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Flood Frequency Analysis in Sabarmati River basin and Estimation of Peak Discharge under Climate Change Scenario

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***Abstract:** Due to climate change, there is an increased/decreased frequency of peak flood discharge in river and streams. The most important concern of planning is to safe passing of the extreme flood discharge influenced by extreme climatic changes. It is a concern for planning for the storage capacity to safely store extreme discharge/inflow of the river. In this paper, probability theories and statistics for flood frequency factor (K) are applied and based on the results; it is found that the Extreme value model results in to a best model for frequency factor K, as it is yielding the minimum relative error. Using the frequency factor, the flood frequency analysis for peak flood is carried out for climate change scenario/Advance scenario. The peak discharge in advance scenario is more as compare to the base line scenario at most of the stations except three stations located on the south-east of the Sabarmati river basin.*

***Key word** - Climate change, Peak flood, Frequency factor, Gumbel's distribution*

I. INTRODUCTION

'Climate Change' is the supreme expressed environmental term to refer the change in modern climate brought fundamentally by human being actions [1]. On of the most affected threat of human beiging demonstrated via extreme event occuring due to climate change, as draught and flood occuring due to extreme rainfall [2]. Climate change is the major factor increasing the risk of extreme hydrological event [3]. Floods are disastrous among all the natural disasters may be experienced global that cause loss of properties, lives, health, and wealth etc. The occurrence of flash flood increases due to urbanization in the worldwide [4]. High climatic variability, driving the flood events in the urbanized area, the statistical modeling has become important to widely apply to estimate the magnitude of floods corresponding to a specified risk. Statistical modeling framework for determining the magnitude of floods corresponding to specific risk is necessary to establish due to high climate variability [5]. Many researches [6-9] conclude that climate change and human activities are responsible for change in flood pattern. Baker and Miller and Kim [10-11] conclude that change in land use pattern causes the runoff to change either increment or decrement.

In India there is no significant change in winter runoff while monsoon and annual runoff in central plain of the subcontinent increases [12].

Understanding of magnitude and nature of the high discharge in a river, flood frequency analysis is one the most essential statistic practice applied through probability distribution [13]. The results will be useful for planning and designing of the hydraulic structure, flood protection schemes, assessment of regions at risk of flooding, and the proper management of flooded region [5]. It is required to estimate peak flood magnitude for a specific return period [14]. To assess the flood defense capacities and to protect livelihood and other properties within the watershed, statistical approach that estimates flood quantities, the probability model to determine the design flood or peak flood [15] should be applied.

II. METHODOLOGY

A. Gumbel's Distribution

Gumbel distribution is a statistical method, frequently used for predicting extreme hydrological events such as floods [16]. In this study, it is applied for flood frequency analysis because peak flow data having a long record (year 1981-2016) are available and it is homogeneous and independent. For many engineering purposes, analysis of flood frequency is essential in order to check the rate of exceeded discharge, so that the protective attempts can be made [3]. Applicability of this method to the study of floods has been widely recognized by numerous researchers in the field [3, 17-18]. Yet many other lean to criticize them on insufficient records, ignorance of the statistical laws, inhomogeneity of records and climatological changes over long periods [19]. The Gumbel distribution as cumulative distribution function (cdf) following as a is given expression [20]

$$F(x) = \exp[-\exp(-y)] = e^{-e^{-y}} \quad (1)$$

Where, F(x) is the probability distribution function of variable 'x'. Also, y is a reduced variable. The return period (T) is correlated with the probability of exceedance. The probability of exceedance of the excluded events is presented by:

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$$F_1(x) = 1 - F(x) = \frac{1}{T} = 1- e^{-e^{-y}} \quad (2)$$

e = base of natural logarithms
y= a reduced variate at n sample
The equation of the Gumbel distribution to analyzed series of flood flows at different return periods T is

$$x_T = \bar{x} + K\sigma_{n-1} \quad (3)$$

$\bar{x}$ = Mean of the variate X
σ_{n-1}= Standard deviation of the sample size n
K= frequency factor expressed as, K= $\frac{y_T - y_n}{S_n}$
y_T = reduced variate as a function of time T and it given by

$$y_T = -\left[ln.\, ln \frac{T}{T-1}\right] \quad (4)$$

y_n, σ_n = Mean and standard deviations of reduce extremes from Gumbel's table.
Mean and standard deviation of reduce extremes as per the Gumbel's table for some value of n (sample size) shows in Table 1.
Table 1: Gumbel's reduced mean variable and standard deviation based on data number (Subramanya, 2008) [21]

