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HYDRO-STATISTICAL ANALYSIS OF FLOOD FLOWS WITH PARTICULAR REFERENCE TO TILPARA BARRAGE OF MAYURAKSHI RIVER, EASTERN INDIA

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ABSTRACT

Flood is a common incidence in Mayurakshi River basin of Eastern India. However, in recent decades it has became quite irregular and its frequency has increased significantly. In the present article flood trend and frequency of lower Mayurakshi River Basin in relation to Tilpara Barrage has been focussed and flood frequency has been analysed in terms of Log-Pearson Type III (LP3) distribution model. For this analysis annual peak discharge data at Tilpara gauge station and rainfall data of district head quarter Suri has been incorporated for the period 1954 to 2013. The results showed that, the distribution of flood flows was highly variable in the in the catchment (Cv = 0.984). Rainfall above a critical range is the leading factor to control barrage discharge and thereby to cause flood. The estimated threshold rainfall is 550 mm. and threshold discharge of 180000 cusec to cause flood. Estimated mean daily discharge available for the barrage is 2602.74 cusec but actual average barrage discharge for the period is 1175.169305 cusec. The extra inflow amount is regularly diverted to other river system through irrigation canal. The estimated discharges as per LP3 for the return period of 2, 5, 10, 25, 50, 100 and 200 years are 19241.35, 59202.45, 109328.29, 214359.44, 334201.82, 502387.10, 733880.19 cusec, respectively. The equation which relates the expected discharge(y) to return period is given y = 14990ln(x) - 18160. These values are useful for hydraulic design of structures in the catchment area and for storm water management.

Keywords: lower Mayurakshi river basin, peak discharges, flood trend, flood frequency, flow duration curve, mass inflow curve, Log-Pearson type III (LP3), return period.

1. INTRODUCTION

Flood is one of the common hydrological phenomena which is to a large extent unpredictable and uncontrollable [1]. More than 1/3rd of the world's land area is flood prone affecting some 82% of the world's population [2]. As per UNDP [3] approximately 170,000 deaths were associated with floods worldwide between 1980 and 2000 [4].

Statisticians agree that floods are strictly random variables and should be treated as elements of statistics [5-7] and flood frequency analysis (FFA) is a viable method for flood flow estimation and critical design discharge in most situations [8]. For distributional analysis of river discharge time series is an important task in many areas of hydrological engineering, including optimal design of water storage and drainage networks, management of extreme events, risk assessment for water supply, environmental flow management and many others [9-16].

The documented history of ruinous extreme flood is more than 200 years old [17] in lower Mayurakshi River Basin. Bulks of flood incidents in the catchment have occurred due to unexpected rainy spells occurring within the monsoon period [17-20]. Preliminary reviewing of the flood incidents of the river basin has revealed that flood frequency has amplified significantly after the barrage construction in the river basin. Jha and Bairaghya [18] argued that Masanjore dam located on the river highly influence the discharge of Tilpara Barrage and mainly Tilpara barrage controls the flood condition of the lower catchment of the MRB. Bhattacharya [17] and Let [21] in their thesis have pertinently shown that there is a positive relationship with flood and water release from the barrage. Hence, it is imperative to investigate flood trend and its frequency of the catchment in relation to the annual peak flow records of Tilpara Barrage. Bhattacharya [17], Jha and Bairagya [18], Mukhopadhyay [22], Mukhopadhyay and Bhattacharya [23] etc. have done some worthy works on the flood characters of this catchment. In the present work flood trend and flood frequency have assessed based on some useful hydro-statistical methods in connections with the annual peak discharge and inflow records of Tilpara barrage and peak rainfall records of the catchment.

2. REGIONAL SETTINGS OF THE STUDY AREA

River Mayurakshi (Length: 288 km.) is a 5th order tributary of Bhagirathi. Its catchment area (5325 sq. km.) lies within the transitional zone between two mega physiographic provinces namely the Chotonagpur plateau and the Bengal basin (Basin Extension: 23°15' N to 24° 34'15" N Lat. and 86°58' E to 88°20' 30" E Long.). The river basin specially the lower part is a well known name in the flood scenario of West Bengal [17, 24-25]. The river Originates from a spring at the foothill of Trickut Pahar, Jharkhand. Several tributaries, distributaries, anabranching loop and spill channels - the Manikornika, Gambhira, Kana Mayurakshi, Mor, Beli or

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Tengramari etc. forms the interwoven network in its lower reaches and flow into the Hizole Beel in the district of Murshidabad. From the Beel, the river Babla starts its journey finally draining into the river Bhagirathi [26-27].

Geologically the catchment is having Dharwanian sedimentary deposition followed by Hercinian orogeny in the upper part, lateritic soil and hard clays deposition in the middle catchment and recent alluvial deposition of alternative layers of sand, silt and clay in the lower extensions [28]. The relief of the catchment ranges between 12 m. to 400 m. Rolling uplands and lateritic badlands in the upstream, wide undulating planation surface, low lying flat and depressed land in the middle and downstream characterizes the morphological features of the basin. Low lying and sometimes depressed lower part is well known for frequent flood incidents and long flood stagnation period.

