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Original Research Paper

Analysis of Magnitude and Frequency of Floods in the Damanganga Basin: Western India



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Abstract

Flood Frequency Analysis (FFA) method was introduced by Fuller in 1914 to understand the magnitude and frequency of floods. The present study is carried out using the two most widely accepted probability distributions for FFA in the world namely, Gumbel Extreme Value type I (GEVI) and Log Pearson type III (LP-III). The Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) methods were used to select the most suitable probability distribution at sites in the Damanganga Basin. Moreover, discharges were estimated for various return periods using GEVI and LP-III. The recurrence interval of the largest peak flood on record (Q_{max}) is 107 years (at Nanipalsan) and 146 years (at Ozarkhed) as per LP-III. Flood Frequency Curves (FFC) specifies that LP-III is the best-fitted probability distribution for FFA of the Damanganga Basin. Therefore, estimated discharges and return periods by LP-III probability distribution are more reliable and can be used for designing hydraulic structures.

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1 INTRODUCTION

An analysis of flood magnitude and frequency is a crucial aspect in the studies of hydro-meteorology, flood geomorphology, flood hydrology, and civil engineering (Makkonen and Tikanmäki, 2019). Therefore, it is essential to select an appropriate probability distribution method for the investigation of magnitude and frequency of floods while evaluating the design flood with return period before the construction dams and bridges (Chow et al., 1988; Hosking and Wallis, 1997). A design flood is the estimated peak discharge at a given site on a river adopted for the design of a structure (Prasad and Subramanya, 1986). However, there is not a single universally recognized magnitude-frequency probability distribution method (Law and Tasker, 2003). As a result, choice of the appropriate magnitude-frequency probability distribution method from numerous methods (Gumbel Extreme Value type I (GEVI), Log Pearson type III (LP-III), Generalized Extreme Value (GEV), Log-

Normal (LN), etc.) is crucial and challenging task of hydrologist and civil engineers.

The U.S. Water Resources Council (USWRC, 1967; 1976; 1981) had suggested that LP-III is the best method for the analysis of magnitude-frequency of floods. However, the GEVI probability distribution method has been applied and recommended by several scholars for predicting flood magnitude and its return period (Gumbel, 1958; Todorovic, 1978; Watt et al., 1989). Besides, numerous studies also focused on the application of the LP-III technique for probability estimation of the magnitude and recurrence interval in the different hydroclimatic environment (Matalas and Wallis, 1973; Phien and Jivajirajah, 1984; Griffis and Stender, 2009; Myronidis and Ivanova, 2020). Further, Srikanthan and McMahon (1981) applied the LP-III distribution to the annual maximum discharges of the river in Australia.

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According to Merz and Blöschl (2008b) and Elleder (2010) accuracy of a hydraulic probability distribution technique is based on the accuracy and length of the available data. However, a continuous Annual Maximum Series (AMS) data of 30 years can be an acceptable period for Flood Frequency Analysis (FFA) (Garde, 1998). In recent times, numerous researchers have applied GEVI and LP-III probability distribution techniques for the FFA of Indian rivers (Jha and Bairagya, 2011; Patil, 2017; Hire and Patil, 2018; Pawar and Hire, 2019; Pawar, 2019; Bhat et al., 2019; Pawar et al., 2020; Samantaray and Sahoo, 2020; Sheikh et al., 2020). Nevertheless, identification of the best-fit probability distribution method is the prime concern in the FFA by applying tests of goodness-of-fit (GoF) (Haddad and Rahman, 2011). As the Damanganga Basin receives heavy spells of rainfall throughout the southwest monsoon season that causes floods in the basin, an attempt has been made to compare and select the best-fit probability distribution for magnitude-frequency analysis between GEVI and LP-III by using GoF tests. Accordingly, discharges for various recurrence intervals (Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , Q_{100} , and Q_{200} years) were estimated and the return period for recorded high magnitude discharges at every site in the Damanganga Basin during the gauge period was determined by the best-fit flood frequency probability distribution techniques.

2 STUDY AREA

The Damanganga River is one of the inter-state west-flowing rivers in western India. It has source at an elevation of 950 m in the Western Ghat near Ambegaon in Dindori tehsil of the Nashik district (Figure 1). The river flows for a length of 140 km in the west and joins the Arabian Sea (near Daman) in the south of the Gujarat State. The Damanganga Basin extends over parts of Maharashtra, Gujarat, Union Territory of Dadra

and Nagar Haveli, and Daman. The total area of the basin is 2300 km² comprises 59% area of the Nashik (Maharashtra), 21% area of the Valsad (Gujarat), and 20% area of the Union Territories of the Dadara and Nagar Haveli as well as Daman. The Wagh River is the main tributary of the Damanganga River that flows for a length of 54 km and joins the Damanganga River from left-bank near Malungi village of the Valsad district of Gujarat in the South. The geology of the Damanganga Basin comprised rock of the Deccan Trap Basalt (Mahoney et al., 2002). The Annual Average Rainfall (AAR) of the basin is 2261 mm and about 94% of rainfall occurs during the monsoon season (June-September) (Figure 2). Moreover, the basin receives heavy to very heavy rain spells during the southwest monsoon season (June-September) under the influence of Monsoon Depressions (MD) developing either over the Bay of Bengal (BoB) and adjoining land or the Arabian Sea.