n	y_n	σ_n	n	y_n	σ_n
9	0.4902	0.9288	20	0.5236	1.0628
10	0.4952	0.9497	21	0.5252	1.0696
11	0.4996	0.9676	22	0.5268	1.0754
12	0.5035	0.9833	23	0.5283	1.0811
13	0.5070	0.9972	24	0.5296	1.0864
14	0.5100	1.0095	25	0.5309	1.0915
15	0.128	1.0206	26	0.5320	1.0961
16	0.5157	1.0316	27	0.5332	1.1004
17	0.5181	1.0411	28	0.5343	1.1047
18	0.5202	1.0493	29	0.5353	1.1086
19	0.5220	1.0566	30	0.5362	1.1124

B. Extreme Value distribution

The stochastic performance of extreme event is simplified by means of extreme value theory [22]. Gumbel (1941) publicize the Extreme Value distribution (EV) to flood frequency analysis[20]. The probability of the future extreme flow event predicted by fitting the historical observation of the selected probability distribution to find the magnitude of extreme events with their frequency of occurrence [23]. This method of prediction of the extreme value has been used when the data available from catchment is too short or it is not representing the present condition due to change in urbanization or other reason [18]. In this y_n and σ_n (expected mean and standard deviations of reduced extremes) is taken as a 0.557 and 1.2811 respectively. The Extreme Value (EV) distribution is extensively used in various arenas together with hydrology for modeling extreme events [24].

C. Regression equation

Prediction of flood frequency factor using Regression Equations derived from expected mean and standard deviations of reduced extremes in Gumbel's table (Table 1). To determine the frequency factor, using regression equation, the return period and number of the years of record are the strongest inflential factor. In the present study, the regression equations derived by Onen and Bagatur [25] for Gumbel distribution is used and it is shown as following:

$$y_n = 0.5775 * n^{\left(\frac{-0.66}{n}\right)} \quad (5)$$

$$\sigma_n = 1.2811 * n^{\left(\frac{-1.268}{n}\right)} \quad (6)$$

D. Powell's modification of Gumbel's method

This method had been modified in such a manner that one can obtain the frequency factor without using the Gumbel's table (Table 1). As shown in Equation 7, Frequency factor K is obtained using Powell's modification method.

$$K = -\left[\frac{6^{\frac{1}{2}}\left(0.5772 + \ln \ln\left(\frac{T}{T-1}\right)\right)}{\pi}\right] \quad (7)$$

The coefficient of variation determined for a given value of recurrence interval for a given data using equation 7[19].
The results obtained from the Powell's method are compared with the simplified version of the Gumbel's statistic.
In the present study, the frequency factor is computed using all of these four methods shown as above at station Kabola. The peak flow values were predicted using equation (3) of the Gumbel's distribution for different recurrence interval of data values of Kabola station using frequency factor obtained from all of the methods shown above.
The relative error is carried out to find the goodness of fit between the predicted and measured flows for the frequency factor using above methods. The method for which the best results are obtained from goodness of fit test is used further for computing the predicted peak flows for 0.5, 0.2, 0.1, 0.05, 0.04, 0.02, 0.01 and 0.005 exceedance probabilities for base line scenarion and climate change/advance scenario at all 16 stations located in a Sabarmati river basin.

III. STUDY AREA AND DATA COLLECTION

Sabarmati River is one of the major west flowing and water scarce rivers of India which is extends over the states of Gujarat and Rajasthan having an area of 21,674 Sq. km originates from the Aravalli hills in Udaipur district of Rajasthan at 1133 m from the mean sea level. It lies between 70°58'E to 73°51'E and 22°15'N to 24°47'N. Figure 1 shows the index map of India along with the Sabarmati basin with all river gauge station.

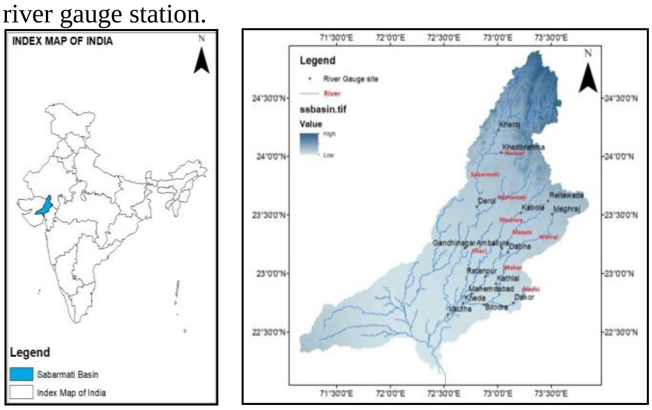

Figure 1: Index map of India and river gauging station situated in Sabarmati river basin and different tributary located in Sabarmati Basin