Sub-tropical monsoonal climatic is prevailing in the basin and Monsoon season (June-September) carries about 80% of total annual rainfall. This seasonal rainfall concentration rainfall mainly results water crowd in the lower catchment. The area covered mostly with the alluvial (Younger and older), laterite, loamy (Red and Plateau Stulfs), clayey (Ustochrents and Huplustulfs) soil [29]. Part of the upper catchment is claded with sal forest. The middle and lower part is prone to soil erosion and agricultural invasion. This often aggravates the rate of sedimentation in channel.

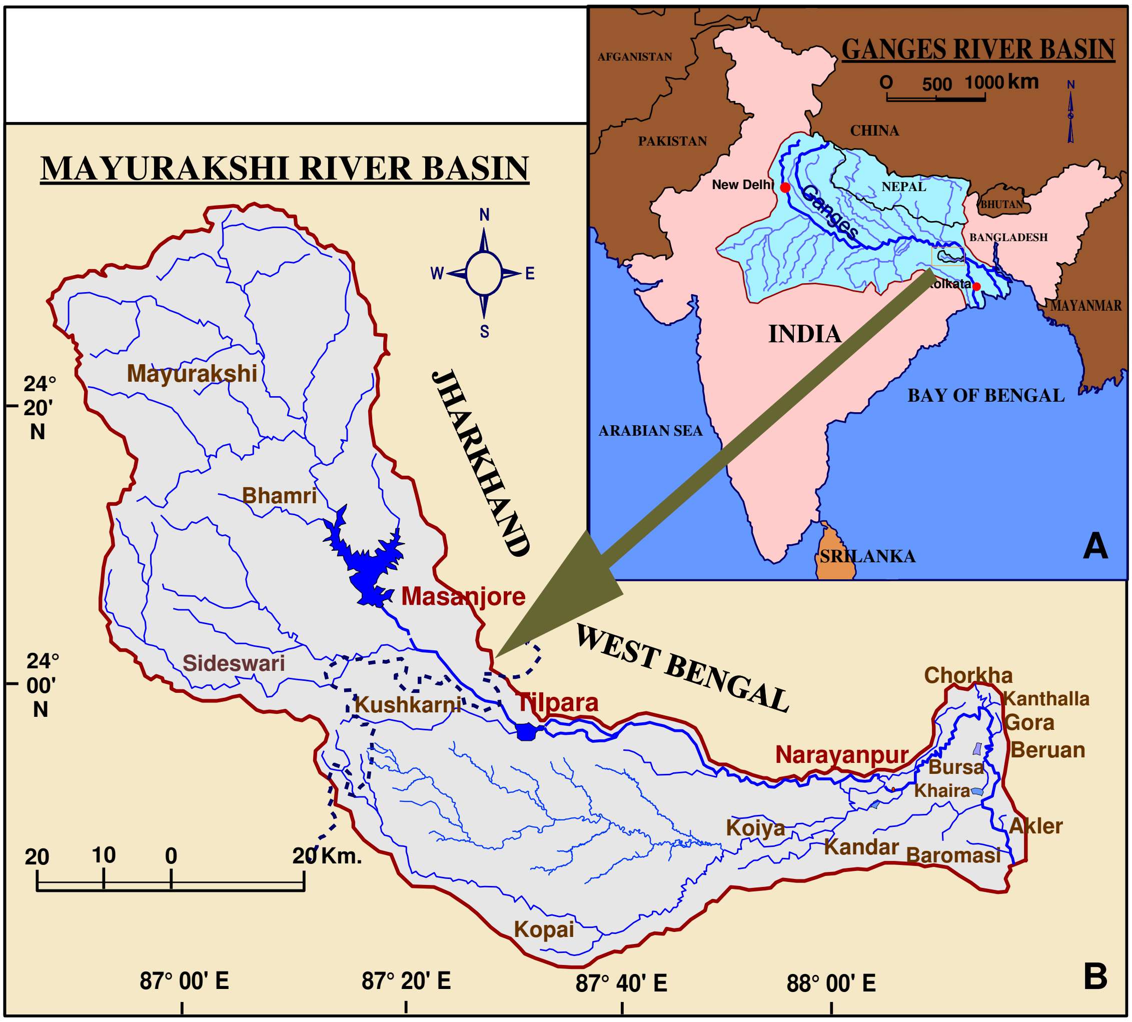

Figure-1. Location map of Mayurakshi River Basin in the Ganges River Basin, India.

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Table-1. Location and hydrological appraisal of the Tilpara Barrage.

Location	Near Suri, District Birbhum on the river Mayurakshi
Distance from Source	148 km. downstream of the source and 49 km. downstream from Masanjore dam.
Co-Ordinates	23°56′46.91″N, 87°31′30.73″ E
Catchment Area	3,208 sq. km
Width Between Abutments	308.81m
Number of weir bays	7 (width 18.29 m each)+ under sluices 8 (Width 18029 m Each)
Linear Water Way	274.39 m
Optimum Pond Level	64.33 m
Design Upstream Water Level	64.63 m
Design Discharge	8,495 cumecs
Canal Discharge	99.11 cumecs
Length of Main Canal	a) Left: 16.62 km., b) Right: 22.53 km.
Irrigable Area	a) Kharif: 2,26,629 Ha; b) Rabi: 20,250 Ha Birbhum, Murshidabad and Burdwan
Maximum Irrigation Achieved	a) Kharif: 2,20,730 Ha, b) Rabi: 8,150 Ha, c) Boro: 25,400 Ha
Maximum Water Level	R.L.-62.789M RL.206.00ft.

