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Flood frequency analysis of Ramganga River Basin in Western Gangetic Plain, India

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Abstract

Flood frequency analysis (FFA) of major rivers of the Indo-Ganga-Brahmaputra plain is very essential for flood hazard assessment, mitigation as well as effective planning and management for the indigenous people. In the present study, FFA has been done on Ramganga river, located in Western Gangetic Plain region. The river in this region is notorious for flood hazards. Among the most popular FFA models, Gumbel, Weibull, and Log Pearson-III models have been applied for the present assessment. Goodness of fit tests also has been performed to find out the best fitting model. The study shows that Log Pearson-III model is recognized most suiTable than other models. To demonstrate the specific trend of seasonal discharge, Mann-Kendall statistical test has been used which shows a decreasing trend of monsoon discharge while an increase in summer and winter discharge.

Keywords : Flood frequency analysis (FFA), Gumbel, Weibull, Log Pearson-III model, Goodness of fit test, Mann-Kendall test,.

Introduction

Indo-Ganga-Brahmaputra (IGB) plain represents one of the longest and mightiest integrated river network of the world. Disastrous floods witnessed at regular interval with an unprecedented rate of occurrence causing severe damage and untold suffering to the native people. This region comes under the monsoon climate where 80 per cent of copious rainfall occurs in the month of June-September. In this plain, strong associations between intense monsoon rainfall and large floods have been widely discerned (Kale, 2012). The monsoon rainfall creates havoc floods in the states like Assam, Bengal, Bihar and Uttar Pradesh. Hence, the estimation and prediction of extreme flood events are very significant for flood hazard and risk assessment, flood plain management, protection of inhabited areas and hydraulic structures, as well as epidemic control (Renard et al., 2013; Benameur et al., 2017; Farooq et al., 2018; Pandey et al., 2018).

A wide number of flood probability models are used globally to determine the frequency of extreme flood conditions. The most widely used probability models are L-moment, Weibull, Log-

Pearson Type III, Generalized Extreme Value (GEV) Lognormal 3P, Gumbel method, Inverse Gaussian (IG) distribution, Generalized Exponential (GE) distributions etc. Hence, it is very essential to select the best fit model for the estimation of future flood extreme. The selection of an appropriate model basically preferred when an adequate record of flood discharge data is available at any gauging site. Besides, future prediction of occurrence and magnitude of the flood discharge would increase concomitantly along with the availability of data for a longer period (Garde, 1998). Over a period of time, the hydrological model has become more complex with the advent of advanced research in mathematical science. These models can give a better insight for future extreme flood events even from the records of a shorter period of data (> 20 years). In most of the gauging sites of the major Indian rivers, discharge data has been recorded since last 50 years. Therefore, flood forecasting of these rivers for a longer period cannot give any satisfactory results.

Since the last five decades, several hydrologists, environmentalists, geographers, engineers have been adapted to different FFA models and suggested best-fitting models for any river catchment. Kumar et al.,(2003); Hussain, (2009); Liu et al., (2015) carried out flood frequency analysis based on annual maximum peak value by using L-moment. The study of Singo et al., (2012) revealed that Gumbel and Log Pearson III distribution provided better results for Luvuvhu river catchment, South Africa than other GE methods. Odunugh and Rajiet et al., (2014) studied FFA of Lower Ogun river basin, Nigeria. They found that Gumbel method provided the best fit. Markeiwicz, et al., (2015) investigated that for Polish rivers, where Inverse Gaussian (IG) distribution showed the best fitting model. Bandopadhyay et al., (2016) suggested that Log-Pearson Type III distribution is the best fitting distribution of FFA for the Ajay river, India. Kamal et al. (2016) found Gumbel is appropriate for lower sample size while LP3 for a larger sample size. Benameur et al., (2017) suggested Generalized Pareto distribution is fitting best. Farooq et al., (2018) carried out FFA of the Swat river at four gauging sites located in diverse geomorphic setting using LP3, GE, Gumbel method. They observed that there was not a single probability distribution fitted for the entire basin. The LP3 was suiTable for steep valley region and GEV for moderate slope region of the Swat valley. Pandey et al., (2018) proved that for forecasting the annual maximum discharge, Log Pearson III distribution is more suiTable for Betwa river, MP, India. In the present study, FFA was done using some mostly used probability based models viz. Gumbel, Weibull, and Log Pearson-III. The objectives of the present study are to predict probable discharge of flood extreme of the Ramganga river using different FFA models, to explore the best fitting model for FFA and to assess the specific trend of seasonal discharge of the Ramganga river.

