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Flood Frequency Analysis of the Par River : Western India

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ABSTRACT

An evaluation of the effectiveness of flows depends on the magnitude and frequency of the events than mean discharges. Magnitude-frequency analysis is one method that identifies the hydrological and geomorphological importance of these events quantitatively, particularly the frequency of flood events of various magnitudes. Therefore, an attempt has been made to understand the magnitude and frequency characteristics of floods on the Par River on the basis of available annual peak discharges and field data. The Annual Maximum Series (AMS) data were available for the Nanivahial site on the Par River for 49 years. To estimate discharges of a given return period, frequency distribution is compiled from a data series of extreme events. By using Gumbel Extreme Value type I (GEVI) probability distribution, peak flows have been estimated for different return periods. The distribution has also been employed to estimate the recurrence interval of mean annual peak discharge, large flood and actually observed maximum annual peak discharge. The magnitude-frequency analysis based on GEVI distribution reveals that the mean annual peak flood has a recurrence interval of 2.33 years, large flood has 6.93 years and maximum peak discharge has 185 years. Two general conclusions emerge from the analyses. First, the river displays extraordinary hydrologic characteristics of a flood-dominated river. Second, large floods are relatively frequent. This fact suggests that large-magnitude events have an important role to play in the bedrock channel morphology of the Par River.

Keywords: Annual Maximum Series, return period, Gumbel Extreme Value type I, recurrence interval.

I. INTRODUCTION

According to Leopoldet al.[1] and Schumm[2] the channel form and the processes of erosion and transportation in a river are closely associated with the river regimes specifically to the flows which they transmit. The regional hydro-climatic regime conditions strongly control the river regime [3]. Numerous case studies in the last six decades have showed that the geomorphic effects of a discharge of a given magnitude and frequency differ from one regime to another [4] For instance, Wolman and Miller [5] revealed that the frequently occurring low and moderate flows largely determine the transfer of sediments and the channel size under humid temperate regime. On the contrary, infrequent large magnitude floods maintain and control the channel size of rivers in arid tropical regime [6]. In semi-arid tropics the channel morphologic properties are not directed by a particular discharge but by a series of discharges taking place at different intervals [7]. Similar conclusion has been proposed by Gupta [8]. He suggested that in seasonal tropics the rivers are not only controlled by the seasonality of discharge but also high-magnitude floods. Hire [4] opines for the Tapi River that the low- or moderate-magnitude flows transport most of the fine-grained sediment (clay, silt and sand) and modify the channel bedforms to some extent. However, the channel size and shape is maintained by large-magnitude floods that occur at long intervals. Considerable attention has been given to morphology of bedrock channels and dynamics and to fluvial erosional processes in recent years [9]. These studies, therefore, point out that a systematic understanding of the main features of the fluvial and flood regime of a river is essential for the estimation of the pattern of geomorphic work. In the present study, hence, an attempt has been made to inspect the magnitude frequency analysis of the AMS data.

II. GEOMORPHIC, GEOLOGIC AND CLIMATIC SETTINGS OFTHE PAR RIVER

The Par River from western India has been selected for study of flood frequency analysis (Fig. 1). It has its source near Harantekadi at an elevation of 982 m ASL. Physiographically, upper Par River and its tributaries flow on the Jawhar Plateau whereas at lower reaches river flows on the Kokan Plains. The Par Basin is bordered by, roughly east-west trending, Surgana and Peth Ranges to north and south respectively and by Western Ghats to the East. The altitude of Surgana and Peth Hills ranges from 450 to 750 m ASL. The Western Ghats (>900 m ASL) is higher in altitude than Surgana and Peth ranges. The basin relief, i.e. Kem Hill (1177 m), is located as offshoot of Western Ghats.