Source: Compiled from: http://wbiwd.gov.in/irrigation_sector/major/stats/mayurakshi_stats.htm and Saha [24].

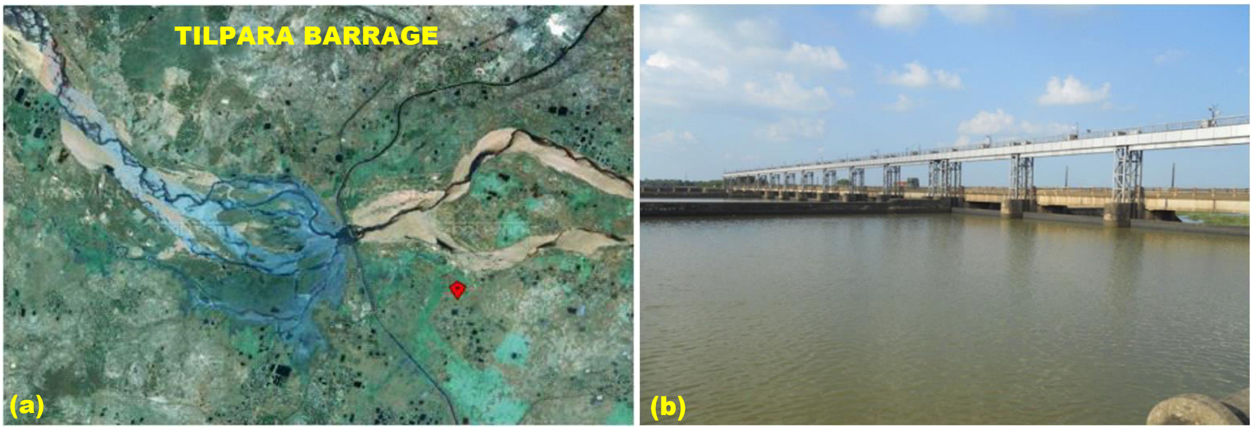

Figure-2. Satellite imagery of Tilpara barrage (a) and respective field photographs (b).

3. DATABASES

The annual peak discharge data of Mayurakshi River at Tilpara Barrage since 1954 to 2013 and monthly inflow and outflow data from 1990-2013 have obtained from the Investigation and Planning Circle, Suri, Birbhum, Irrigation and Waterways Directorate, Govt. of W.B. Annual peak rainfall data (1954-2013) have obtained from District Census handbook [30] and Indian Meteorology Department [31].

4. METHODOLOGIES

Descriptive statistics, curvilinear regression, moving average, flood series data plotting probability analysis etc. were applied for hydro-statistical interpretation of stream flow data. To analyse flood frequency Log Pearson Type III distribution (LP3) have used. MS Office Excel 2007, Easy Fit 5.5 Professional software were used for necessary calculation and plotting.

4.1 Mass curve analysis

The flow–mass curve is a plot of the cumulative discharge volume against time [32]. The ordinate of the mass curve, V at any time, t is thus -

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$$V = \int_{o}^{t} Qdt \quad (1)$$

Where t_0 is the time at the beginning of the curve and Q is the discharge rate. Since the hydrograph is a plot of Q VS t, it is to see that the flow-mass curve is an integral curve (summation curve) of the hydrograph. The maximum vertical ordinate was measured which gives the maximum storage capacity of the reservoir.

4.2 Flow Duration Curve (FDA) analysis

The annual or monthly or daily discharge data is commonly used for drawing the FDC. In FDC mean flow is plotted against the exceedance probability, P [33] which is calculated as follows:

$$P=\left[\frac{M}{n+1}\right]\times 100 \quad (2)$$

Where, P = the probability that a given flow will be equalled or exceeded (% of time), M = the ranked position on the listing (dimensionless) and n = the number of events for period of record (dimensionless)

4.3 Flood Frequency Analysis (FFA): LP3 Probability Distribution Model

Annual flood series were found to be often skewed which led to the development and use of many skewed distributions with the most commonly applied distributions now being the Gumbel (EV1), the Generalized Extreme Value (GEV) and the Log Pearson Type III (LP3) [34]. However, there is no theoretical basis for adoption of a single type of distribution [35]. Actually EV1 and GEV is fitted well when a river is less regulated [36] but the river Mayurakshi is to some extent regulated by Masanjore Dam and Tilpara Barrage [17] hence LP3 distribution model have used for the present assessment of flood frequency.

Using LP3 distributions technique extrapolation can be made of the values for events with return periods well beyond the observed flood events and widely used by Federal Agencies in the United States [37]. In carrying out FFA using the LP3 distribution, the steps suggested by Jagadesh and Jayaram [38] have followed.

Step I: Peak flow (X_i) during a water year [39] was assembled to fairly satisfy the assumption of independence and identical distribution [40].

Step II: Estimates of the recurrence interval, Tr are obtained using the Cunane plotting position formula [41] as recommended in Ojha *et al*. [42].

$$Tr = \frac{n+0.2}{m-0.4} \quad (3)$$

Where, n is the number of years of record and m is the rank obtained by arranging the annual flood series in descending order of magnitude with the maximum being assigned the rank 1.