Study Area

The extension of the Ramganga watershed lies between 27^0 9' 06'' N to 30^0 06' N and 78^0 15' E to 80^0 04' 08''E (fig.1). In Uttarakhand, it covers 11395.54 km² area. In Western Uttar Pradesh, it occupies 19239.52 km² area. The Ramganga river is one of the largest tributaries of the Ganga river. The total catchment area of Ramganga basin is 30635.1 km². Ramganga River originates from a spring called Ramnali, formed in the Dudhatoli Crystalline Formation of Lesser Himalaya at an elevation of 2926 m above sea level, at the place Diwali Khal, near Gairsen, Chamoli District, Uttarakhand (Mukherjee et al., 2017). It has a total length of ~ 649.11 km, out of which ~167.91 km is in the Himalaya and ~481.2 km in the Western Gangetic Plain.

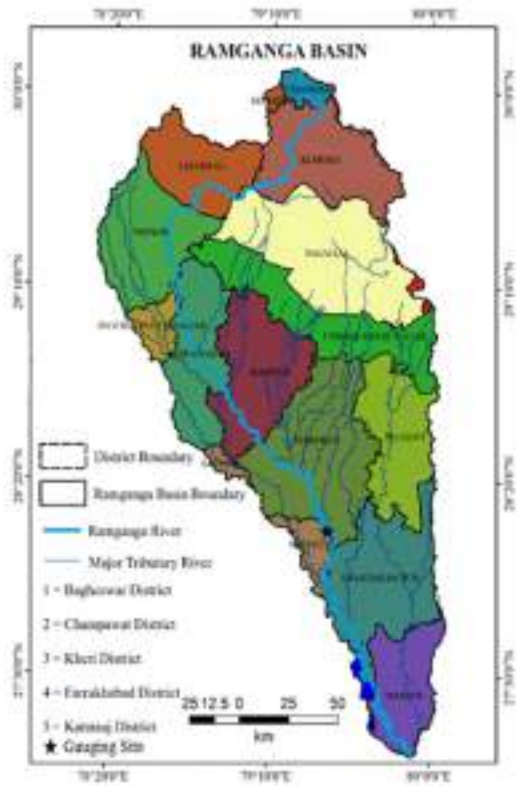

Figure1: Location and extent of Ramganga Basin

The hydrological study of any river basin is very essential to understand the river regime and also to assess flood behaviour (Roy, 2009). The fluvial regime of the Ramganga River is largely controlled by the monsoon climate. In the monsoon season, a large amount of precipitation is received in the Ramganga watershed that caused an exceptionally higher amount of water discharge. Apart from the monsoon season, no such significant variation in the discharge is noticed. The hydrological data for several stations along the Ramganga river has been recorded by the Central Water Commission (CWC). The monthly average discharge data (2003-2012) of Ramganga river for Bareilly and Dabri has been displayed in figure 2. The discharge starts to rise from July and peaks in September and then starts to decline from October. High monthly discharge is recorded from July to October. November to June is designated as the period of low monthly discharge. The month of August and September register as an exceptionally higher amount of water discharge.

Methodology

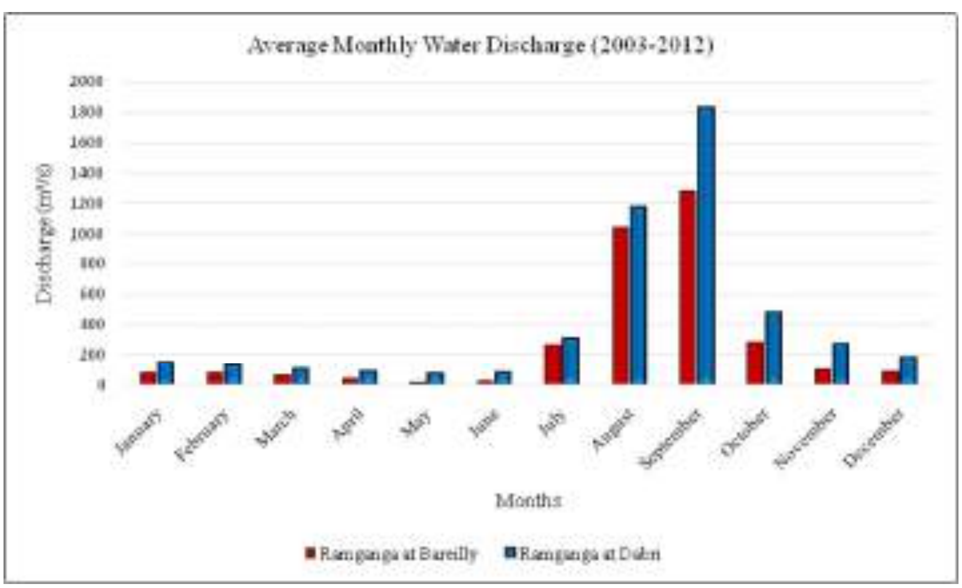

Figure 2: Average Monthly Water Discharge (2003-2012)

Fluvial Regime of the Ramganga River

The fluvial regime of the Ramganga river is effectively controlled by the monsoon climate. As Ramganga river is a spring-fed river and most of its tributary channels are groundwater-fed, the majority of the water discharge of Ramganga and its tributary channels derives from the monsoon rainfall. To discuss the fluvial regime of Ramganga, the annual seasons are classified into spring, monsoon and winter season. To see the specific trend of seasonal discharge Mann-Kendall Statistical test has been used. To demonstrate the seasonal variability of discharge Z score has been applied.