Rainfall occurs in the monsoon season (June-October) in Sabarmati river basin contributes almost 91-94% of annual rainfall. So, in the present study, the monsoon months data are only considered to find peak discharge

Peak discharge carried in the river under two scenario, i.e. base line scenario and advance scenario. Base line scenario is considered as a upper half of the data series and later half data series is considered as an advance scenario. Consecutive hourly discharge data has been collected from State water data center (SWDC) and daily discharge data are collected from the Central water commission (CWC). These stations were chosen as the database having a good quality of datasets, sufficient data length up to 2016 fro 1981 onwards of data records. There are 16 stations from which the data are collected, which are shown in Fig. 1.

IV. RESULT

Four methods, Gumbel's Distribution method, extreme value distribution method, Regression equation, Powell's modification to Gumbel's distribution method are used in the present study to compute frequency factor K of the Gumbel's distribution. The K value obtained from the best method is used to predict the peak discharge for the recurrence interval at all the stations in a Sabarmati river basin.

1. Table 2 shows the part of the results of the relative error for goodness of fit test between observed values and predicted values of the peak discharge at station Kabola using the freuency factor K, which is computed from the four method explained in the methodology. From Table 2, it is observed that the Extreme value gives lowest value of 8.23 as a relative error. So, the extreme value method is further used to compute the predicted peak flow.
2. Results are shown for peak discharge using regression equation method for various probabilities of exceedence for base scenario and advance scenario at different stations in Sabarmati river in Table 3.
3. From Table 3, it is observed that the more value of the peak discharge is obtained in advance scenario in comaprison to the the base line scenario at all station except three stations Kathlal, Dakor, and Bilodra located on south-east of the sabarmati river basin.

Flood magnitudes for 0.5, 0.2, 0.1, 0.05, 0.04, 0.02, 0.01 and 0.005 exceedance probabilities for base line scenarion and climate change/advance scenario at all 16 stations located in a Sabarmati river basin.

Table 2: Relative errors of prediction Models for peak discharges

		Relative error = $\left(\frac{\text{Observed data} - \text{Calculated data}}{\text{Obseved data}}\right)$			
m	T= $\frac{n}{m}$	Gumbel's	Extreme	Regression equation	Powell's
A. 1	B. 34	C. -0.08	D. 0.02	E. -0.09	F. -0.33
2	17	0.09	0.16	0.08	-0.15
3	11.3	0.09	0.16	0.09	-0.16
4	8.5	0.16	0.23	0.16	-0.08
5	6.8	0.07	0.14	0.06	-0.21
6	5.67	0.13	0.19	0.13	-0.14
7	4.86	0.08	0.14	0.08	-0.22
8	4.25	-0.1	-0.03	-0.1	-0.47
9	3.78	-0.06	0.01	-0.06	-0.43
10	3.4	0	0.05	0	-0.38
11	3.09	0.01	0.06	0.01	-0.38
12	2.83	-0.23	-0.18	-0.24	-0.74
13	2.62	-0.25	-0.2	-0.25	-0.78
14	2.43	-0.21	-0.17	-0.21	-0.75
15	2.27	-0.25	-0.22	-0.25	-0.85
16	2.13	-0.18	-0.16	-0.18	-0.77
17	2	-0.28	-0.26	-0.28	-0.95
18	1.89	-0.22	-0.21	-0.22	-0.9
19	1.79	-0.13	-0.14	-0.13	-0.81
20	1.7	-0.12	-0.14	-0.12	-0.84
21	1.62	-0.04	-0.07	-0.04	-0.76
22	1.55	0.06	0.01	0.06	-0.66
23	1.48	-0.09	-0.17	-0.09	-1.01
24	1.42	0.02	-0.08	0.02	-0.92
25	1.36	0.16	0.04	0.16	-0.77
26	1.31	0.04	-0.16	0.04	-1.24
27	1.26	0.2	-0.04	0.21	-1.15
28	1.21	0.41	0.11	0.42	-1.04
29	1.17	0.55	0	0.56	-1.73
30	1.13	1.11	0.43	1.12	-1.32
31	1.1	2.51	1.06	2.54	-1.92
32	1.06	4.36	2.58	4.39	-0.21
33	1.03	7.38	5.1	7.42	2.69
34	1	-	-	-	-
Total error		15.19	8.23	15.33	-20.37