3 MATERIALS AND METHODS

3.1 Database

Flood Frequency Analysis (FFA) of the Damanganga Basin was carried out by using AMS data. Accordingly, AMS data were procured from the water year book 2017-18 published by Central Water Commission (CWC), Gandhinagar (Gujarat). The data were available for the Damanganga River at Nanipalsan and the Wagh River at Ozarkhed gauging sites located in the Damanganga Basin (Figure 1). The record length for both sites is 27 years from 1991 to 2017. Additionally, rainfall data of the Damanganga Basin were procured from the India Meteorological Department (IMD), Pune, to comprehend the mean rainfall characteristics of the Damanganga Basin. Table 1 specifies hydrological and geomorphological characteristics of the Damanganga Basin at sites under the study.

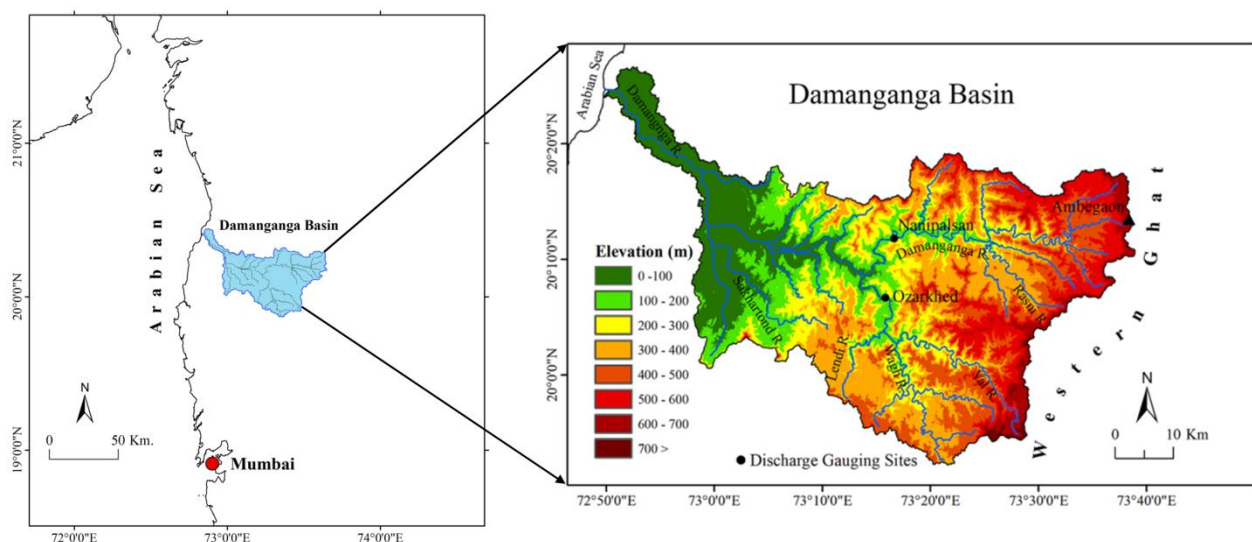


Figure 1. Study area: Damanganga Basin with discharge gauging sites

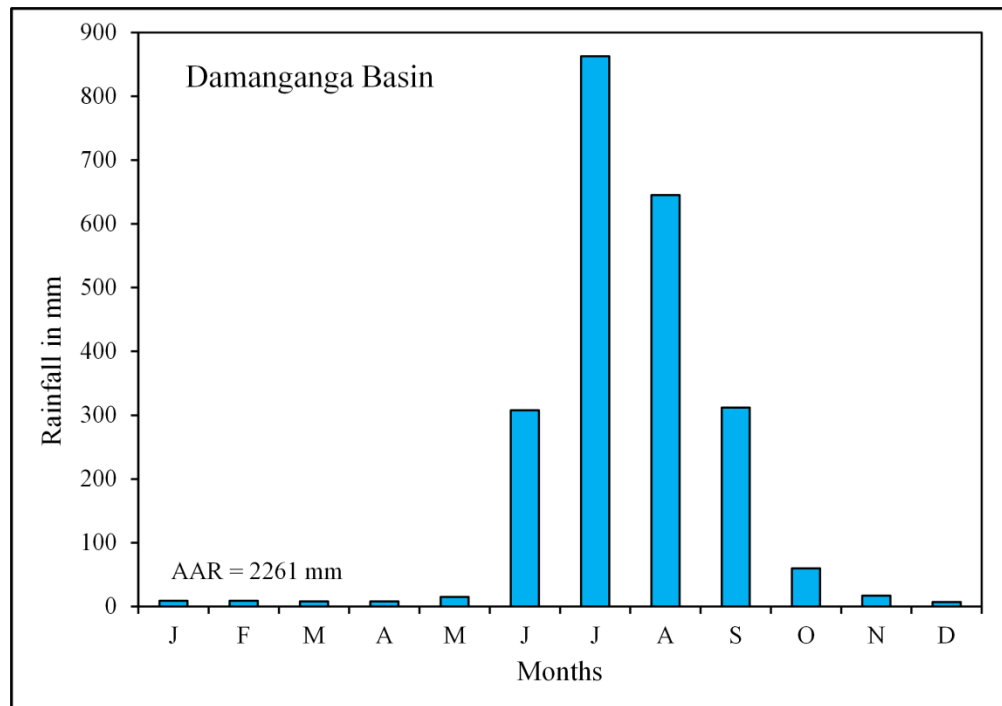


Figure 2. Monthly average rainfall of the Damanganga Basin

Table 1. Hydro-geomorphic parameters of the Damanganga Basin at sites under review