The Mann-Kendall statistics (S) can be express as follows-

$$S = \sum \sum sgn(xj - xi)$$

$$sgn(xj - xi) = \begin{cases} +1 > (xj - xi) \\ 0 = (xj - xi) \\ -1 < (xj - xi) \end{cases}$$

Here, x?, x2 ….. xn represent number of data where xj and xi represent the data at j and i times. In this study the gauging station has the data sets for more than 10 years, hence variance statistic needs to incorporate. Moreover, in the data sets, there is no tie value and for that tie, value correction is not needed. Variance is formulated in the following equation

$$Var\,(S) = \frac{(2n+5)(n^2-n)}{18} \quad (1.3)$$

For standard normal approximation Z statistics can be computed here,

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & S < 0 \end{cases} \quad (1.4)$$

Where a positive value of Z indicates an upward trend and a negative value indicates a downward trend (Kendall, 1973; Rao and

$$Q_i = \frac{x_j\,x_k}{j-k} \quad for\ i = 1, \cdots N$$

Where x_j and x_k are the value at times j and k (j>k) respectively

Flood Frequency Analysis (FFA)

For flood frequency analysis, annual maximum discharge data has been used. For this analysis, the probability density function (PDF) is fitted with the methods of FFA to observe the exceedance of peak discharge of certain magnitude of the flood (Kale, 1993; Bandyopadhyay et al., 2016). The two forms of extreme value distribution viz. EV-I (Gumbel's method) and EV-III (Weibull's method) as well as Log Pearson III distribution have been attempted for assessing the FFA of Ramganga River. The models of annual peak discharge and their probability density function and cumulative distribution function (CDF) is presented in figure 5 and 6. For PDF and CDF Easy fit 5.5 software has been used. For estimating parameters of the selected flood probability models (Table 1), the maximum likelihood estimation method has been considered.

Gumbel's Distribution

It is most widely applied for determining flood frequency analysis (FFA) of any river basin. Gumbel has taken into consideration of the annual series of the extreme value of daily discharge. Gumbel's extreme value distribution is a double exponential distribution $((F(x))=e^{-e^{-y}})$. According to his theory, the probability of occurrence of an event equal to or larger than X_0 is expressed as (Subramanya, 2010) -

$$P(X \geq x_0) = e^{-e^{-y}} \quad (1.6)$$

where y is a dimensionless variable which can be defined by

$$y = \alpha(x - a) \qquad a = \bar{x} - 0.45005\sigma_x \qquad \alpha = 1.2825/\sigma_x$$

From the above-mentioned formulas, the y

$$y = \frac{1.285(x - \overline{x})}{\sigma_x} + 0.577$$

where, $\bar{x}$ = mean and Q_x= standard deviation of the variate X. Here, X is a value for a given P that can be transposed as

$$y_p = -In[-In(1-p)\,] \qquad (1.8)$$

Here, the return period (T) is required to calculate reduced variate and it can be expressed as the return period

$$T=\frac{1}{p} = \frac{N+1}{m} \qquad (1.9)$$

where P is the probability of each event,

N is the number of observations and m is the rank of an individual event.

For a given T, the reduced variate (y_T) commonly designated as

$$y_T = -\left[In.In\,\frac{T}{T-1}\right] \qquad (1.10)$$

$$\text{or,}\quad y_T = -\left[0.834 + 2.303\log\log\frac{T}{T-1}\right] \qquad (1.11)$$

Now, the value of the variate x with a return period T can be expressed as

$$x_T = \bar{x} + K\,\sigma_x \qquad (1.12)$$

$$K = \frac{(y_T - 0.577)}{1.2825} \qquad (1.13)$$

Where K is the frequency factor, $\bar{x}$ and σ_x are the reduced mean and the reduced standard deviation, and their function values for are 0.577 and 1.2825 respectively for an infinite sample size (i.e. $n \rightarrow \infty$.)

Log-Pearson Type III Distribution

It is widely applied to analyze the flood frequency analysis of the tropical river because it is fitting well to their flood peaks.

