Regional Flood Frequency Analysis of River Chambal – A Case Study

REWA BOCHARE[1], MITIKA FARKYA[2]
[1] Assistant Professor, Prestige Institute of Engineering, Management & Research, Indore
[2] Assistant Engineer, Madhya Pradesh Rural Engineering Services

Abstract- Erratic Climate changes all over the world have been a roaring concern in the past decade. Irrational floods are a natural disaster whose frequency as well as intensity, appears to have increased in recent years. This study aims at determining peak floods for different return periods on river Chambal. The frequency analysis was performed on 36 years of usable flood record. The Goodness of fit test was done for all distribution using D-Index test. These computed peak discharge is not only useful for assessing the flood frequency analysis in flood forecasting management but also is a potential tool for designing important hydraulic structures like Concrete Gravity Dam, Weir, Barrage, Bridge across the river, Guide bank etc.

Indexed Terms- climate change, flood, frequency, return period, peak, goodness of fit, forecasting

I. INTRODUCTION

Since ancient times, man is building hydraulic structures for different purposes. In the modern age, the design of any water project consists of the following consequent steps: Hydrologic design, hydraulic design and structural design. Among these steps, hydrologic design has very important role because any mistake made at this point will result in the failure of design no matter how correct the other steps are carried out.

Hydrologists are dealing with nature. Hydrologic events appear as uncertainties of nature. Since there are numerous sources of uncertainty about the physical processes that give rise to observed events, a statistical approach is often desirable. For instance, it is not possible to predict stream flow and precipitation on a purely deterministic way in either the past or future since it is impossible to know all their casual mechanisms quantitatively. Fortunately, methods of statistical analysis provide ways to reduce and summarize observed data, to present information in precise and meaningful form, to determine the underlying characteristics of the observed phenomena and to make predictions concerning future behavior. In other words, statistical methods acknowledge the existence of the uncertainty and enable its effects to be quantified. Frequency analysis, being a statistical method, is the estimation of how often a specified event will occur. The goal of frequency analysis is to obtain a useful estimate of the quantile X_T for return period of T where X is magnitude of the event that occurs at a given time at a given site. An estimate should not only be close to the true quantile but should also come with an assessment of how accurate it likely to be.

Flood frequency analysis has a significant role in social and economic assessment of water resources projects. The beneficial effects of frequency analysis may be stated as it helps to estimate the magnitudes of the extreme events that will occur in the future and thus will create a reasonable design criterion for the water resources projects. A frequency analysis is an efficient tool in design via forecasting which reduces the cost of projects by determining the values of extreme events in a rational way.

Frequency analysis is an information problem. If the length of the available data increases, the shape of the frequency distributions is determined more precisely and accurately. If an adequately long record of flood flows or rainfall is available then a frequency distribution for a site could be correctly calculated, so long as the relationships of concern are not changed externally, like change in the vegetal cover in the region or building a hydraulic structure on the river. Such changes may affect the relationships between the hydrologic elements like rainfall-runoff.

Flood series at an individual site are seldom long enough to accurately estimate flood quantiles for return periods of interest. In other cases, flood data are unavailable at the site of interest, making at-site flood frequency analysis impossible. Regional flood frequency techniques which employ data from nearby sites have thus been developed to overcome the lack of flood data at a particular location.

II. METHODOLOGY

2.1 FLOOD DREQUENCY ANALYSIS

One of the major problem in faced in hydrology is the estimation of design flood from fairly short data. If the length of data is more, then the same data can be used to estimate the design flood, but the length of data generally available is very less. So the sample data is used to fit frequency distribution, which in turn is used to extrapolate from the recorded event to design the event either graphically or estimating the parameter of frequency distribution. The following continuous distributions are used to fit the annual peak discharge series.

2.2 Gumbel's Distribution

Gumbel distribution is a statistical method often used for predicting extreme hydrological events such as floods. In this study it has been applied for flood frequency analysis because peak flow data are homogeneous and independent hence lack long-term trends; the river is less regulated, hence is not significantly affected by reservoir operations, diversions or urbanization; and flow data cover a relatively long record and is of good quality. The equation for fitting the Gumbel distribution to observed series of flood flows at different return periods 'T' is

$X_T = \bar{X} + k\sigma$

Where, X_T denotes the magnitude of the T- year flood event, K is the frequency factor; X and σ_{n-1} are the mean and the standard deviation of the maximum instantaneous flows respectively.

The reduced variate is expressed as,

$Y_T = -[\ln \ln (T/(T-1))]$

The frequency factor expresses as,

$K = ([Y_T - Y_n])/S_n$

Where Y_n is Reduced Mean and S_n is Reduced Standard Deviation.

