Flood Frequency Analysis (FFA) of Annual Maximum Stream Flows for Dwarakeswar-Mundeswari Interfluve in West Bengal, India

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Abstract

Flood is one of the most destructive natural hazards which cause damages to both life and property at an alarming rate. Changes in the flood magnitude, frequency or duration adversely affect the physical and socio-economic environment worldwide. Dwarakeswar-Mundeswari interfluvial area in West Bengal witnesses frequent flood almost every year due to its physiographic peculiarities. For the quantitative assessment of flood situation, a flood frequency analysis has been worked out in the present context to develop a better understanding of flood in this interfluve. To perform flood frequency, the present paper includes probability distribution functions where 34 years of annual maximum series of discharge/gauge data of 3 gauging station have been used. To find the trend of flood occurrence, two types of probability analysis have been used. These are (i) Weibull's Plotting Positions and (ii) Gumbel's Extreme Value Distribution. The study confirms the increased risk damage with the high recurrence interval (RI), and accordingly flood control structures can be built as per the design values estimated after proper field verification which can reduce the magnitude of loss.

Introduction

Flood is undoubtedly the most dreadful natural calamity in the state of West Bengal experiences. It has been estimated that 42.43 percent of the total area of state is flood prone (Rahim, 2005). Flood in Dwarakeswar-Mundeswari is a disaster which can destroy the total environmental set up of the area. It causes river bank erosion, depression of land, shifting of river courses, river channel widening etc due to its high discharge, elevation, volume and long duration, which leads to deficiency in agricultural productivity, unemployment, and even starvation death. So, proper and scientific management of flood in this area is essential to solve the environmental problems to give better life for the future generations. Before taking up any structural or non-structural measures for flood management, it would be wise to examine the flood frequency (recurrence intervals) and probability of occurrence. Flooding in Dwarakeswar-Mundeswari interfluve is a recurrent problem. This area of West Bengal has experienced many devastating floods since long back.

Objectives

The main objectives of this study are:

1) To assess the flood characteristics such as flood elevation, discharge, volume, and duration in the study area.
2) To apply the Weibull's and Gumbel's methods for analyzing the frequency, magnitude and probability of flood.

Study area

In the present treatise, the study area is Dwarakeswar-Mundeswari interfluve in Hugli

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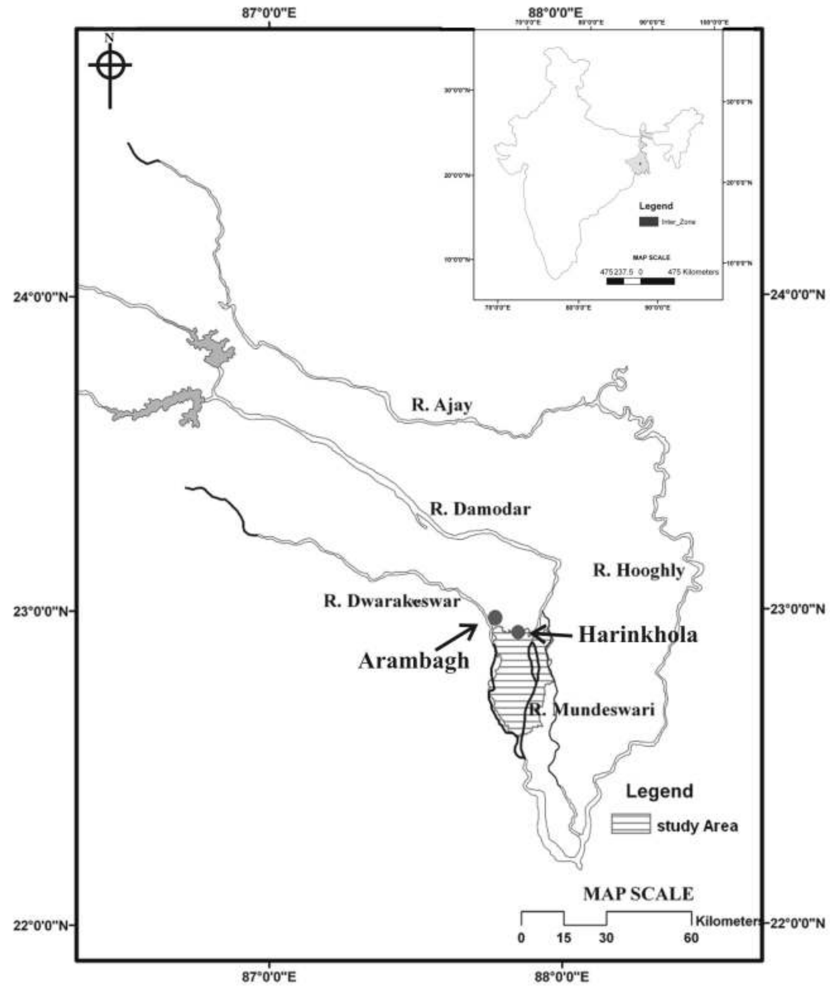