At first, all the annual extreme value of flood is transformed into logarithms-

$$Y = log\;x \qquad (1.14)$$

The mean ($\bar{y}$), standard deviation ($\boldsymbol{\sigma_y}$), and skewness coefficient (C_s) of y series are estimated as

$$\bar{y} = \frac{1}{n}\sum y_i \qquad (1.15)$$

$$\sigma_y = \sqrt{\sum(y-\bar{y})^2\;/(N-1)} \qquad (1.16)$$

$$C_s = \frac{N\sum(y-\bar{y})^3}{(N-1)(N-2)(\sigma_y)^3} \qquad (1.17)$$

The logarithm of the designed flood is computed as

$$Y_T = \bar{y} + K_T\,\sigma_y \qquad (1.18)$$

The frequency factor $K_T = f(C_s, T)$ is given in Table 6
After calculating y_T by Eq. (1.13), the corresponding value of X_T is calculated as

$$X_T = antilog\ (y_T) \quad (1.19)$$

Weibull's Method

The recurrence interval and percent probability of flood have been estimated by extreme annual value of flood for 19 years, collected from Dandi, Badaun district have been done using peakdischarge.

Weibull's method has been applied for this purpose. It involves the following formula for computing return period-

$$T = \left(\frac{n+1}{m}\right) \times 100 \quad (1.20)$$

Where T = recurrence interval
n = number of years of record
m = order or rank of extreme flood discharge when the flood magnitude is arranged in the descending order (m = 1 for the maximum flood)

The probability of exceedance is –

$$P = 1/T \text{ or} \quad (1.21)$$

The percent chance of its occurrence in any one year is designated as

$$F = 1/T * 100 \quad (1.22)$$

Table 1: Estimated Statistical Parameters for selected three Probability Distributions

Sl. No	Parameters	Parameters	σ	α	β	γ
1	Gumbel (EV-I)	1721.9	299.66	-	-	-
2	Weibull (EV-III)	-	-	4.4709	1653.2	
3	Log-Pearson Type III(LPT-3)	-	-	2.5403	549.1	901.85

Source: Calculated by Researchers

Hamed, 1998).

(1.5)

Goodness of Fit (GOF)

To extract reliable information about flood prediction, it is necessary to test the most suiTable methods of FFA. In that purpose three most commonly used GOF statistical tests viz. Kolmogorov Smirnov, Andersson Darling, and Chi-Squared test have been applied. The reason for selecting three tests for the same purpose is that no single test can give a conclusive outcome.

Results and Discussion

The Mann Kendal test shows the decreasing trend in discharge in the monsoon season. During the period of the last eighteen years, the monsoon discharge of Ramganga of this gauging station shows a decreasing trend. On the other hand, both the spring and winter seasons show an increasing trend (Table 2). The monsoon discharge shows highly positive Z-score value in 2000 and 1998 and 2010. These years are experienced with high flood events. During the period of 2000-2009, the monsoon discharge is experienced with the decreasing trend. In 2010, a remarkable increase in Z-score is observed. Since 2011 again show negative Z value of the monsoon discharge (Table 3).

Like the monsoon season, the negative Z score value predominates over the period of 1998-2016 for the winter discharge. The maximum negative Z-value is observed in 2004 and

Table 2: Results of Trend Analyses of Discharge in the Ramganga River.

Discharge	Z	Sen's slope:	p-value (Two-tailed)	Significant level
Spring	0.234605	1.3807	0.1722	0.05
Winter	0.0760	1.5	0.6787	0.05
Monsoon	-0.2164	-5.3857	0.2109	0.05
Annual Maximum	-0.2047	-20.5455	0.2378	0.05

Source: Calculated by Researchers

Table 3: Temporal variation and Linear Trends in Average Discharge(m^3/s) of Monsoon, Winter, Spring Discharge in the Ramganga River.