Station	Record length (Years)	Length of the River (Km)	Upstream catchment area (Km ²)	Elevation (m)	Q _{max} m ³ /s (year)
Nanipalsan	1991-2017 (27)	66	704	107	3173 (2004)
Ozarkhed	1991-2017 (27)	42	658	92	2700 (2004)

Q_{max} = Maximum annual peak discharge

3.2 Methodology

The flood discharge characteristics of the Damanganga Basin were derived by applying elementary quantitative techniques (mean, standard deviation (σ), coefficient of variation (C_v), and coefficient of skewness (C_s)) to AMS data. Further, the best-fit probability distribution at both sites (Nanipalsan and Ozarkhed) was selected by using the Kolmogorov-Smirnov (KS) test and Anderson Darling (AD) test of GoF. The discharges for various recurrence intervals (Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , Q_{100} , and Q_{200} years) were predicted based on GEVI (Gumbel 1941, 1958) and LP-III (Pearson, 1916) probability distributions. Besides, the return periods for mean annual peak flows (Q_m), large floods (All floods that exceed the mean plus one standard deviation (Q_{lf})), and observed peak discharge on record during gauge period (Q_{max}) were calculated by using GEVI and LP-III probability distribution (Hire, 2000).

3.2.1 Gumbel Extreme Value type I (GEVI) Model

An identification of the best-fit flood frequency probability distribution at every site in the Damanganga

Basin is the prime focus of this research. Therefore, the widely applied probability technique of GEVI was used for the estimation of recurrence interval of the flood and discharges for various recurrence interval by applying equation (1), (2) and (3):

$$\bar{Q} = \frac{\sum Q}{n} \quad (1)$$

$$\sigma Q = \sqrt{\frac{\sum (Q - \bar{Q})^2}{n-1}} \quad (2)$$

$$Q_T = \bar{Q} + (K_{(T)} * \sigma Q) \quad (3)$$

where Q_T is a discharge of given return period; $\bar{Q}$ is a mean annual peak discharge; n is the number of years of records; σQ is a standard deviation of AMS and $K_{(T)}$ is a frequency factor which is the function of the return period T . Consequently, $K_{(T)}$ values were obtained from the book entitled "Hydrology in Practice" by Shaw (1994).

The return periods were calculated for Q_m , Q_{lf} , and Q_{max} at each site using equations (4), (5), (6), and (7):

$$F(X) = e[-e^{-b(X-a)}] \quad (4)$$

where, $F(X)$ is the probability of an annual maximum $Q \leq X$ and a and b are two parameters related to the moments of the population of Q values.; e is the exponent. The parameters 'a' and 'b' were determined by using equations (5) and (6):

$$b = \frac{\pi}{\sigma_Q \sqrt{6}} \quad (5)$$

$$a = \bar{Q} - \frac{\gamma}{b} \quad (6)$$

$$(\gamma = 0.5772)$$

Lastly, the recurrence interval for desired discharges (Q_m , Q_{lf} , and Q_{max}) was designed using equation (7):

$$T = \frac{1}{1 - F(X)} \quad (7)$$

where, $F(X)$ is the probability of an annual maximum obtained using equation (4).

3.2.2 Log Pearson Type III (LP-III)

The LP-III probability distribution was applied by Foster (1924) for estimating flood discharges and return period. Bedient and Huber (1989) specified that when log values of the AMS data are used then it is referred to as the LP-III probability distribution. In this analysis, design floods for Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , Q_{100} , and Q_{200} year return period were also estimated by LP-III probability distribution with the help of the following equations:

$$\overline{\log Q} = \frac{\sum \log Q}{n} \quad (8)$$

$$\sigma_{\log Q} = \sqrt{\frac{\sum (\log Q - \overline{\log Q})^2}{n-1}} \quad (9)$$

$$C_s = \frac{n \sum (\log Q - \overline{\log Q})^3}{(n-1) \cdot (n-2) \cdot (\sigma_{\log Q})^3} \quad (10)$$

$$\log Q_T = \overline{\log Q} + (K_{(T)} * \sigma_{\log Q}) \quad (11)$$

$$Q_T = \text{Antilog}(\log Q_T) \quad (12)$$

where, $\log Q_T$ is the base 10 logarithms of the discharge of desired return period; $\overline{\log Q}$ is a mean of the logarithms of AMS; $\sigma_{\log Q}$ is a standard deviation of the logarithms of AMS and $K_{(T)}$ is a frequency factor of the return period (T). The $K_{(T)}$ value is based on the skewness coefficient of the logarithms of AMS data. The $K_{(T)}$ values were acquired from Hydrology book (Raghunath, 2006).