Fig. 1: Map showing the major rivers of the Dwarakeswar-Mundeswari Interfluve and the location of river gauging sites (Detailing of gauging station given in Table 1)

District of West Bengal. It is situated in the south-western part of the district. This area (73N/13 & 73N/14 in SOI Topographical Map) lies between the latitudes 22°36'15" N to 22°57'35"N and Longitudes 87°45'E to 88°58'10"E. The study area has an average elevation of 15.4 meters (Arambagh) to 3.8 meters (Khanakul) above the mean sea level (Majumdar, 1978). Geologically the study area is covered by alluvium, brought down by the Rivers Dwarakeswar and Mundeswari (Roy Chowdhury, 1973). The general slope of this area is from north to south. The drainage of the area is mainly controlled by the R. Mundeswari, Dwarakeswar, Kana-Dwarakeswar and Rupnarayan. Mundeswari is the most important river which is one of the main sources of flood water in the study area. Dwarakeswar River is another important river of flood water in the study area. In addition, several canals are found in the study area like Arora khal, Hurhura khal, kata khal, Chhabis Bigha Khal, Bara khal etc. which carries huge amount of water and

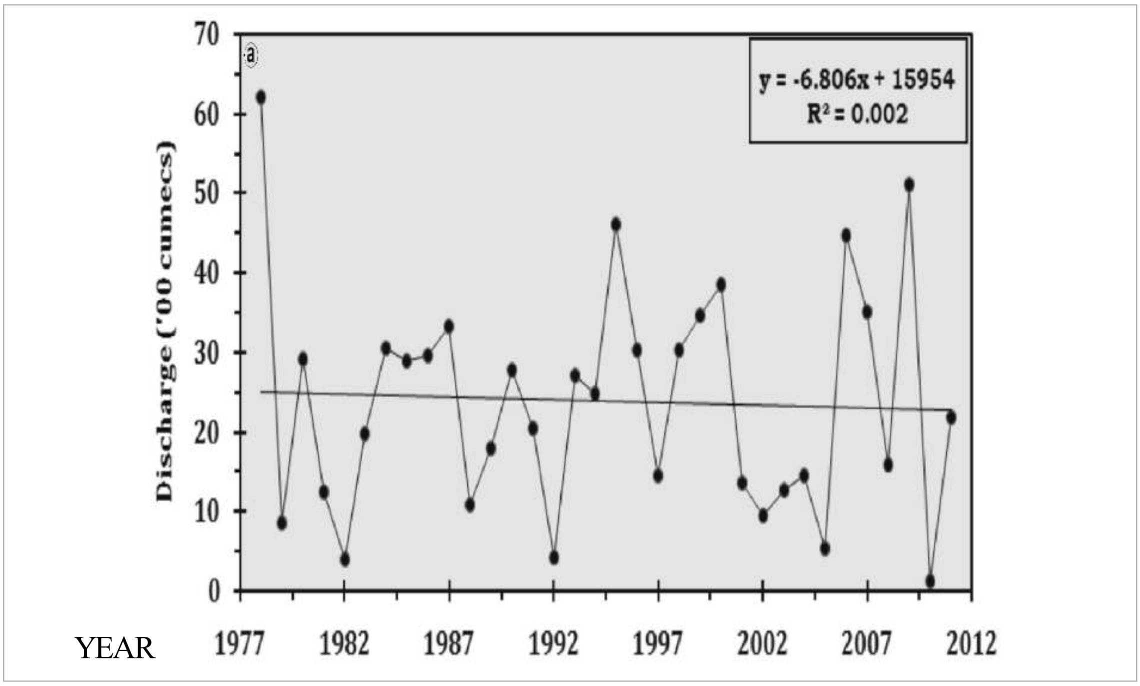

Fig-2 (a) Annual peak discharge (Q) (recorded maximurn discharge observed on a particular day during the whole year) record from 1978 to 2011 at the Mundeswari River; discharge station at Harinkhola, in Hugli District