Year	Monsoon	Z Score	Winter	Z Score	Spring	Z Score	Maximum Annual discharge (m^3/s)	Z Score
1998	712.00	1.56	355.00	1.83	119.00	-0.46	1980.00	1.12
1999	477.80	-0.13	197.75	-1.05	88.67	-1.23	1394.00	-0.40
2000	899.40	2.91	270.50	0.29	162.00	0.62	2258.00	1.85
2001	403.80	-0.66	248.50	-0.12	120.00	-0.44	1353.00	-0.51
2002	371.00	-0.90	218.50	-0.67	102.67	-0.87	1294.00	-0.66
2003	495.40	0.00	259.00	0.08	126.00	-0.29	1280.00	-0.70
2004	475.40	-0.15	195.00	-1.10	127.33	-0.25	1642.00	0.24
2005	505.60	0.07	194.75	-1.10	67.00	-1.77	2104.00	1.44
2006	396.00	-0.72	209.25	-0.84	217.67	2.01	1583.00	0.09
2007	553.00	0.41	229.75	-0.46	161.33	0.60	1151.00	-1.04
2008	571.60	0.55	233.00	-0.40	135.33	-0.05	2087.00	1.40
2009	404.00	-0.66	197.25	-1.06	131.67	-0.15	1282.00	-0.69
2010	659.40	1.18	307.25	0.96	114.67	-0.57	2018.00	1.22
2011	447.00	-0.35	349.25	1.73	235.67	2.47	1057.00	-1.28
2012	310.60	-1.33	306.00	0.94	164.00	0.67	1055.00	-1.29
2013	402.40	-0.67	347.75	1.70	153.00	0.39	1138.00	-1.07
2014	390.60	-0.76	268.75	0.25	127.33	-0.25	1747.00	0.52
2015	468.40	-0.20	242.00	-0.24	136.33	-0.03	1416.00	-0.35
2016	472.80	-0.16	213.00	-0.77	122.00	-0.39	1590.00	0.11

Source: Calculated by Researchers

2005, whereas in 1998, the highest positive z-value is recorded. The winter discharge decreases from normal since 2004-2009. In contrast, in 2010-2014 it is experienced with the

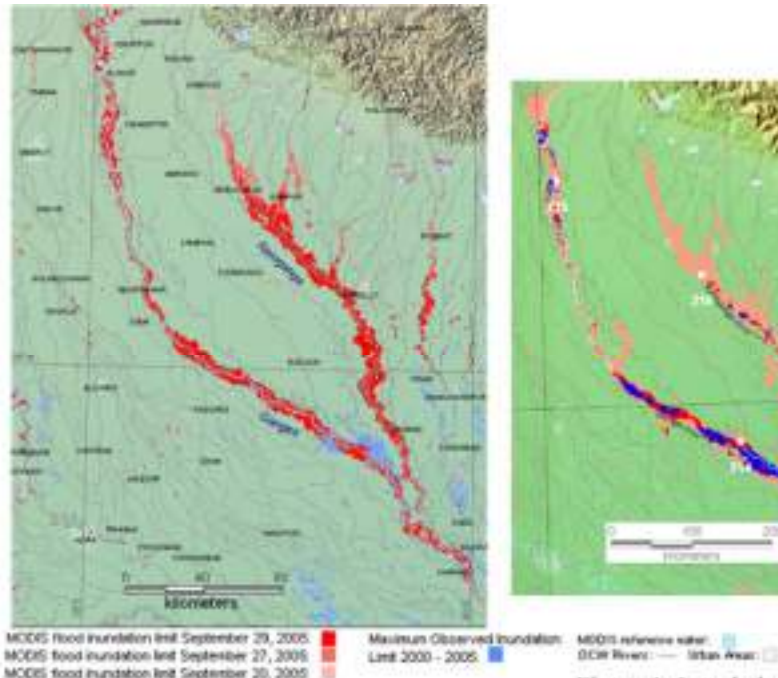

Figure 3: Inundation map derived from MODIS Data

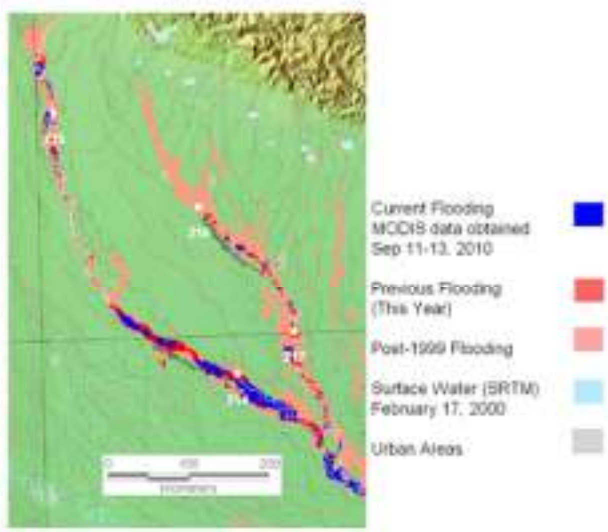

Figure 4: Inundation map derived from MODIS Data (Dartmouth Flood Observatory, 2016)