Step III: The logarithms (base 10) of the annual flood series are calculated as

$$Yi = Log\ Xi \quad (4)$$

Step IV: The mean $\bar{y}$, the standard deviation σ_y and skew coefficient C_{sy} or g of the y_i (i.e. Log Xi) were calculated by the formulas-

$$\bar{Y} = \overline{LogX} = \frac{\sum_1^n (Log\ Xi)}{n} \quad (5)$$

$$\sigma y = \sigma LogXi = \left[\frac{\sum (LogXi - \overline{LogX})^2}{(n-1)}\right]^{1/2} \quad (6)$$

$$Csy \quad or \quad g = \frac{n\sum (LogXi - \overline{LogX})^3}{(n-1)(n-2)\sigma^3 LogX} \quad (7)$$

Where, n is the number of entries.

Step V: The logarithms of the flood discharge i.e. log Q for each of the several chosen probability level P (or return period, Tr) are calculated using the following frequency formula [43-44].

$$Log\ Q = \bar{y} + K\ \sigma y \quad (8)$$

$$Or,\ Log\ Q = \overline{LogX} + K\ \sigma LogXi \quad (9)$$

Where, K is the frequency factor, a function of the probability, P and Skewness coefficient C_s (g) and can be read from published tables of Hann [45] developed by integrating the appropriate probability density function (PDF).

Step VI: The flood discharge X for each probability level P is obtained by taking antilogarithms of the Log Q values. The design flood itself is given by:

$$X = AntiLog\, Q \quad (10)$$

As the real frequency distribution of the observed data is unknown, so plotting positions (PP) for the data i.e. estimates for the likely annual exceedance probability or return period of the observed flood magnitudes need to be found. A frequently used approach is to rank the flood

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events from largest to smallest and the largest observation is assigned plotting position 1/n and the smallest n/n = 1 for its annual exceedance probability (AEP). The return period of an event is then the inverse of the AEP [46]. In practice, there is a range of PP methods available. In the present FFA Cunnane PP have used for LP3 as recommended by Ojha *et al.* [42].

5. RESULTS AND DISCUSSIONS

5.1 Trend of annual peak discharges

A 5-year moving average of the yearly peak discharges data highlights a little bit rising trends (Figure-3). Highest discharge (317124.2 cusec) is recorded in the year 2000 and lowest discharge (1909.39 cusec) is recorded in the year 1966. The calculated 60-year mean instantaneous peak discharge is 46505.96 cusec with a standard variation of 71311.08 cusec and a mean coefficient of variation (Cv) is 153.34%. In Figure-3 peak discharge above threshold discharge (i.e. the critical discharge limit above which usually causes flood) of 140,000 cusec [47] reflects the high flood discharge in the year 1956, 1959, 1978, 1987, 1999, 2000 and 2007. Notably, in the devastating deluge year 2000 peak discharge amount (317124.152 cusec) have even crossed the design discharge (i.e. the quantity of discharges that a barrage structure is sized to handle) limit of 300,000 cusec.

The peak discharge curve (Figure-3) has roughly six consecutive phases. Namely, High discharge phase (1953 to 1960), Low discharge phase (1961 to 1977), High discharge phase (1978 to 1991), Low discharge phase (1992 to 1997), Very high discharge phase (1998 to 2007) and Low discharge phase (2008 onward). Notably, the highest peak discharge phase is concentrated between 1998 and 2007. In the recent years (2008 onwards) the reduced volume of discharge does not signify reduction of spilling magnitude because, substantial river bed aggradations as observed by Bhattacharya [17] can supply momentum for steady inundation in the lower reach.

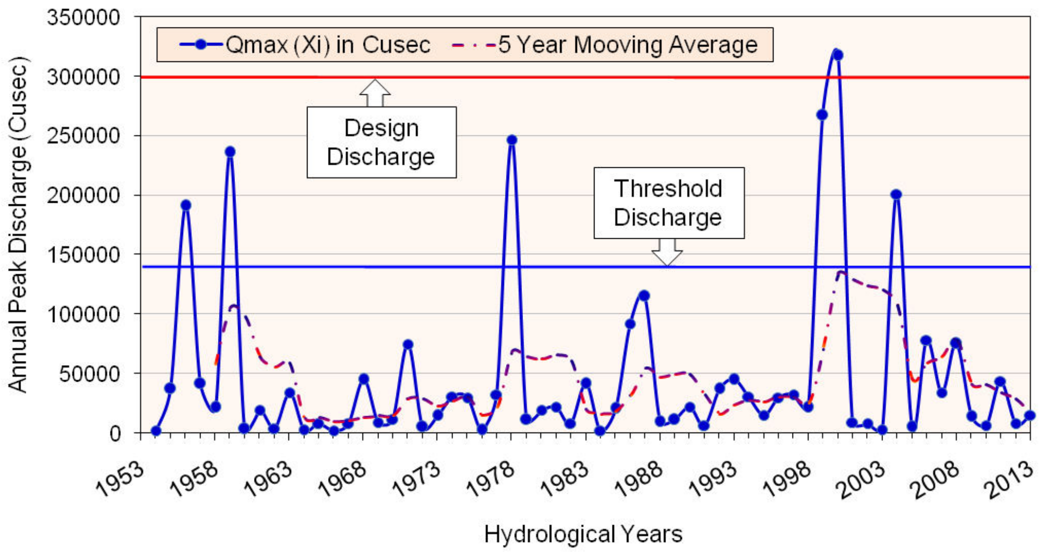

Figure-3. Time series (1954-2013) plot of the annual peak discharge and 5 year moving average discharges for Mayurakshi River from Tilpara Barrage.