3.2.3 Plotting Position and Frequency Curves

In view of Cunnane (1978) and Shaw (1988), the Gringorten formula for plotting position and frequency curve is the best-fit because the outliers fall into line better than other plotting positions. Therefore, $F(X)$ values were computed by applying the subsequent equations (Gringorten, 1963):

$$P(X) = \frac{r-0.44}{N+0.12} \quad (13)$$

$$F(X) = 1 - P(X) \quad (14)$$

where, r is flood magnitude ranks (from largest to smallest); N is the number of years of records; $P(X)$ is the probability of exceedance. The Gumbel probability graph paper and Log-probability graph paper were used to plot Flood Frequency Curves (FFC). The FFC were derived based on results of the GoF at a site. The 95% confidence limit was placed on FFC. A method proposed by Beard (1975) was applied to form the reliability band of the confidence limit.

3.2.4 Goodness-of-Fit (GoF)

The tests of GoF are indispensable to select the best-fit distribution amongst several probability distributions (Millington et al., 2011). Therefore, the most extensively applied KS and AD test were used and results were obtained using the Easyfit software.

4 RESULTS AND DISCUSSIONS

4.1 Annual Maximum Series (AMS) Analysis

The statistical analysis reveals that the coefficient of variation (C_v) ranged between is 0.83 (Nanipalsan) and 0.51 (Ozarkhed). The highest value of the coefficient of skewness (2.07) of the Nanipalsan site specifies occurrence of the high-magnitude floods during the gauge period in the Damanganga Basin. Further, Q_{max}/Q_m ratio indicates that Q_{max} (the largest floods during the gauge period) recorded at both sites in the Damanganga Basin was about three-to-four times higher than Q_m (mean annual flows) (Table 2). Figure 3a and 3b show a year-to-year variation with one or two large flood peaks throughout the gauge period in the Damanganga Basin.

Table 2. Flood flow characteristics of the Damanganga Basin

River	Stations	N	Q_{min} (m^3/s)	Q_m (m^3/s)	Q_{lf} (m^3/s)	Q_{max} (m^3/s)	Q_{max}/Q_m ratio	σ	C_v	C_s
Damanganga	Nanipalsan	27	220	856	1076	3173	3.7	709	0.83	2.07
Wagh	Ozarkhed	27	252	1046	1298	2700	2.6	532	0.51	0.90