The river flows to the west through Maharashtra (46.45% area) and Gujarat (53.55% area) States and drains into the Arabian Sea near Umarsadi in the Gujarat State. The length of the river is 142 km. The Nar River, with the length of 87 km, is the major tributary of the Par River and joins from the north. Other major tributaries of the Par River are the Manmora, the Keng, the Vajri, and the Bhimtas. The Par Basin extends over an area of 1664 km^2. The entire basin is underlain by horizontally bedded Cretaceous-Eocene Deccan Trap basalts. The river has single, sinuous, and well-defined channel, incised into bedrock. The channel floor is either of bedrock or covered by pebbly/cobbly material or boulders. The Par River and its tributaries are south-west summer monsoon fed (June to September). The average annual rainfall of the basin is 2076 mm and 93% of the annual rainfall occurs during south-west monsoon season. The basin occasionally receives heavy rains due to cyclonic storms and depressions originating over the Bay of Bengal or adjoining land and the Arabian Sea.

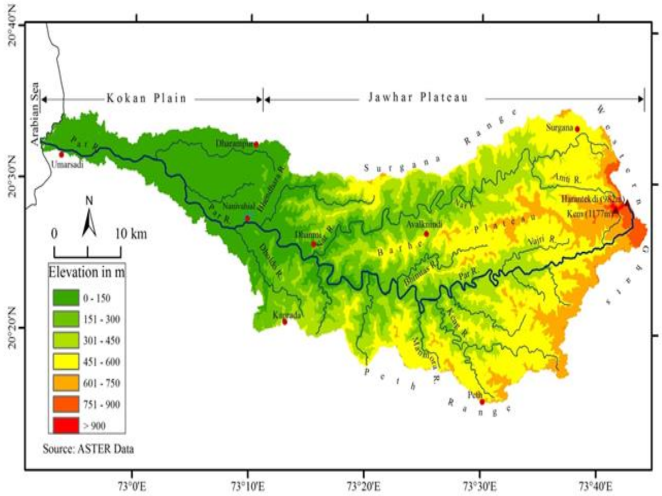

Figure 1. Geomorphic setting of the Par River

III. METHODOLOGY

The Par River, similar to other monsoonal rivers, also subjected to high-magnitude floods at regular intervals. Thus, it is of paramount significant to know the hydrologic characteristics of floods in terms of magnitude, frequency and distribution. Therefore, flood frequency analysis has been carried out for the Par River. FFA necessitates a good quality, long and continuous records. Typically the AMS data have been more frequently used for the analysis. In case of the study area, the AMS data of flood stage and magnitude are available for Nanivahial site (Fig. 1) on the Par River for the last 49 years (since 1961). This data have been used for magnitude-frequency analysis. In order to estimate discharges of a given return period, a frequency distribution is compiled from a data series of extreme events. By using Gumbel extreme value type I (GEVI) probability distribution, peak flows have been estimated for different return periods such as 2, 5, 10, 25, 50, and 100 years. The distribution has also been employed to estimate the recurrence interval of mean annual peak discharge (Qm), large flood (Qlf) and actually observed maximum annual peak discharge (Qmax). A visual inspection of the fit of the frequency distribution is possibly the best way in determining how fine an individual distribution fits the AMS dataset or which distribution fits "best" [10]. Therefore, flood frequency of the Nanivahial site is represented graphically (Fig. 2) which fairly represents the Par Basin.

A. Gumbel Extreme Value Type I (GEVI) Distribution

Assuming the GEVI distribution for the AMS data of the selected site, an estimate of flows for a desired recurrence interval were obtained by using the following equation [11].

$$Q_T = Qm + [K(T) * \sigma Q] \quad .....Eq.\ 1$$

where, Q_T = discharge of required return period, Qm = mean annual peak discharge, σQ = standard deviation of AMS, and K(T) = frequency factor and is the function of the return period T. K(T) values were obtained from tables provided in the standards books on Applied Hydrology.

The recurrence intervals (T) of given discharges (X), such as mean annual peak discharge (Qm), large flood (Qlf) and peak on record (Qmax), have been estimated by applying the following equation [11].