5.2 Trend of flood frequency

Study of the past flood incidents from Ankur Patrika [48], Dasgupta [47], Ray [49], Sechpatra [50-51] and several flood reports of the IWD [52-56] of the Govt of West Bengal have revealed that, out of the total 37 micro to macro sized flood since 1900, 28 floods happened after the construction of Masanjore dam (1954) where as 17 floods occurred after the construction of Tilpara barrage (1976) and 14 devastating floods have been recorded during 1950-2010 (Figure-4). Flood affected areas in the lower Mayurakshi catchment after the barrage construction has increased by 32% and embankment breaching has risen to 41.2% [17].

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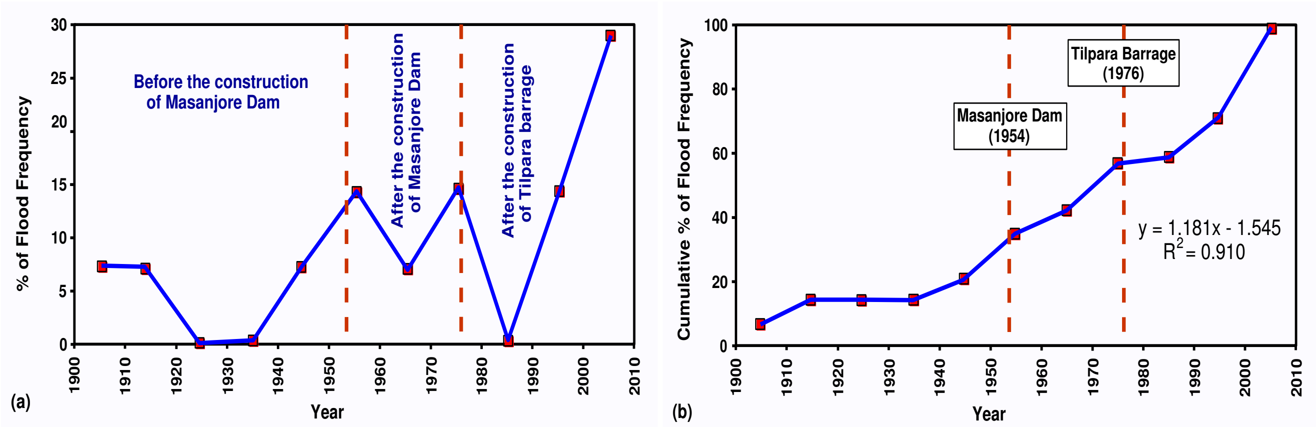

Figure-4. Trend of flood frequency (a) and trend of cumulative flood frequency (b) (**Source:** Bhattacharya [17]).

5.3 Annual peak rainfall and peak discharges relation

Storm rainfall associated with sudden dam discharge results in a potential acceleration of the hydrologic cycle leading to frequent increase of floods events. Bhattacharya [17] in his thesis (pp. 125-127) has clearly revealed that, short duration heavy rainfall during late monsoonal months in most of cases have resulted flood incidence on the present river basin. In Figure-5 annual peak rainfalls and peak discharges relation has shown. The co-relation between the two is positive however, the R^2 value (0.316) demonstrates a poor fit. This signifies that, the control of rainfall on high flood discharge is somehow less which in turn reflects that the barrage controls peak discharges escalating the potentiality of flood.

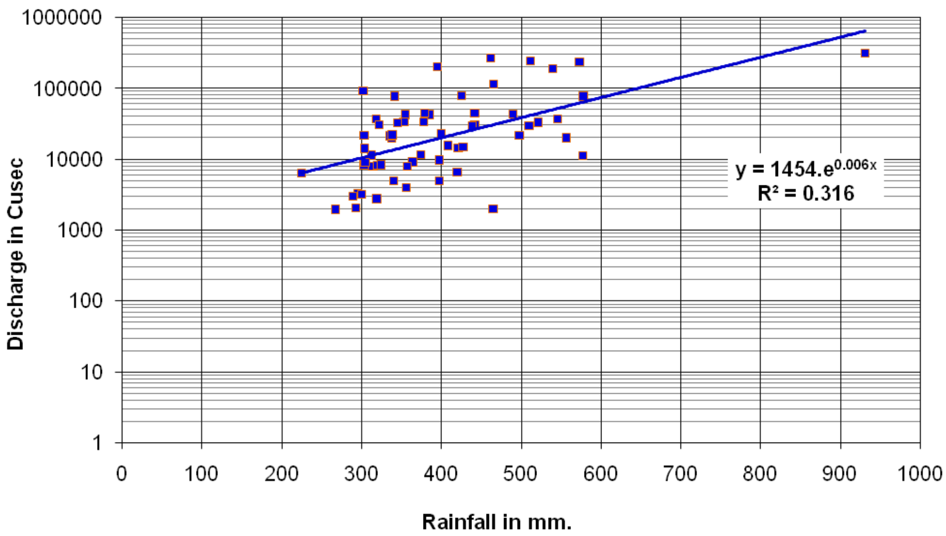

Figure-5. Regression relationship between rainfall and peak discharge for period of record (1954-2013).