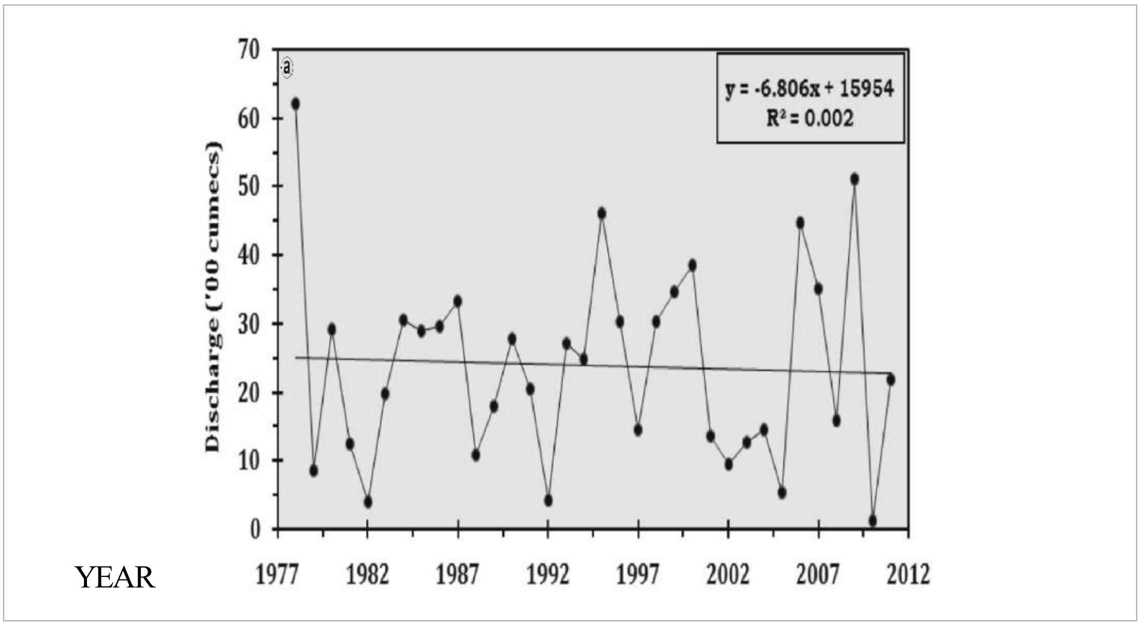

Fig-2 (b) Peak flow level in different flood years (1978-2011) at Arambagh and Sheikpur gauging station on Dwarakeswar River

Table 2: Application of Weibull's method to observed gauge height data (1978-2011) at the site Arambagh and Sheikpur on Dwarakeswar River