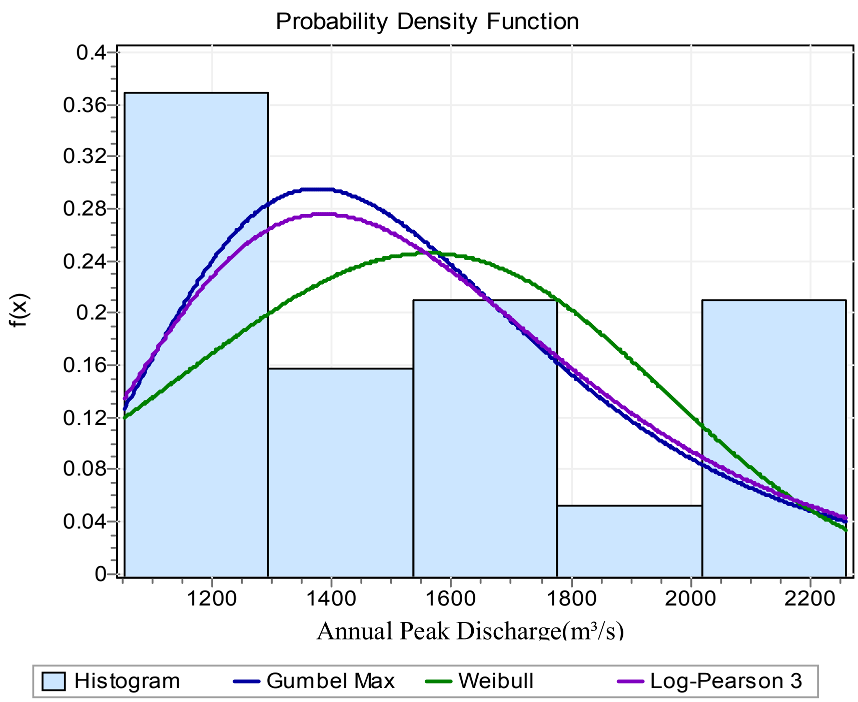

Figure 5: Probability density function

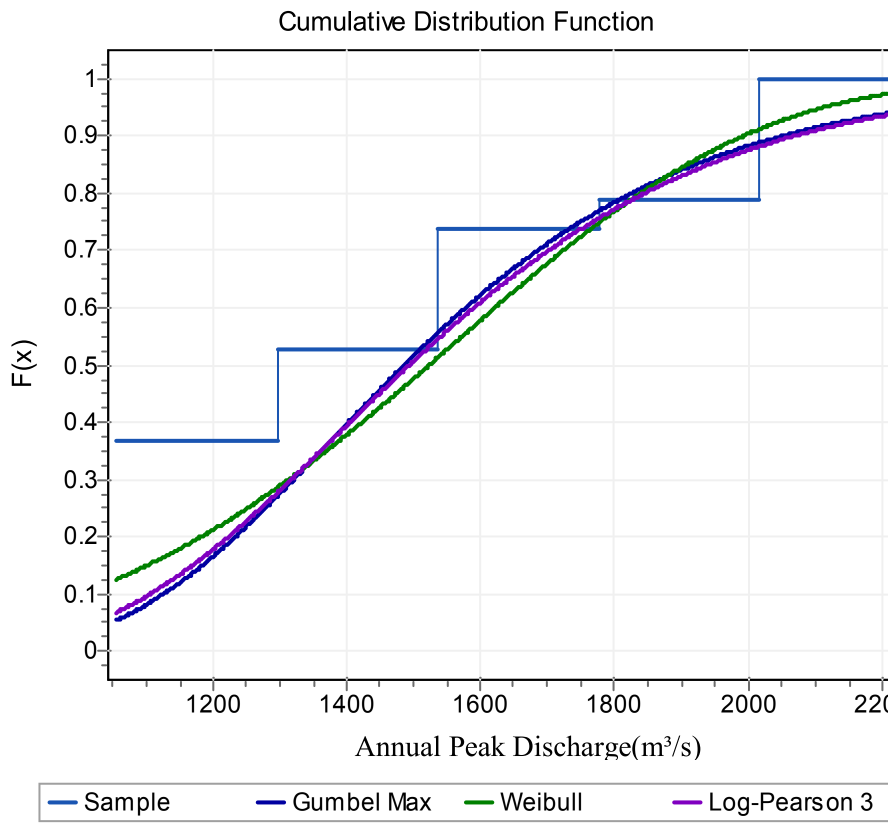

Figure 6: Cumulative distribution function

constant increase. Like monsoon and winter discharge, spring discharge is characterized by negative Z-value. The higher positive Z-value is recorded in 2011 (2.47), 2006 (2.01) whilst it shows high negative value in 2005 (-1.77) and 1999 (-1.23).

The higher positive Z-value of Qmax is observed in 2000 (1.85), followed by 2005 (1.44), 2008 (1.40), 2010 (1.22) and 1998 (1.12) (Table 3). From the flood map produced by Dartmouth Flood Observatory, it has become evident that all of the aforementioned years are experienced with heavy floods (Figure3 and 4).