In Figure-6 the annual magnitude and probability of flood discharges and storm rainfalls are plotted to annual exceedance probability (AEP) where it is important to notice that the discharge curve shows clear break of slope when rainfall amount go beyond 500 mm. and corresponding activation of major flood events at around the AEP 20%. So it can be estimated that the threshold rainfall is about 500 mm. which often promotes excess discharge from the barrage. The critical discharge for the barrage during storm rainfall period to cause flood is about 14, 0000 cusec [47]. The curvature of discharge plot also displays almost the same. Hence, rainfall above a critical range is the leading factor to control the barrage discharge and thereby to cause flood downstream.

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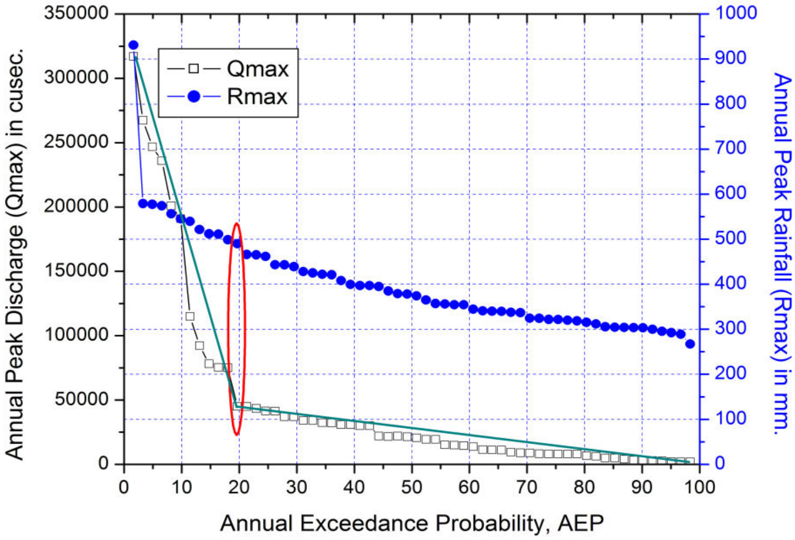

Figure-6. Annual peak rainfall and peak discharges plotting against annual exceedance probability.

5.4 Reservoir water level-discharge relations

The discharges with simultaneous reservoir water level (stage) observation for the period of 1976 to 2013 have shown graphically in Figure-7. Notably, the highest and erratic discharges are associated with the water level above 62 metre. This again conform that the unsteady and accelerated discharge during flood is caused by the barrage. This curve also helps to calculate discharge by simply putting the gauge height. If Q and H are discharge and water level, then for Tilpara Gauge station the relationship can be expressed as- $H = 41.87Q^{0.031}$. The co-efficient of determination (R^2) calculated was 0.916 indicating that the curve satisfied the statistical goodness of fit criteria.

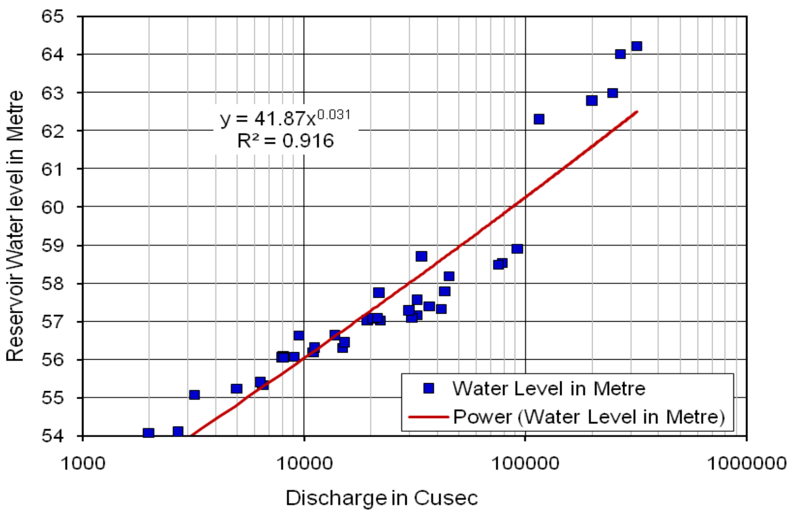

Figure-7. Relationship between the observed stages (reservoir water levels) and the corresponding discharges.

5.5 Assessment from the mass inflow curve

The cumulative stream inflow data (1990-2013) at Tilpara barrage were used to derive the mass inflow curve for calculating the reservoir capacity corresponding to specific yield. The mass curve is shown in Figure-8.The average cumulative inflow is obtained as 681834.3023 cusec and total cumulative inflow into the reservoir for a period of the 24 years is 16364023.26 cusec. From the mass curve, it was estimated that total quantity of water available for storage is about 950000 cusec for a year. Therefore mean daily discharge available is 950000/365 = 2602.74 cusec.