Year	*Arambagh Station*				*Sheikpur Station*			
	Gauge height in meters	*Rank of flood (m)*	*Recurrence interval (T)=* $\frac{n+1}{m}$	*Freq of occurrence(f)=* $\frac{1}{T}\times 100\%$	*Gauge height in meters*	*Rank of flood (m)*	*Recurrence interval (T=* $\frac{n+1}{m}$	*Freq of occurrence (f)=* $\frac{1}{T}\times 100\%$
1978	19.14	1	35	2.857	11.73	14	2.50	40.000
1979	13.75	28	1.25	80.000	9.88	30	1.17	85.47
1980	15.54	16	2.19	45.662	11.69	15	2.33	42.918
1981	15.03	18	1.94	51.546	11.19	19	1.84	54.347
1982	12.80	32	1.09	91.743	9.28	32	1.09	91.743
1983	14.63	23	1.52	65.789	10.66	23	1.52	65.789
1984	16.61	-	-	-	12.37	8	4.38	22.83
1985	17.40	6	5.83	17.135	12.58	5	7.0	14.285
1986	165.61	-	-	-	11.91	13	2.69	37.175
1987	18.71	2	17.5	5.714	12.92	3	11.67	8.568
1988	14.66	22	1.59	62.893	10.60	-	-	-
1989	16.61	-	-	-	12.34	-	-	-
1990	14.78	-	-	-	11.15	20	1.43	58.82
1991	14.93	19	1.84	54.347	11.34	17	2.06	48.544
1992	13.96	25	1.40	71.429	10.60	26	1.35	74.074
1993	18.38	3	11.67	8.568	12.89	4	8.75	11.428
1994	14.35	24	1.46	68.493	11.03	21	1.67	59.446
1995	17.25	8	4.38	22.83	12.45	7	5.00	20.000
1996	16.09	13	2.69	37.175	12.06	11	3.18	31.446
1997	13.78	26	1.35	74.074	10.65	24	1.46	68.493
1998	13.39	30	1.17	85.47	10.04	28	1.25	80.000
1999	17.86	5	7.0	14.285	12.93	2	17.50	5.714
2000	16.03	14	2.5	40.000	12.34	10	3.5	28.57
2001	12.65	33	1.6	62.500	9.15	33	1.60	62.5
2002	16.61	12	2.92	34.246	12.05	12	2.92	34.246
2003	13.04	31	1.13	88.496	9.68	31	1.13	88.496
2004	15.39	17	2.06	48.544	11.31	18	1.94	51.546
2005	13.44	29	1.21	82.645	9.92	29	1.21	82.645
2006	14.78	21	1.67	59.446	10.67	22	1.59	62.893
2007	18.04	4	8.75	11.428	12.96	1	35	2.857
2008	13.84	27	1.30	76.923	10.11	27	1.30	76.923
2009	176.31	7	5.0	20.000	12.51	6	5.83	5.83
2010	11.71	34	1.03	97.087	7.25	34	1.03	97.087
2011	16.0	15	2.33	42.918	11.67	16	2.19	45.662

Table-1: Data used in this study (see Figure 1 for location) and regional data

River	Discharge or Stage Site	Latitude, Longitude and Elevation	Data type/ variable	Data source	Average Slope	Average annual rainfall (mm)
Dwarakeswar	Sheikpur	-	Peak flood stage	Irrigation and Waterways Directorate, Arambagh	0.325 mt/km	1440.3
Dwarakeswar	Arambagh	22°53'N, 87°47'E, 15m	Peak flood stage	Irrigation and Waterways Directorate, Arambagh	0.369mt/km	1439.6
Mundeswari	Harinkhola	22°50'N, 87°54'E, 16m	Annual maximum flood discharge	Irrigation and Waterways Directorate, Harinkhola	-	1443.2

River	Discharge or Stage Site	P.D.L. IN Mt.	D.L. IN Mt.	E.D.L. Mt.
Dwarakeswar	Sheikpur	11.12	11.75	12.35
Dwarakeswar	Arambag	16.16	17.22	17.83
Mundeswari	Harinkhola	12.19	12.80	13.41

accelerates the probability of flood in area under study.

The climate is normally tropical savanna. Oppressive hot summer with high humidity (75%-80%), monsoon rainfall and dry cold winter season are some of the typical characteristics of the climate of the study area. The average temperature is 26.8° C and its monthly temperature range from 16°-33°C and maximum temperature often exceeds 38°C. Most of the rainfall (80 %) occurs due to onset of summer monsoon (June to August). The average yearly rainfall is 1500 mm. The study area is covered by alluvial soil both newer and older. The older is observed mainly in the Salepur-I&II, Gourhati-I&II Madhabpur and Batanal Gram Panchayat. The rest of the study area is dominated by newer alluvium.