2.3 LOG PEARSON TYPE III DISTRIBUTION

The log-Pearson Type III distribution is a statistical technique for fitting frequency distribution data to predict the design flood for a river at some site. Once the statistical information is calculated for the river site, a frequency distribution can be constructed. The probabilities of floods of various sizes can be extracted from the curve.

The probability density function (PDF) for the distribution is given as

$X_T = X - K\sigma_{n-1}$

Here $K = f(C_S, T)$

C_S = coefficient of skewness

T = return period

2.4 LOG NORMAL DISTRIBUTION

When C_S (skewness) = 0 then log pearson type III distribution reduced to log normal distribution. The log normal distribution plots as a straight line on a logarithm probability paper.

The probability density function (PDF) for the distribution is given as

$X_T = X - K\sigma_{n-1}$

Here $K = f(C_S, T)$

C_S = coefficient of skewness

T = return period

2.5 D-INDEX TEST FOR GOODNESS OF FIT

In order to compare the relative fit of distribution to hydrological data, D-INDEX method is used. From the studies carried out in NIH (National institute of hydrology) it has been found appropriate to use largest 6 observations and the corresponding values based on the fitted distribution in calculating the D-INDEX test. To carry out the D-Index test the following steps are followed for each distribution used in the analysis:

1. Select six peak discharge value.
2. Find corresponding probability of occurrence along with the return period. Various plotting position formulae have been recommended for assigning probability to a given set of flood peak data by different investigators.
3. Find reduced variable with corresponding return

period.

4. Find frequency factor (K) for corresponding return period for the 3 different distributions:

- Gumbel Distribution
- Log Normal Distribution
- Log Pearson Distribution

5. Compute the discharge for each corresponding frequency factor by the equation:
   Xcomp = X+ Kσ_{n-1}

6. The D-INDEX for comparison purpose for the fit of different distribution is given as:
7. D-INDEX = 1/X [ABS (Xi observed – Xi computed]
8. The distribution which gives minimum D-index is considered as best fit distribution.

III. STUDY AREA

For the purpose of the accomplishment of the Regional Flood Frequency Analysis, Chambal river basin is adopted as a case study. As a specific case study, the Gandhisagar Dam site is chosen. Malwa region is a geographic sub-division situated in the North West of Madhya Pradesh in India. It is situated between latitudes 22027'N and 2505'N and beween longitudes 74045'E and 77015 E. It encompasses districts of Dhar, Ratlam, Neemuch, Mandsaur, Ujjain, Indore, Shajapur, Dewas, Rajgarh and Sehore and admeasures an area of about 35,879 Sq.km. Main river system in the region is river Chambal and its tributaries, namely, Kalisindh Parbati Kshipra, Gambhir, Chawala, Siwana Choti Kalisindh; and river Mahi. Chambal is one of the important rivers of central India which not only famous for its geomorphic pattern as well as their historical significance, sculpture, hydrological and structural set-up. Chambal River origin is situated under the valley of the Manpur Reserve Forest, Janapav Kuti Village Madhya Pradesh, India. Chambal River shows different gradient in different areas. Chambal is Pollution free river. The Chambal River originates in the form of groundwater seepage from columnar joint of basaltic Malwa ridge. Chambal River basin is bounded by the Aravalli mountain ranges and the great Vindhyan hill ranges. The Chambal basin located between 22º27'N-73°20'E to 27º20'N-79°15'E and its rain fed catchment and drains a total area of 143,219 sq.km². This river is also characterized by undulating flood plains, gullies, forest, ravines and scrub land. Chambal River is bounded by Vindhyan range (West-East-South) and Aravallis range (NW).

The Gandhisagar dam already built on river Chambal is located near Gandhisagar colony of Bhanpura tehsil in Mandsaur district of M.P.

The climate of the project area is sub-humid. It has three seasons; the cold season from November to February, the summer season from March to mid-June and the south-west monsoon season from the mid-June to October. The temperature varies from maximum 42o C in May to minimum 9o C in January. The average annual rainfall in the project area varies from 800 mm to 1200 mm and it is in the medium rainfall zone.

IV. DATA ACQUISITION

The Upper Chambal sub-basin is formed in Malwa region due to construction of Gandhisagar hydel Project in 1960-61 which is the Northern most extremity of this sub-division. The project is at a distance of 260 km from the origin of river Chambal and has a catchment area of 22,745 Sq.km. The general data sets for the model formulations viz. the physical and hydrologic data that have been acquired from NWDA and the annual peak inflow values of 36 years (1975-2011) at Gandhisagar reservoir are look up in Table 1.