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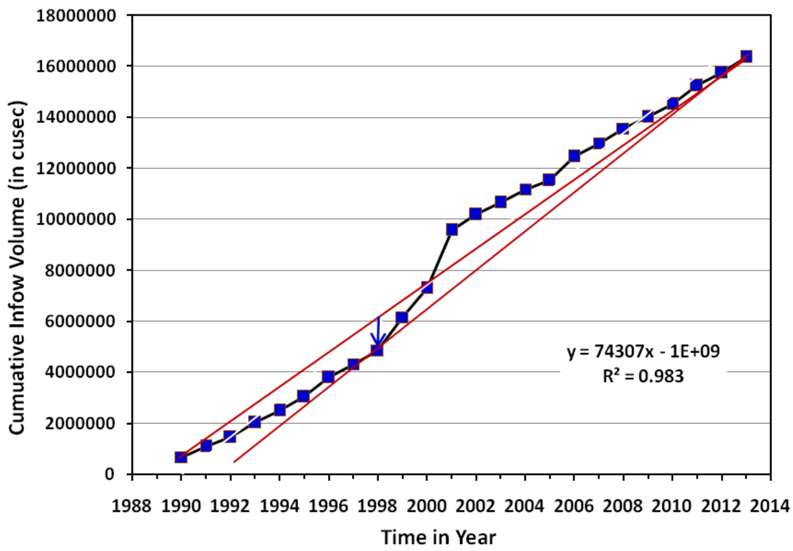

Figure-8. Cumulated inflow volume VS time in years for storage capacity of reservoir from mass curve.

5.6 Flow duration curve assessment

The mean daily discharge data (1990-2013) it has found that, the maximum and minimum discharges are 19792 Cusec (Feb, 2005) and 2.02 cusec (Nov, 2005) respectively. The average annual, average monthly and average daily discharges for the said period is calculated as 411144.42 cusec, 34262.04 cusec and 1175.17 cusec respectively. It has also noticed that the estimated mean daily discharge available as inflow (i.e. 2602.74 cusec) is more than the actual daily discharge (i.e. 1175.17 cusec). Actually, the extra inflow amount is regularly diverted to (i) Deucha barrage located on Dwarka River through Mayurakshi-Dwarka canal system [21] and (ii) Kultore barrage located on Kopai River through Mayurakshi Bakreshwar Main Canal and Bakreshwar-Kopai Main Canal [57]. This diversion is high during non-monsoon periods.

The flow duration curve as shown in Figure-9 clearly reveals that, the two extreme ends have steep slopes. The upper-flow region indicates the type of flow regime where the basin is likely to have flooded where as the low flow region suggests relatively small contributions from natural storage like groundwater. Considering the central portion of the graph, the median flow is almost equal to 500 cusec.

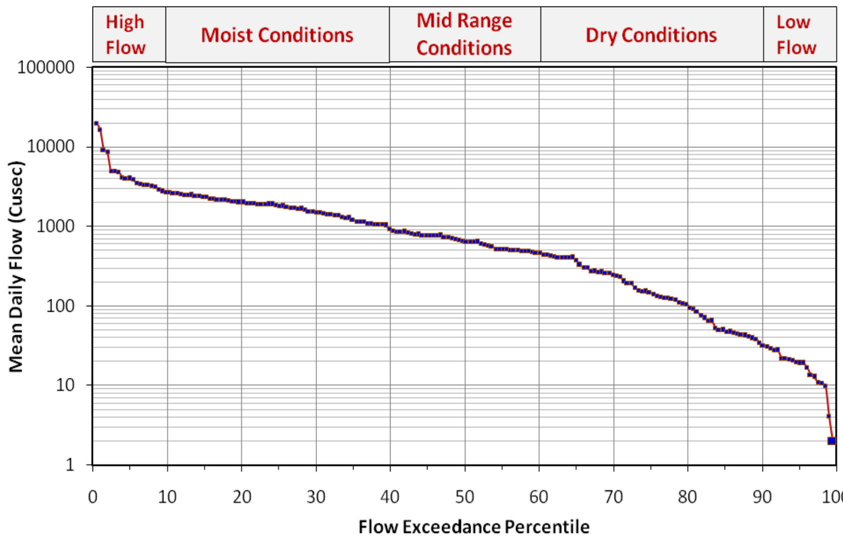

Figure-9. A plot of mean daily discharge verses the flow exceedance percentile For FDC of Mayurakshi River gauged at Tilpara barrage.

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5.7 Estimated peak flows based on LP3 model

Flood peaks corresponding to return periods of 2, 5, 10, 25, 50, 100 and 200 years are estimated in this section to get a trend of flood in different magnitude in the lower Mayurakshi river basin. The estimated discharges using LP3 distributions have shown in Table-2.

Table-2. Results of the application of the LP3 distribution to observed discharge data.