The soil types noted in the area ranging in thickness from 1 to 2 m. include sandy, silty clayey and mixed loam of which the clayey to mixed loams are very common (Roy Chowdhury, 1973). The clayey loam covers major portion of the southern sector and the mixed loam occurs all over the area. The study area is a highly rich agricultural region and is noted for its rice mills and cold storages. Rice and potato are the principal crops grown here. Jute, nut, oil seeds and different type of vegetables are also grown in some part of the study area. But due to flood during rainy season, Aman paddy is damaged in almost every year. The Dwarakeswar-

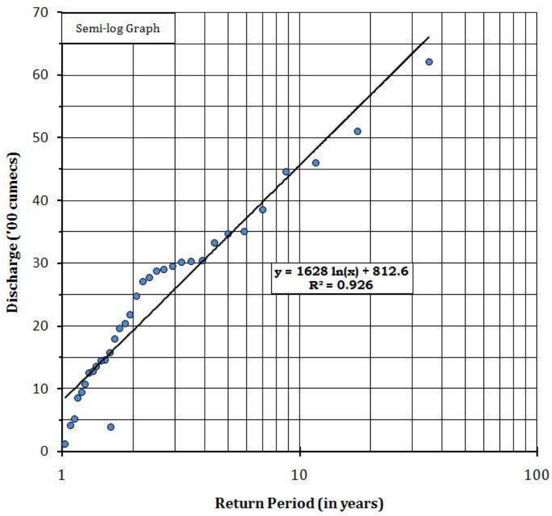

Fig. 3: Weibull's probability plot illustrating the different return period with corresponding river discharge of annual maximum series (1978-2011) for the River Mundeswari at Harinkhola site.

Mundeswari Interfluve is highly populated. The total population of the study area is 8, 45,800 with a density of 1501 per sq. km. The male population is 50.9 % to total population and the percentage of female population is 49.1 %.

Dataset and Methodology

a. Available data for the study

The data analyzed in this paper consists of long-term (34 years) annual peak discharge/stage series available for two rivers *viz.* Dwarakeswar and Mundeswari of this interfluve. Normally the annual peak discharge/stage is used as an indicator of the flood response for a river. A total of three gauging sites were selected because they are located in the lower reaches and thus represent the flood characteristics of the entire interfluve. Harinkhola site of Mundeswari River and Arambagh and Sheikpur site of Dwarakeswar River have been undertaken to examine FFA. The data were mostly obtained from office. The details of data are given in Table 1. The table also includes the available regional data and catchment characteristics used in this study.

b. Methods

The methodology being followed here consists of available FFA methods either based on probability or empirical. Methods based on probability theory are Weibull's Plotting Positions and Gumbel's Extreme Value (GEV) distribution, used here to evaluate the efficacy of different techniques of flood analysis towards assessing the disastrous nature of floods. The methods employed in this study discussed vividly below:

i. Weibull Plotting Position

Weibull's plotting position has been used in this paper for the analysis of return period with flood magnitude taking 34 years of peak water discharge data. The technique of plotting this distribution is to rank the data in descending order. By ranking, we determine the number of the times any particular flood is equaled or exceeded during the period of record, N. Thus the largest flood is equaled or exceeded once. Now, if we define the 'recurrence interval' or 'return period' as the mean time in years for the mth largest value among annual maxima series of length N to be equalled or exceeded once on the average in n future trials (Pal, 1998), the mean number of exceedences in future n years as û= n. (m/n+1). If the mean number of exceedences û = 1, we can have the probability, p of a flood of given mth rank, occurring in the n next year's simplified to 'relative frequency' as P= m/ (N+1) which is commonly referred to as 'Weibull's (1939) Plotting Position formula' for unspecified distributions. The percent probability is P×100 percent. The mth largest flood in a data series has been equalled or exceeded m times in the period of record N years and an estimate of its recurrence interval, T, as given by Weibull's formula is T= 1/P year or T= (N+1)/m. T is (N+1) year for the highest flood and T is 1 year for the lowest flood.

ii Gumbel's Extreme Value (GEV) Distribution

The distribution of extreme value by Gumbel (1941) is commonly known as Gumbel's distribution. This method can be applied for prediction of flood peak, maximum rainfall, maximum wind speed etc. According to his theory of extreme events, According to his theory of extreme events, the probability of occurrence of a peak discharge, *u* equal to or less than a value, u_0 is given by P= $1-e^{-e-Y}$ in which e is the base of nepierian logarithms and Y is a dimensionless variate given by Y=1/0.78ä (u_T-û)+0.577 where $u_{T=}$ the event (or, magnitude of the discharge with probability of occurrence) in T-year return period, û the arithmetic mean and ä the standard deviation of all the data in the series. For computing the return period, T= 1/ (1- e^{-e-Y}) and since the event u of T year return period is $u_{T,}$ we can compute u_T as u_T= û + ä (0.78Y-0.45) in which the frequency factor *K* is (0.78Y-0.45).