Table 1: Annual Peak Flood Values of Gandhisagar Reservoir

Year	Discharge (MCM)	Year	Discharge (MCM)
1975-76	5603	1993-94	3427
1976-77	5394	1994-95	3834
1977-78	7117	1995-96	5005
1978-79	6133	1996-97	5479
1979-80	4992	1997-98	4078
1980-81	3232	1998-	5040

		99	
1981-82	3403	1999-00	3534
1982-83	2417	2000-01	913
1983-84	3179	2001-02	1464
1984-85	3938	2002-03	481
1985-86	3979	2003-04	1698
1986-87	4515	2004-05	3812
1987-88	4302	2005-06	1702
1988-89	4000	2006-07	9730
1989-90	2575	2007-08	5632
1990-91	3284	2008-09	1189
1991-92	5098	2009-10	1447
1992-93	2944	2010-11	1128

V. RESULTS

With reference to the methodology described above, we obtained the following results upon analysis of the acquired data.

- The D-Index value was calculated for all the three distributions as described above. The results for these D-index values are given in Tables 2, 3 and 4 respectively.

Table 2: Calculation of D-Index for Gumbel distribution

Rank	Discharge	P	T =1/P	YT	K	X_{comp}	ABS (X_{obs} - X_{comp})	D=1/X̄* Col(9)
1	9730	0.015504	64.5	4.158863	3.197969	9913.019	183	1.191358
2	7117	0.043189	23.15385	3.120167	2.279826	8149.174	1032	
3	6133	0.070875	14.10938	2.610309	1.829142	7283.365	1150	
4	5632	0.09856	10.14607	2.265654	1.524488	6698.095	1065	
5	5603	0.126246	7.921053	2.002805	1.292146	6251.742	648	
6	5479	0.153931	6.496403	1.788835	1.10301	5888.392	409	
						∑ Col (9) =	4490	

Table 4: Calculation of D-Index for Log Normal distribution

Rank	Discharge	P	K	Mean +K *S.D	Xcomp	ABS(Xobs-Xcomp)	D=1/X̄* Col(8)
1	9730	0.0	2.1	9.4	12459	2729	2.837444
2	7117	0.0	1.6	9.1	9477	2360	
3	6133	0.0	1.4	9.0	8250	2117	
4	5632	0.1	1.2	8.8	7260	1628	
5	5603	0.1	1.1	8.8	6720	1117	

6	5479	0.1	1.0	8.7	6220	741	
					∑Col (8) =	10695.35	
Mean	8.073694						
S.D.	0.637175						

Table 5: Calculation of D-Index for Log Pearson Type III distribution

Rank	Discharge	P	K	Mean+ K* S.D	Xcomp	ABS(Xobs-Xcomp)	D=1/ X̄* Col(8)
1	9730	0.01	1.4	9.0	8154.2	1575.7	1.20871
2	7117	0.04	1.3	8.9	7373.4	256.8	
3	6133	0.07	1.2	8.8	6914.0	781.1	
4	5632	0.09	1.1	8.7	6505.6	873.4	
5	5603	0.12	1.0	8.7	6213.6	610.7	
6	5479	0.15	0.9	8.6	5936.5	457.9	
					∑Col (8) =	4556.063	
Mean	8.073694						
S.D.	0.637175						

from the D-index tables, it may be concluded the flow data for Chambal river follows Gumbel's distribution , the value of D-index for Gumbel's distribution is the lowest.

- the discharge values as calculated by analytical method is given below in table 6.

Table 6: Calculation of Discharge by Analytical Method

Discharge	Rank	P	T	T/T-1	YT	K	Xcomp
9730	1	0.015504	64.5	1.015748	4.158863	3.197969	9913.019
7117	2	0.043189	23.15385	1.045139	3.120167	2.279826	8149.174
6133	3	0.070875	14.10938	1.076281	2.610309	1.829142	7283.365
5632	4	0.09856	10.14607	1.109337	2.265654	1.524488	6698.095
5603	5	0.126246	7.921053	1.144487	2.002805	1.292146	6251.742
5479	6	0.153931	6.496403	1.181937	1.788835	1.10301	5888.392
5394	7	0.181617	5.506098	1.221922	1.607317	0.942559	5580.15
5098	8	0.209302	4.777778	1.264706	1.448853	0.802486	5311.056
5040	9	0.236988	4.219626	1.310595	1.307552	0.677585	5071.109
5005	10	0.264673	3.778243	1.35994	1.179474	0.564372	4853.615
4992	11	0.292359	3.420455	1.413146	1.061842	0.460393	4653.861
4515	12	0.320044	3.124567	1.470684	0.952624	0.36385	4468.393
4302	13	0.34773	2.875796	1.533107	0.850277	0.273382	4294.595
4078	14	0.375415	2.663717	1.601064	0.753602	0.187927	4130.426
4000	15	0.403101	2.480769	1.675325	0.661635	0.106634	3974.254
3979	16	0.430786	2.321337	1.756809	0.573589	0.028807	3824.741
3938	17	0.458472	2.181159	1.846626	0.488803	-0.04614	3680.763
3834	18	0.486157	2.056948	1.946121	0.406709	-0.11871	3541.356
3812	19	0.513843	1.946121	2.056948	0.326807	-0.18933	3405.671
3534	20	0.541528	1.846626	2.181159	0.248645	-0.25842	3272.942
3427	21	0.569214	1.756809	2.321337	0.171805	-0.32635	3142.457
3403	22	0.596899	1.675325	2.480769	0.095885	-0.39345	3013.534
3284	23	0.624585	1.601064	2.663717	0.020486	-0.4601	2885.497
3232	24	0.65227	1.533107	2.875796	-0.0548	-0.52665	2757.651
3179	25	0.679956	1.470684	3.124567	-0.13041	-0.59349	2629.255
2944	26	0.707641	1.413146	3.420455	-0.20683	-0.66104	2499.484
2575	27	0.735327	1.35994	3.778243	-0.2	-0.7298	2367.383