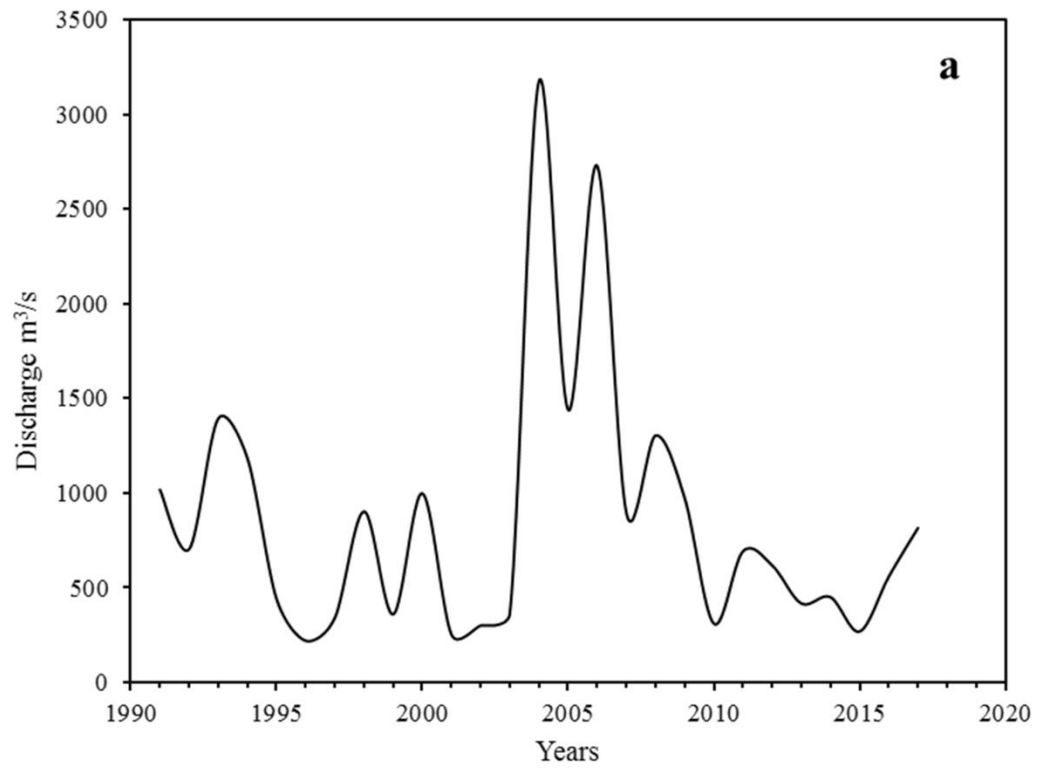


Figure 3a. Annual maximum series: Damanganga River at Nanipalsan

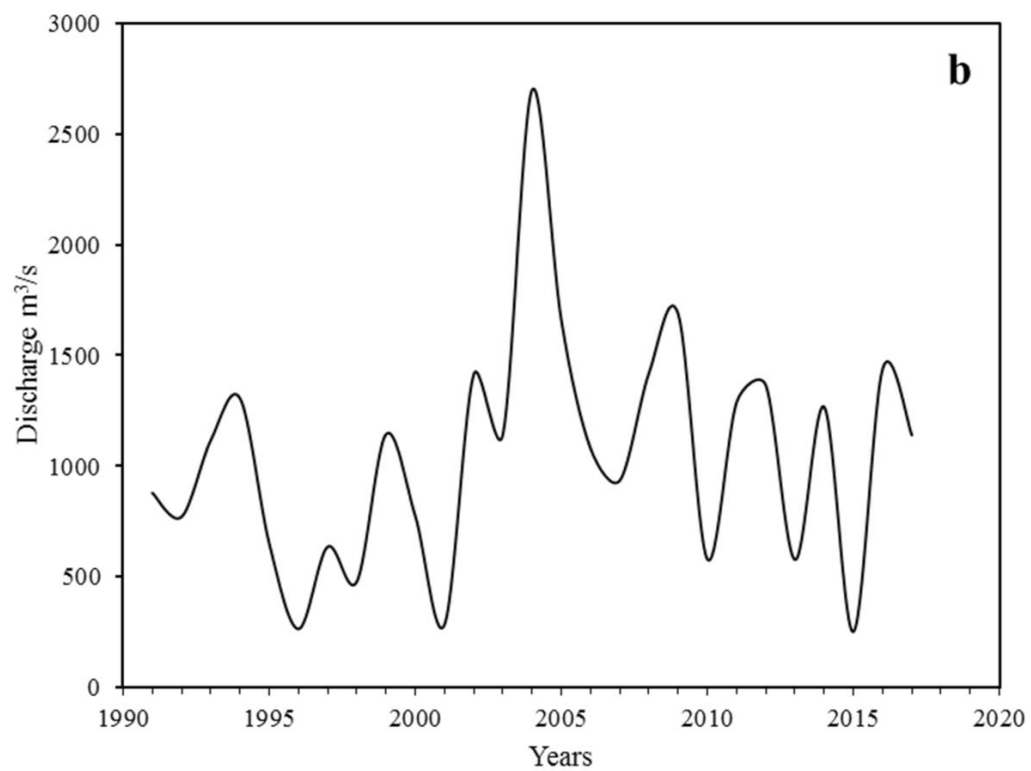


Figure 3b. Annual maximum series: Wagh River at Ozarkhed

4.2 Goodness-of-Fit Analysis (GoF)

The prime objective of the FFA of the Damanganga Basin is an identification of the best-fit probability distribution at sites under investigation. Accordingly, KS and AD tests of GoF were used to AMS in Easy-fit software and results were acquired by considering critical value at a 95% confidence level ($\alpha=0.05$). The ranks were given to the probability values for GEVI and LP-III. Rank 1 shows best-fit distribution and ranks 2 specifies elimination of the probability distribution techniques at each site (Table 3). According to the KS and AD tests analysis, the results of acceptance and rejection were the same for both sites (Table 3). The comparative analysis of GEVI and LP-III indicates that LP-III is the best-fit probability distribution for sites (Nanipalsan and Ozarkhed) in the Damanganga Basin.

4.3 Estimation of Discharges for the Return Period

One of the purposes of the FFA is to predict discharges for various recurrence intervals. Accordingly, discharges were estimated for Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , Q_{100} , and Q_{200}

years return period by GEVI and LP-III probability distribution techniques, and results have been shown in (Table 4). The comparison of estimated discharges by GEVI and LP-III (Table 4) denotes that estimated discharge ($3288 \text{ m}^3/\text{s}$) by best-fit distribution (LP-III) for Q_{50} recurrence interval at Nanipalsan is close to the observed $Q_{\max}$ ($3173 \text{ m}^3/\text{s}$) (Table 2; Table 4). In the case of the Ozarkhed site on the Wagh River, the estimated discharge of the Q_{200} return period shows nearness with the observed $Q_{\max}$ ($2700 \text{ m}^3/\text{s}$). The peak discharge ($Q_{\max} = 3173 \text{ m}^3/\text{s}$) on the Damanganga River (at Nanipalsan) was observed in the year 2004 (Table 2). Therefore, to estimate accurate discharges using the best-fit probability distribution for the flood studies and designing of the hydraulic structures is an integral part of the FFA (Chow et al., 1988; Hosking and Wallis, 1997). The Figure 4a and 4b show that the predicted discharges for different recurrence intervals are near the observed floods (Q_m , Q_{lf} , and $Q_{\max}$) as per GEVI and LP-III probability distribution. Moreover, graphs (Figure 4a and 4b) show that predicted flows Q_2 return period are less than the average annual discharges (Q_m).

