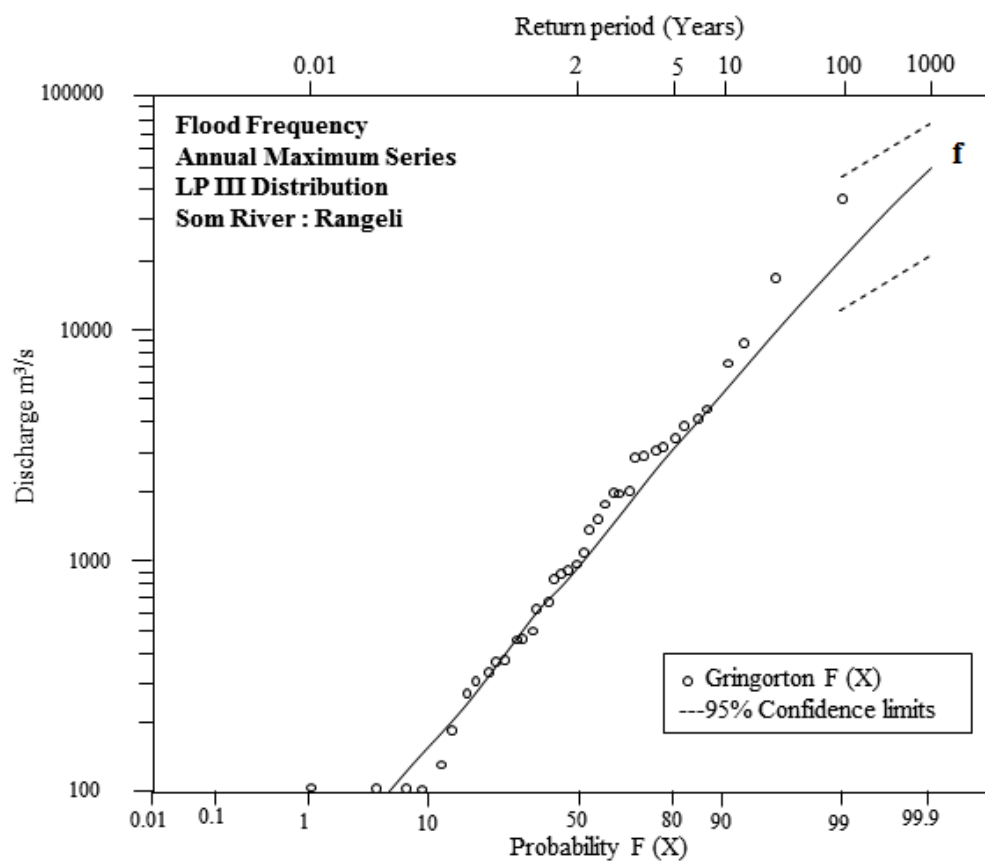


Figure 4f. Flood frequency, annual maximum series, LP III distribution, Som River: Rangeli

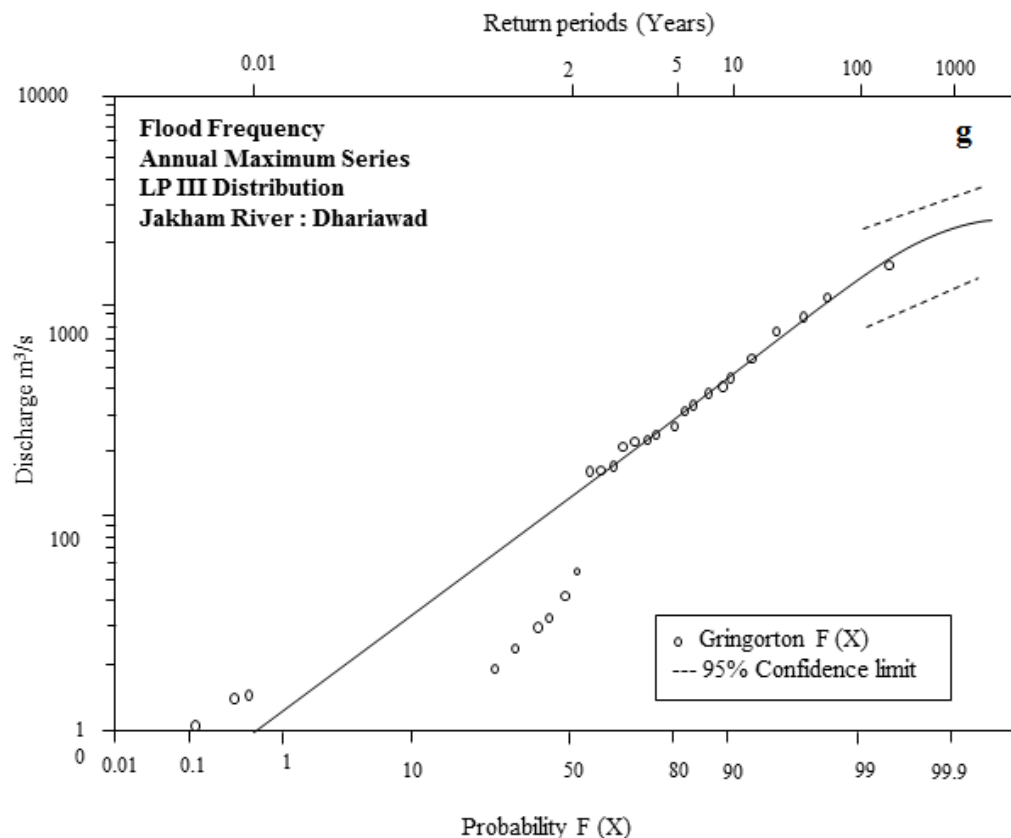


Figure 4g. Flood frequency, annual maximum series, LP III distribution, Jakham River: Dhariawad

5 CONCLUSIONS

The LP-III analysis shows estimated discharges for low recurrence interval are close to the observed peak discharges and return period of the mean annual flood (Q_m), large floods (Q_{lf}) and peak flood (Q_{max}) also fairly reliable. Besides, the value of design flood (46871 m^3/s) of the Kadana Dam and estimated discharge (47632 m^3/s) of 100-yr return period for Wanakbori site (downstream of Kadana Dam) based on the flood of 1973 are perfectly matching. Flood frequency fitted lines are fairly close to the data points indicate the best fit to annual maximum series of the river under review. Therefore, based on the observations it is said that the LP-III distribution is most suitable for flood frequency analysis of the Mahi River and its tributaries.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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