Return Period, Tr(Yrs)	**Probability, P** (%)	**Frequency Factor, K** (g = 0.2328)	$\text{LogQ} = \bar{y} + K\sigma y$	X = AntiLogQ	**Relation between expected discharge and return period**
2	50	-0.033	4.28423553	19241.34958	y = 14990ln(x) - 18160R² = 0.903
5	20	0.83	4.7723397	59202.45277	
10	10	1.301	5.03873259	109328.2987	
25	4	1.818	5.33114262	214359.4431	
50	2	2.159	5.52400881	334201.8195	
100	1	2.472	5.70103848	502387.1008	
200	0.5	2.763	5.86562517	733880.1989	

As can be seen from Table-2 that the estimated stream discharges for return periods of 2 yrs, 5yrs, 10 yrs, 25yrs, 50yrs, 100yrs and 200yrs as per LP3 distribution are 19241.35, 59202.45, 109328.29, 214359.44, 334201.82, 502387.10, 733880.19 cusec respectively. These values are useful in the engineering design of hydraulic structure in the catchment and predicting probable flood magnitudes over time.

5.8 Regional growth curve

In the Figure-10 return periods are shown against annual observed peak discharges at the site Tilpara. This plot of the annual peak discharge against return period using LP3 presented in figure-10 having the model relationship y = 70264ln(x) -22888 (R^2 = 0.919) can effectively be used to extrapolate values of expected peak discharges for several return periods in order to promote integrated water resources planning and management. Further improvement of the curves might, however, be possible by considering discharge data from several nearby sites [58].

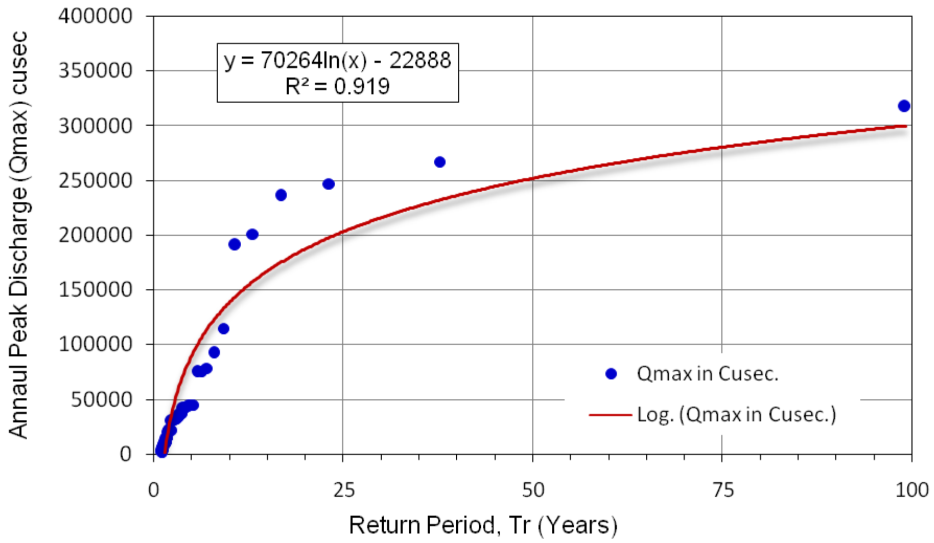

Figure-10. Regional growth curve (discharge VS return period/frequency) for the Mayurakshi river.

6. MAJOR FINDINGS

- The flood flows were highly variable and yearly peak discharges are a little bit rising in trend. There is a sequence of high and low flow and quite intensive flow character is noticed between 1998 and 2007
- Frequency of flood event has risen after the construction of Masanjore dam and Tilpara barrage.
- Regulation power of rainfall to flood flow is quite less due to anthropogenic regulation by the Tilpara barrage. However rainfall above a critical range is the leading factor to control barrage discharge and thereby to cause flood event in the present river basin.
- Peak annual rainfall exceeding 500mm leads to heavy discharge above 170000 cusec in the 10 to 60 recurrence interval year range and the estimated threshold rainfall is 550 mm.
- The highest and erratic discharges are associated with the water level of the barrage above 62 metre.
- Estimated quantity of water available for storage is about 950000 cusec for a year and mean daily discharge available is 2602.74 cusec. Estimated average annual, average monthly and average daily discharges from the barrage are 411144.42 cusec, 34262.035 cusec and 1175.169305 cusec respectively.
- The estimated mean daily discharge available is far more than the actual daily discharge. Actually, the extra inflow amount is regularly diverted to other river system.
- Steep slope in low flow region of the FDC signifies dying condition of the river during lean season.
- The expected discharges for return periods of 2 yrs, 5yrs, 10 yrs, 25yrs, 50yrs, 100yrs and 200yrs as per LP3 distribution are 19241.35, 59202.45, 109328.29, 214359.44, 334201.82, 502387.10, 733880.19 cusec respectively. Recurrence interval of high flood above 200000 cusec discharge is 28 years.

7. CONCLUSIONS

In fine, it is to be stated that Tilpara barrage have positive role to foster flood event in lower Mayurakshi river basin. So, this information and analysis done in the present study can help to start work of the aspirant scholars from this point and provide decision support toward concerned executions. Implementation of more number of river gauge stations and rain gauges and systematic recording of data will certainly help to construct more down to earth assessment. Also the results, identified from the statistical analysis, need to be cross-checked with physical information on the floods or any other information on historical floods. The most important investigation of further need, however, would be the analysis of the stationarity in the extreme value series and the investigation of cycles and trends.

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