Table 3. Goodness-of-fit (GoF) result of gauging sites in the Damanganga Basin

Site	Kolmogorov-Smirnov (KS) Test				Anderson-Darling (AD) Test			
	GEVI	Rank	LP-III	Rank	GEVI	Rank	LP-III	Rank
Nanipalsan	0.16944	2	0.09842	1	0.94913	2	0.2824	1
Ozarkhed	0.15138	2	0.12702	1	0.52808	2	0.45692	1

Table 4. Estimated discharges in m^3/s for different return periods for gauging sites in the Damanganga Basin based on GEVI and LP-III probability distribution

Sites	Probability distribution	N	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}
Nanipalsan	GEVI	27	743	1367	1778	2303	2707	3083	3466
	LP-III	27	632	791	2245	2510	3288	4225	5352
Ozarkhed	GEVI	27	961	1430	1738	2132	2436	2718	3005
	LP-III	27	979	1030	1796	2119	2325	2504	2662

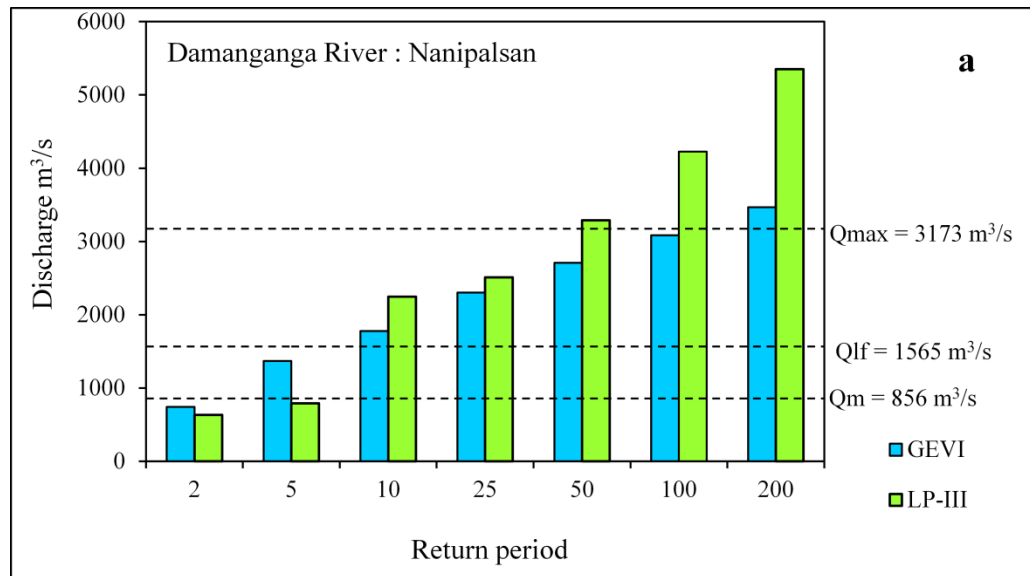


Figure 4a. Estimated discharge for different return period by GEVI and LP-III

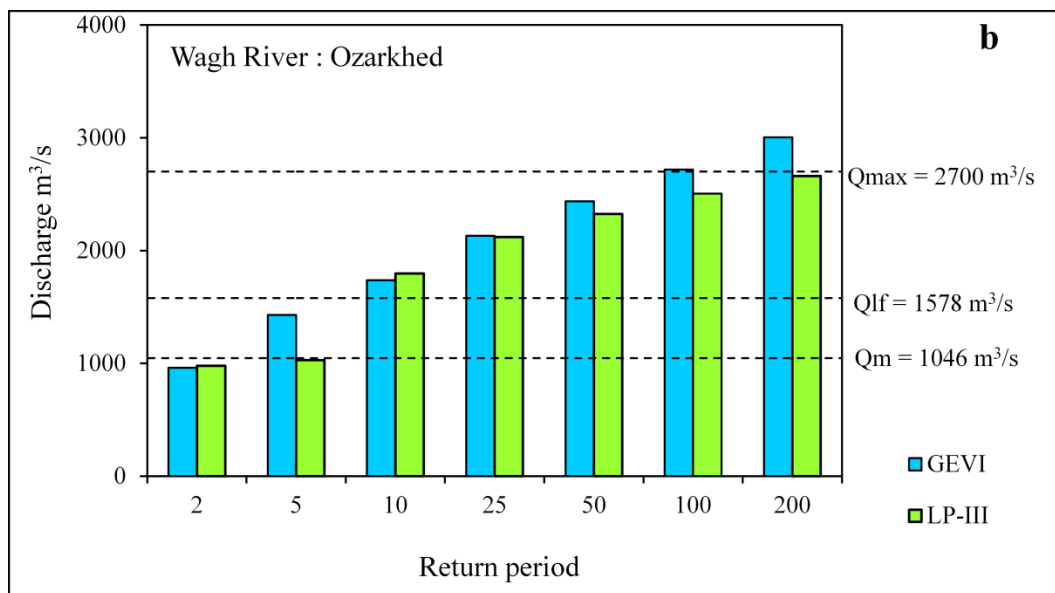


Figure 4b. Estimated discharge for different return period by GEVI and LP-III

4.4 Estimation of the Return Period

According to Kale and Gupta (2010), the high magnitude floods that have recurrence interval of several decades are more catastrophic than that of the average annual flows (Q_m). Therefore, it is important to estimate the return period of the observed high magnitude floods during the gauge period. Accordingly, return periods for Q_m , Q_{lf} , and Q_{max} were predicted using GEVI and LP-III probability methods. The result of GEVI probability distribution shows that the return periods for Q_m , Q_{lf} ($Q_m + 1\sigma$) for both sites (Nanipalsan