					8462		
2417	28	0.763012	1.310595	4.219626	-0.36447	-0.80038	2231.795
1702	29	0.790698	1.264706	4.777778	-0.44723	-0.87354	2091.25
1698	30	0.818383	1.221922	5.506098	-0.53407	-0.95029	1943.791
1464	31	0.846069	1.181937	6.496403	-0.62661	-1.03209	1786.648
1447	32	0.873754	1.144487	7.921053	-0.72732	-1.12112	1615.624
1189	33	0.90144	1.109337	10.14607	-0.84031	-1.22099	1423.749
1128	34	0.929125	1.076281	14.10938	-0.97337	-1.33861	1197.802
913	35	0.956811	1.045139	23.15385	-1.14491	-1.49024	906.4961
481	36	0.984496	1.015748	64.5	-1.42712	-1.73969	427.2735

- The basic parameters of flood record have been shown in Table 7.

Table 7: Basic Parameters for flood record

Parameters	Symbol	Values
Average	$\bar{X}$	3769
Standard Deviation	σ	1921.130347
Variance	σ 2	3690741.809
Coefficient of Skew	Cs	-1.1

CONCLUSION

The estimation for the best fitting distribution for Annual peak flood data amount has been the main interest in several studies. Various forms of distributions have been tested in order to find the best fitting distribution. Test for goodness of fit have been attempted in this study. The Gumbel's distribution curve has been identified as the best fitting distribution for flood data in Chambal River at Gandhisagar Dam. This study can be further extended for preparation of flood inundation map for various return periods. The study can be also applied in flood forecasting management. Based on the results obtained in the present study following major conclusions are derived:

- For any anticipated T, X_T can readily be estimated from the developed model as shown in the Figure 2 and corresponding equation has also been furnished there.
- However, the model will give reasonable estimate of X_T for any desired value of T, without any instrumentation and expensive and time consuming field work.
- Moreover, Peak Discharge (X_T) is a potential tool for designing important hydraulic structures like Concrete Gravity Dam, Weir, Barrage, Bridge across the river, Guide bank etc.

REFERENCES

[1] Zakaullah, U., Saeed, M. M., Ahmad, I., & Nabi, G. (2012). Flood frequency analysis of homogeneous regions of Jhelum River Basin. International Journal of Water Resources and Environmental Engineering, 4(5), 144-149.

[2] Mujiburrehman, K. (2013). Frequency Analysis of Flood Flow at Garudeshwar Station in Narmada River, Gujarat, India. *Universal Journal of Environmental Research & Technology*, *3*(6).

[3] Mukherjee, M. K. (2013). Flood frequency analysis of River Subernarekha, India, using Gumbel's extreme value distribution. *International Journal of Computational Engineering Research*, *3*(7), 12-19.

[4] Şahin, M. A. (2013). *Regional flood frequency analysis for Ceyhan Basin* (Doctoral dissertation,

M. Sc. Thesis, Middle East Technical University, Ankara).

[5] Ahn, J., Cho, W., Kim, T., Shin, H., & Heo, J. H. (2014). Flood frequency analysis for the annual peak flows simulated by an event-based rainfall-runoff model in an urban drainage basin. *Water*, *6*(12), 3841-3863.

[6] Ranjan, R. (2017). Flood disaster management. In *River System Analysis and Management* (pp. 371-417). Springer, Sin

[7] Liongson, L. Q., Tabios, G. Q., & Castro, P. P. (Eds.). (2000). *Pressures of urbanization: flood control and drainage in Metro Manila*. UP-CIDS