In the present study, it was observed that within the last eighteen years a large scale of variability in the fluvial regime. Variability of monsoon, flow regulation by dam authority, retarding channel flow and diversion of the channel flow collectively affect the flow regime of the channel.

Estimation of Flood Recurrence Interval and Percent Probability

Figure 5 and 6 depicts the probability density function and cumulative density function. The peak discharge data has been normalized and plotted against reduced variate (Y_T) (Figure 7.a). The figure 7.b shows exponential changes in peak discharge (r^2=0.9723). For Gumbel's and Log Pearson III methods, frequency factor (k) has been used for measuring peak flow.

The peak discharge of 5 to 10 years flood recurrent interval is estimated 1905.785 m^3/s to

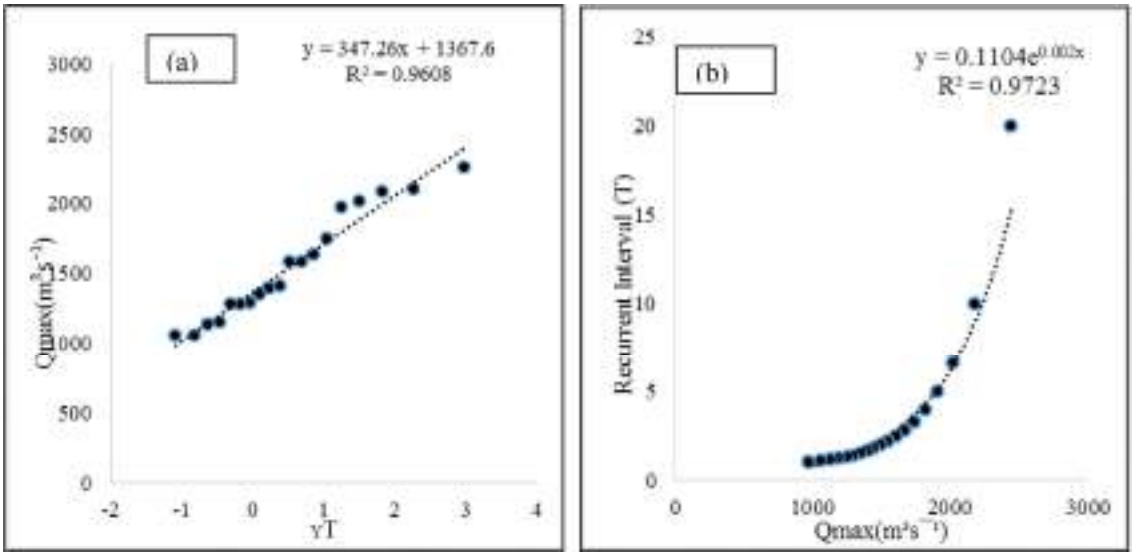

Figure 7. a: Relationship between Peak Discharge and Reduced Variate (yT) b. The Return Period

Table 4: Year-wise Calculation of Probable Peak Discharge by using Gumbel's Method of the Ramganga River.

Year	Peak Discharge(m³/s)	rank	T	yT	k	xT	p
2000	2258	1	20.00	2.97	2.32	2439.28	5
2005	2104	2	10.00	2.25	1.64	2177.65	10
2008	2087	3	6.67	1.82	1.23	2020.12	15
2010	2018	4	5.00	1.50	0.93	1904.89	20
1998	1980	5	4.00	1.25	0.69	1812.56	25
2014	1747	6	3.33	1.03	0.48	1734.42	30
2004	1642	7	2.86	0.84	0.30	1665.81	35
2016	1590	8	2.50	0.67	0.14	1603.87	40
2006	1583	9	2.22	0.51	-0.01	1546.70	45
2015	1416	10	2.00	0.37	-0.15	1492.93	50
1999	1394	11	1.82	0.23	-0.28	1441.50	55
2001	1353	12	1.67	0.09	-0.41	1391.49	60
2002	1294	13	1.54	-0.05	-0.54	1342.05	65
2009	1282	14	1.43	-0.19	-0.67	1292.25	70
2003	1280	15	1.33	-0.33	-0.80	1241.00	75
2007	1151	16	1.25	-0.48	-0.94	1186.75	80
2013	1138	17	1.18	-0.64	-1.10	1126.98	85
2011	1057	18	1.11	-0.83	-1.28	1056.58	90
2012	1055	19	1.05	-1.10	-1.53	960.93	95

Source: Calculated by Researchers

Table 5: Calculation of Probable Peak Discharge by using Gumbel's Method of the Ramganga River at Dandi, Badaun District, UP

Recurrent Interval	K	Peak Discharge(m^3/s)
5	0.929	1905.785
10	1.641	2179.429
15	2.042	2333.623
20	2.324	2441.927
25	2.774	2615.030
50	3.065	2727.024
75	3.595	2930.413
100	3.870	3036.181
150	3.991	3082.869
200	4.113	3129.612
500	5.085	3503.374
1000	6.058	3877.098

Source: Calculated by Researchers

Table 6: Calculation of Probable Peak Discharge by using Log Pearson-III Method of the Ramganga River.