and Ozarkhed) in the Damanganga Basin are 2.33 and 6.93 years respectively. However, the recurrence interval for Q_{max} ranged between 96 years (Ozarkhed) and 118 years (Nanipalsan) as per the GEVI (Table 5). The LP-III analysis indicates that the return period of Q_m is 7.42 year for Nanipalsan (Damanganga River), and 5.52 years for Ozarkhed (Wagh River). The return periods of the large flood (Q_{lf}) obtained by the LP-III probability distribution for Damanganga River at Nanipalsan and Wagh River at Ozarkhed are 28.10 years and 23.09 years respectively. Moreover, the estimated

return period by LP-III for $Q_{\max}$ at Nanipalsan (Damanganga River) and Ozarkhed (Wagh River) is 107 years and 146 years respectively (Table 5). The comparative study of GEVI and LP-III shows that the LP-III probability distribution is best-fitted for both the sites (Nanipalsan and Ozarkhed) and is appropriate to estimate design flood for constructions of hydraulic structures and disaster management in the Damanganga Basin.

4.5 Flood Frequency Curve (FFC)

The FFC were obtained as per the results of the test of GoF for Nanipalsan and Ozarkhed. The LP-III probability distribution is best-fit for both the sites in the Damanganga Basin. Therefore, FFCs were obtained only for LP-III probability distribution by best-fit line to AMS data plotted on Log probability graph paper (Pawar et al., 2020). The FFC shows that the best-fit lines are fairly adjacent to most of the AMS data points and, therefore, can be reliably and conveniently used to obtain the return period for a specified magnitude and vice versa (Figure 5a and 5b). Besides, to predict the future trend of the discharge, 95% confidence limit was calculated for each graph and shown by dotted lines. The FFC of Nanipalsan and Ozarkhed sites show a rising trend in the magnitude of discharges but within the confidence limits. The graphs indicate that the return periods of $Q_{\max}$ at Nanipalsan and Ozarkhed sites in the Damanganga Basin predicted by LP-III are likely to be relatively trustworthy and can be used for the designing of hydraulic structures (dams and bridges) on the Damanganga and Wagh Rivers. Consequently, the LP-

III model is best-fitted for the flood frequency analysis of the Damanganga Basin.

5 CONCLUSIONS

An analytical study of the flood frequency conducted for the Damanganga Basin significantly indicates that the LP-III is the best-fit probability distribution. Moreover, estimated discharges for various return periods (Q_2 , Q_5 , Q_{10} , Q_{25} , Q_{50} , Q_{100} , and Q_{200}) as per best fit (LP-III) probability methods are more reliable than the GEVI method. Further, the analysis shows that high magnitude floods ($Q_{\max}$) in the Damanganga Basin have a large return period than that of mean flows (Q_m) and large floods (Q_{lf}). Nevertheless, there are no remarkable variation between the observed and estimated discharges using the GEVI and LP-III distributions. The study conducted for FFA of the Narmada River Pawar et al. (2020) and Tapi River by Hire (2000) indicates that LP-III probability distribution gives good results for a small record length of AMS. The FFC of the Nanipalsan and Ozarkhed in the Damanganga Basin show that AMS data points are very near to the best-fit line and can be reliably and appropriately used to estimate the return period for a given magnitude and vice versa. Consequently, FFA based on the LP-III distribution is trustworthy and can be applied for watershed management, designing of hydraulic structures, and disaster management in the Damanganga Basin. The present study can be a significant contribution towards the Damanganga-Pinjal project and water divergent project of the Government of Maharashtra.

Table 5. Estimated return period for Q_m , Q_{lf} and $Q_{\max}$ for gauging sites in the Damanganga Basin based on GEVI and LP-III probability distribution

River	Sites	Record length (years)	$Q \text{ m}^3/\text{s}$	Return period (years)	
				GEVI	LP-III
Damanganga	Nanipalsan	27	$Q_m = 856$	2.33	7.42
			$Q_{lf} = 1565$	6.93	28.10
			$Q_{\max} = 3173$	118.00	107.00
			$Q_m = 1046$	2.33	5.52
Wagh	Ozarkhed	27	$Q_{lf} = 1578$	6.93	23.09
			$Q_{\max} = 2700$	96.00	146.00