V.CONCLUSION

1. The results shows that the minimum relative error between observed value and predicted value of peak discharge is obtained by incorporating the frequency factor K computed using Extreme value method. Thus, EV method make it an attractive option for approximating quantiles for future prediction of extreme event. The highest value of relative error between observed and predicted peak flow is obtained through computing frequency factor K by Powell's method. Thus, Powell's method unfailingly gives inferior results than other method for frequency factor K.
2. It is concluded from Table 2 that the Gumbel's method for peak flow estimation gives the good result after Extreme value method.
3. In the Extreme value method, the necessity of the Gumbel's table is eliminated. Thus it is also resulting in to the practical way of estimating the flood frequency factor.
4. The effective model (Extreme value) takes into consideration only the value of n (total of number of data set) and T (recurrence interval for which the peak discharge value is computed) as the two parameters for discharge prediction.
5. Peak flood discharge is more in advance scenario with changing climate over the basin except three stations located on the south-east of the sabarmati river basin. This shows the impact of climate change on the peak discharge value at various rivergauging stations in the sabarmati river basin.

Table 4: Peak discharge at different recurrence interval in Sabarmati Basin

Station	Return Period	Peak Discharge(m^3/s) Base Scenario	Advance scenario	Station	Return Period	Peak Discharge(m^3/s) Base Scenario	Advance scenario
Ambaliyara	2	272.89	321.26	Kabola	2	284.63	200.88
	10	978.75	1143.07		10	691.03	667.33
	50	1597.61	1863.59		50	1047.34	1076.29
	100	1859.22	2168.19		100	1197.97	1249.18
	200	2119.90	2471.69		200	1348.06	1421.44
	500	2463.80	2872.08		500	1546.06	1648.70
Bilodra	2	633.53	407.58	Khedbrahma	2	666.47	682.72
	10	1973.59	1135.83		10	2487.80	2533.84
	50	3148.47	1774.31		50	4084.62	4156.79
	100	3645.14	2044.23		100	4759.67	4842.88
	200	4140.03	2313.17		200	5432.29	5526.51
	500	4792.91	2667.98		500	6319.66	6428.39
Dabha	2	556.54	496.25	Mahemdabad	2	641.46	667.39
	10	1664.92	1768.84		10	1923.28	2085.90
	50	2636.68	2884.56		50	3047.11	3329.56
	100	3047.48	3356.23		100	3522.19	3855.30
	200	3456.81	3826.20		200	3995.58	4379.17
	500	3996.82	4446.22		500	4620.09	5070.27
Dakor	2	185.69	152.22	Megharaj	2	382.67	386.24
	10	522.33	462.03		10	1290.41	1301.86
	50	817.47	733.65		50	2086.27	2104.62
	100	942.24	848.47		100	2422.71	2443.98
	200	1066.56	962.89		200	2757.94	2782.13
	500	1230.57	1113.83		500	3200.20	3228.22
Kathalal	2	340.34	239.84	Rellawada	2	59.35	152.11
	10	858.26	697.93		10	363.38	444.40
	50	1312.33	1099.55		50	629.93	700.66
	100	1504.29	1269.34		100	742.61	808.99
	200	1695.56	1438.51		200	854.88	916.93
	500	1947.89	1661.70		500	1003.01	1059.34
Gnadhinagar	2	1104.75	1111.97	Derol	2	508.96	669.55
	10	3659.42	4153.48		10	2306.20	2658.35
	50	5899.20	6820.09		50	3881.92	4402.01
	100	6846.05	7947.37		100	4548.04	5139.13
	200	7789.51	9070.62		200	5211.78	5873.60
	500	9034.16	10552.47		500	6087.41	6842.56
Kheda	2	668.08	823.41	Ratanpur	2	341.54	445.92
	10	2097.33	3443.26		10	1344.70	2401.97
	50	3350.41	5740.19		50	2224.20	4116.91
	100	3880.14	6711.19		100	2596.01	4841.89
	200	4407.97	7678.72		200	2966.48	5564.28
	500	5104.32	8955.13		500	3455.22	6517.28
Kheroj	2	386.23	817.97	Vautha	2	1218.27	1449.18
	10	1349.06	5038.56		10	3735.62	3169.33
	50	2193.22	8738.91		50	5942.69	4677.45
	100	2550.07	10303.20		100	6875.71	5314.99
	200	2905.66	11861.89		200	7805.38	5950.26
	500	3374.76	13918.19		500	9031.86	6788.33

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