Recurrent Interval	K	yT	xT
5	0.83	3.265792	1844.132
10	1.301	3.315832	2069.339
15	1.4733	3.334137	2158.425
20	1.6457	3.352453	2251.401
25	1.818	3.370758	2348.325
50	2.159	3.406986	2552.621
75	2.3155	3.423613	2652.241
100	2.472	3.44024	2755.75
150	2.54475	3.447969	2805.232
200	2.763	3.471156	2959.074
500	2.9944	3.49574	3131.411
1000	3.38	3.536707	3441.174

Source: Calculated by Researchers

2179.339 m^3/s by Gumbel's method (Table 4 and 5); 1844.132 m^3/s to 2069.339 m^3/s for Log Pearson-III (Table 6); and 2258 m^3/s to 2104 m^3/s by Weibull's method (Table 7). The peak discharge for 50 to 100 years recurrent interval is estimated 2727.024 m^3/s to 3036.181 m^3/s by

Table 7: Probability of Peak Discharge at Dandi, Badaun District, UP (based on Weibull's Method)

Year	Peak Discharge (m^3/s)	rank	T=n+1/rank	P
2000	2258	1	20.00	5
2005	2104	2	10.00	10
2008	2087	3	6.67	15
2010	2018	4	5.00	20
1998	1980	5	4.00	25
2014	1747	6	3.33	30
2004	1642	7	2.86	35
2016	1590	8	2.50	40
2006	1583	9	2.22	45
2015	1416	10	2.00	50
1999	1394	11	1.82	55
2001	1353	12	1.67	60
2002	1294	13	1.54	65
2009	1282	14	1.43	70
2003	1280	15	1.33	75
2007	1151	16	1.25	80
2013	1138	17	1.18	85
2011	1057	18	1.11	90
2012	1055	19	1.05	95

Source: Calculated by Researchers

Table 8: Goodness of fit Summary for selected Probability Distributions fitted to Ramganga River. Annual Peak Discharge Data (Qmax) (n = 19)

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumbel	0.13844	2	0.39759	2	0.74169	2
Log-Pearson III	0.13063	1	0.34995	1	0.89851	3
Weibull	0.15672	3	0.64771	3	0.4719	1

Source: Calculated by Researcher

Gumbel's method and 2552.621 and 2755.75 m^3/s by Log-Pearson-III method. For 500 and 100 years flood recurrent interval it ranges from 3503.374 m^3/s to 3877.098 by Gumbel's method. On the other hand, it varied from 3131.411 m^3/s to 3441.174 m^3/s by Log Pearson-III method.

The results of all tests of Goodness of Fit (GOF) are given in Table 8. It depicts that among the three methods of FFA, Log Pearson III type method ranked 1st for Kolmogorov Smirnov, Andersson Darling test. The same test provides rank 3 for Weibull's method. All of the three tests gave the second rank to Gumbel's method.

Conclusion

The hydrological characteristics of the Ramganga River are largely governed by the monsoon climate. The fluvial regime of Ramganga shows a remarkable variation in the monsoon period but in spring and winter seasons no such notable variation in the water discharge. For predicting, the temporal trend of monsoon discharge, Mann-Kendal statistical test has been applied. The result shows the monsoon discharge is experienced with a decreasing trend, on the other hand, the spring and winter discharge depict increasing trend. The variability of monsoon and river regulation by the man largely determined the annual flow pattern. For flood frequency analysis, annual peak discharge data has been used. To observe the chance of peak discharge of certain magnitude of flood for Ramganga river EV-I (Gumbel's method), EV-III (Weibull's method) as well as Log Pearson III distribution has been attempted. For testing of the goodness of fit for various methods of FFA, Kolmogorov Smirnov, Anderson Darling, Chi-Squared statistical tests have been applied. The first two tests ranged from 1 to Log Pearson III method while all three tests ranked two for EV-I (Gumbel's method). For 10-50 years of the recurrent interval of the flood, the peak discharge ranged from 2069.399 m^3/s to 2252.621 m^3/s for Log Pearson III whereas for 100 years, it estimated as 2755.75 m^3/s. For Gumbel's method, the recurrent interval of peak discharge shows quite a similar result. By applying the Gumbel's method, the recurrent interval for 10 to 50 years has been estimated as 2179.429 m^3/s to 2727.024 m^3/s. For 100 years it depicts 3036.181 m^3/s peak discharges.

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