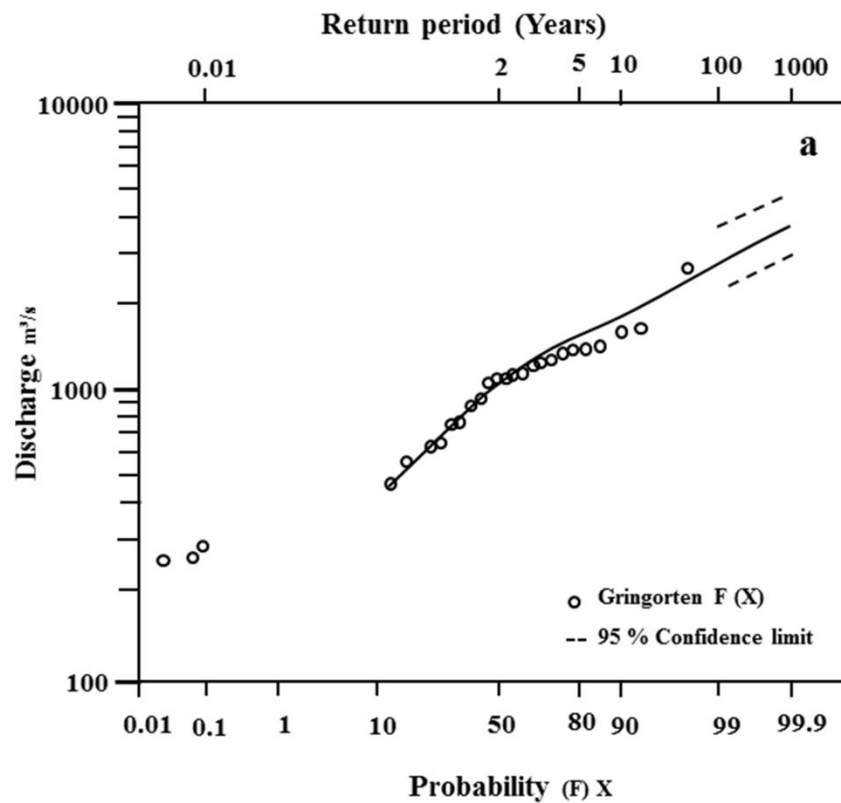


Figure 5a. Flood frequency, annual maximum series, LP-III distribution: Damanganga River (Nanipalsan)

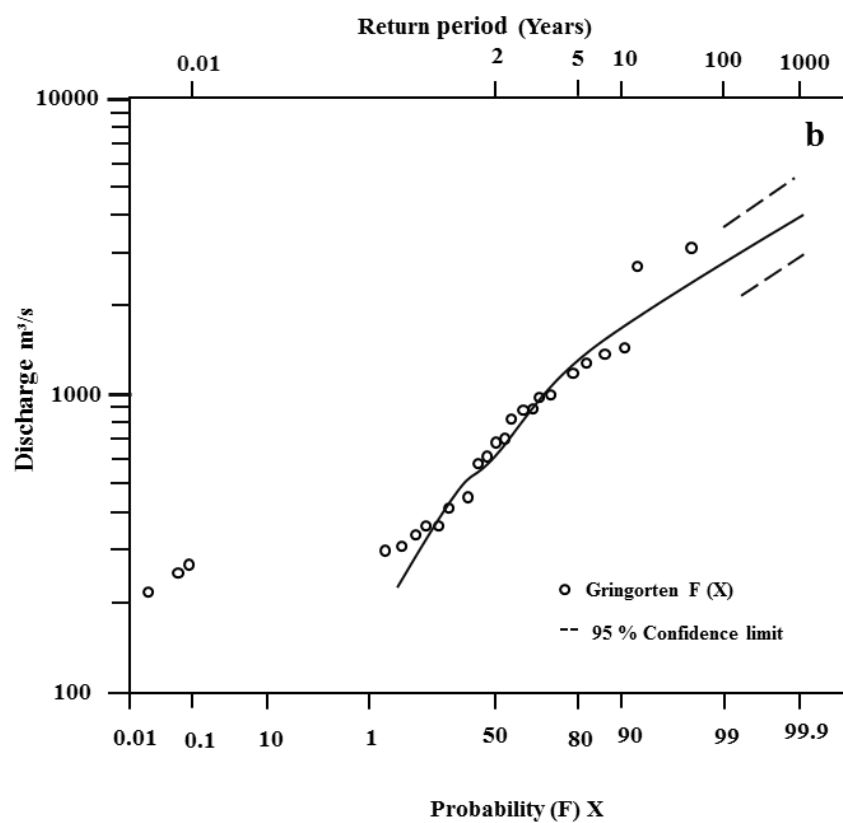


Figure 5b. Flood frequency, annual maximum series, LP-III distribution: Wagh River (Ozarkhed)

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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ABBREVIATIONS

AAR: Average Annual Rainfall; **AD:** Anderson-Darling; **AMS:** Annual Maximum Series; **BoB:** Bay of Bengal; **CWC:** Central Water Commission; **FFA:** Flood Frequency Analysis; **FFC:** Flood Frequency Curves; **GEV:** Generalized Extreme Value; **GEVI:** Gumbel Extreme Value type-I; **GoF:** Goodness-of-Fit; **IMD:** India Meteorological Department; **KS:** Kolmogorov-Smirnov; **LN:** Log-Normal; **LP-III:** Log Pearson type-III; **MD:** Monsoon Depression.

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