Results and Discussion

The maximum gauge height was recorded 14.49 meter against the discharge 6208.7 cusec in the year 1978 at Harinkhola station. The minimum gauge height was observed 7.42 meter against the discharge 120.2 cusec in the year 2010 at Harinkhola station. The extreme danger level (EDL) crossed in the years 1978, 1980, 1984, 1985, 1986, 1987, 1990, 1993, 1994, 1995, 1996, 1998, 1999, 2000, 2006, 2007 and 2009 i.e. 17 times out of 34 years. The peak flood level was observed almost every flood during the month of September. Sudden increase in flood level is caused due to the release of excess water from D.V.C. Sometime sudden falling in recession limb from one upstream station to another downstream station which is mostly due to breaching of embankment. The recurrence interval of highest rank of flood (the flood of 1978 rank-1) is 35 years and the probability of

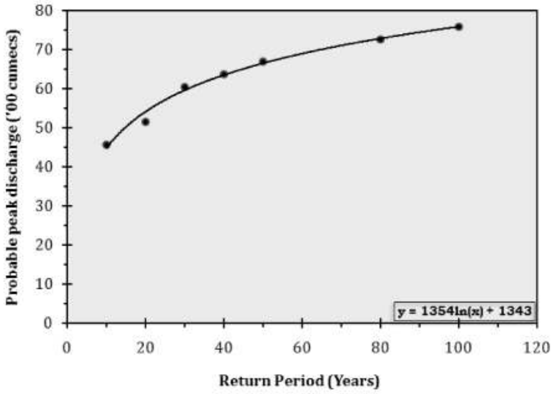

Fig 4: Discharge-frequency analysis (Gumbel's Method) for Mundeswari River at Harinkhola site

occurrence of such flood is 2.9 %. So, there is no chance of such devastating flood within 35 years. The recurrence interval of lowest rank of flood (the flood of 2010, rank -34) is 1.03 years and the probability of occurrence of such flood is 97 %. So, the chance of occurrence of such flood is 97 % on an average every year. In addition, the magnitude of flood having frequency of 10 , 20 , 30 ,40, 50 , 80 , and 100 years have been calculated as 4566.90, 5145.1,6035,6368.38 , 6696.4, 7257.6 and7574.2cumecs respectively 2011) at Arambagh and Sheikpur gauging station on Dwarakeswar River. Linear regression coefficient (b) manifests the long-term decreasing trend (b= 0.035 at Arambagh and b= -0.020 at Sheikpur) of gauge height with increasing year

Suggested Measures for Reducing Flood Risks

On the basis of analysis of the present paper several structural and non-structural measures for reducing flood risks in the area under study can be suggested :

Structural measures

include construction of levees or channel improvements for modifying flood behaviour i.e. keeping water away from the people.

Non-Structural Measures

include appropriate land use zoning in the floodplain that needs to be done keeping in view the intensity of flood hazard (extreme, high, medium, low, very low) with the objective of maximizing the benefits from floodplain and minimizing the risks and consequences of flooding (as per the guidelines of Floodplain Management in Australia) (CSIRO, 2000).

Flood emergency measures

include flood forecasting, evacuation and recovery plans for reducing the magnitude of flood hazard by modifying the responses of the population at risk.

Conclusion

Flood disasters are usually associated with very infrequent events, for example when recurrence interval (T) is of the order of 50 to 100 years. Estimation of probable peak discharge for these return periods is generally subject to uncertainty. In the first place many data do not cover periods of 50 years or more, so that estimation of peak discharges of lesser frequency necessitates indecisive graphical extrapolation. Secondly, the data being analyzed represent only a sample. There is nothing to suggest that the following 50 years or so will reveal the same hydrological environment. In spite of such limitation, flood frequency and probability analysis is essential for the planning of any engineering structure on the river.

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