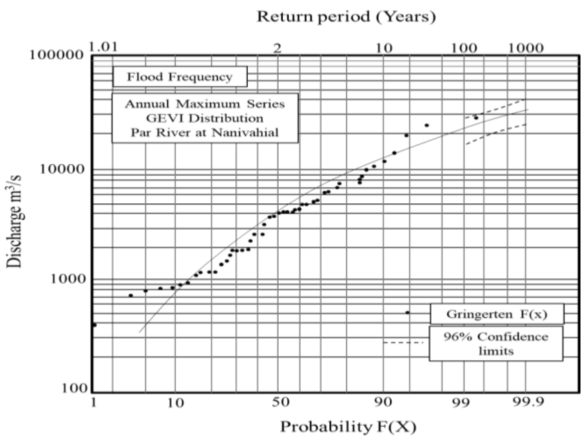

Figure 2. Annual Maximum Series, GEVI distribution, Nanivahial, Par River

$$\frac{1}{T} = 1 - F(X) = 1 - \exp[-e^{-b(X-a)}] \quad .....Eq.\ 2$$

where, T = recurrence interval for a given discharge, F(X) = probability of an annual maximum Q ≤ X, and a and b are two parameters related to the moments of population of Q values. The parameters a and b were determined by the following equations.

$$a = Qm - \frac{\gamma}{b} \quad (\gamma = 0.5772) \quad ......Eq.\ 3$$

$$b = \frac{\pi}{\sigma Q \sqrt{6}} \quad ......Eq.\ 4$$

where, Qm = mean annual peak discharge, and σQ = standard deviation of annual peak discharge. The return periods of required discharges have been calculated by applying Equation 3.

In the GEVI analysis, the observed annual peak discharges have been plotted against the return period or F(X) values (plotting positions) on the Gumbel graph paper, designed for GEVI probability distribution. 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 [11]. The F(X) values have been calculated as follows;

$$P(X) = 1 - F(X) = \frac{r - 0.44}{N + 0.12} \quad .....Eq.\ 5$$

where, r = flood magnitude rank and N = the number of years of records.

A line can be drawn by eye to fit the scatter, especially using the Gringorten plotting positions. However, it is sensible to draw the line mathematically. Additionally, since most of the AMS data are available for short period of time, it is essential to construct confidence limits about the fitted line relationship between the AMS and the linearized probability variable [11]. Shaw[11] has given procedure to fit the line mathematically and to

$$P(X) = 1 - F(X) = \frac{r - 0.44}{N + 0.12} \quad ....Eq.\ 5$$

construct the confidence limits. The same procedure has been followed in this study.

IV. RESULTS AND CONCLUSIONS

By using GEVI probability distributions, peak flows have been estimated for different return periods such as 2, 5, 10, 25, 50, and 100 years. The estimated discharges are given in Table 1.

Table 1. Estimated discharges in m^3/s for different return periods for Nanivahialsite on the Par River (Based on GEVI distribution)

Record length	**Return period (years)**					
	2	5	10	25	50	100
49	4200	8767	11777	15618	18576	21327

See Figure 1 for location of site

The distribution has also been employed to estimate the recurrence interval of mean annual peak discharge (Qm), large flood (Qlf) and actually observed maximum annual peak discharge (Qmax) (Table 2).

Table 2. Return period of Qm, Qlf and Qmax for Nanivahialsite on the Par River (Based on GEVI)

Record length	**Q m^3/s**	**Return period (yr)**
49	Qm = 5030	2.33
	Qlf = 10220	6.93
	Qmax = 23820	185.47

Qm = mean annual peak discharge; Qlf = large flood; Qmax = maximum annual peak discharge; GEVI = Gumbel Extreme Value Type I; See Fig. 1 for location of site

In the GEVI analysis, the observed annual peak discharges have been plotted against the return period or F(X) values (plotting positions) on the Gumbel graph paper, designed for GEVI probability distribution. The plotted graph is shown in Fig. 2 which 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. Interestingly, in plot of GEVI distribution, the actually observed peak on record (Qmax) falls well close to the fitted lines. This means the return period of Qmax of Nanivahial station predicted by GEVI distribution are likely to be quite reliable.

Two general conclusions emerge from the analyses. First, the river displays extraordinary hydrologic characteristics of a flood-dominated river. Second, large floods are relatively frequent. This fact suggests that large-magnitude events have an important role to play in the bedrock channel morphology of the Par River.

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