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Flood Risk Assessment of Guddu Barrage using Gumbel's Distribution

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Abstract: This paper presents the results of the study carried out on Indus River at Guddu barrage, to analysis flood frequency using Gumbel distribution for the prediction of next flood by using pervious data. The catastrophic flood of 1976,1986 and 2010 were the examples of heavy flood in the last 50 years .The Gumbel distribution has been applied to the annual records of 36 years flood peak discharge data .The trend line equation suggest a 0.983 coefficient of determination, which shows that there is no significant differences between recorded and predicted flood flows. At the area of study, information of preceding 18 flood's peaks of 36 years have been collected and analyzed for flood risk assessment. The forecast peak flows were obtained by proposed Gumbel's flood frequency and analytical method have been used for different return periods.

Keywords: Flood Frequency Analyses, Probability, Gumbel Distribution, Return Period, Guddu Barrage, Indus River

1. Introduction

Flood is a major natural catastrophe, defined as the flow discharge of water, which is relatively high and overflows the natural or manmade banks of the river. Pakistan being a South Asian country where global warming and monsoon rainfall are two major and regular features causes flood [8]. Floods in the Indus River and its tributaries have frequently affected the low laying and agricultural regions of the country. Floods of 1928, 1929, 1955, 1957, 1959, 1973, 1976, 1988, 1992, 1995, 1996, 1997and 2010 are the most severe incidents that resulted in the mass destruction of inhabitants' lives and their possessions. The floods have been recorded after the establishment of flood warning and forecasting mechanism, in year 1947 it is therefore crucial to gauge the flood risk in the flood-affected areas. Flood risks are predicted through the probability of event occurrence and the related consequences [1]. When the river capacity of carrying water has been stretched excessively, the channels of river become insufficient to accommodate the excess amount of water runoff due to heavy rainfall/snow melt which cause the banks of river to spill over and swamp the low-lying areas [9].

Other aspects are also involved in the cause of flood besides river overflow. These aspects may include the hydraulic structures that are of failure to accumulate colossal amount of water due to certain damage or leakage that cause the abrupt release of water enormously, resulted in huge destruction of human lives and their valuables. Once an estimate of peak discharge which occur at a particular site can be estimated, an ideal solution can then be proffer by a hydraulic Engineer [3].Hydraulic structure design requires an adoption of a specific flood discharge while considering the economic as well as hydrological factor, is termed as design flood. It is essential to choose a design flood, which is unlikely occur in the life of hydraulic structure and is designed in such a way that the difference between the estimated life of the structure and the return period of design flood should be relatively large. This is the reason to take long duration of return period related to hydraulic structure so that the risk of failure is reduced [7].Metrological and hydrological parameters are often used for flood risk analysis. However, the risk of flood is also estimated by GIS (geographical information system) technique [5, 8]. Recently a study has been conducted to estimate the flood risk along the River Indus in Pakistan by applying the suitable probabilistic distributions (i.e. Weibul distribution, Pearson type-3 analysis) to the flood peak values of observed data by which the associated return periods have been obtained of various dams in Pakistan [6].The results obtain from analysis provide an extensive information related to the anticipated flow discharge in the barrage at the several return periods according to the observations. This acknowledgement will be crucial for the

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purposes of engineering such as structure, designed, near or in the river that is probably at flood risk to ensure protection against the anticipated disaster [4]. The Gumbel distribution has been applied to the annual recorded flood peak discharge data of the Osse River located in the city of Benin for the span of 1989- 2008 [11]. Therefore, this effort also suggests the application of extreme value distribution (EV 1) called Gumbel Distribution for analyzing annual peak discharge data and predicting flood design for return period of 2yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs, 200yrs, and 400yrs.

Guddu barrage on the Indus River is situated in the province of Sindh, Pakistan. An attempt is being made to carry out flood frequency analysis of Guddu barrage by using its observed annual peak discharge data from 1977 -2012. Flood frequency analysis is defined as the applicability of probability distribution on the observation of annual recorded flood peak discharge over a given time period. Hence, flood frequency analysis provides guidance related to the behavior of anticipated flood flows using historical flow records .The Gumbel distribution is a statistical approach that is mostly used to predict the extreme events; here we have applied it for analyzing flood data. Flood frequency distributions may have many forms related to the equation used for obtaining the statistical analysis.

2. Methodology

2.1 *Area of Study:*

Guddu Barrage on the river Indus is located near Kashmore in the province of Sindh, Pakistan. Barrage is used for controlling flow of water in the Indus River for the purpose of irrigation and control of flood. The Barrage holds a discharge capacity of 1.2 million cubic feet per second. It is a gate-controlled weir type barrage with a navigation lock. The barrage has 64 bays, each 60 feet (18 m) wide. The maximum flood level height of Guddu Barrage is 26 feet (8m). The barrage was designed for storing water from the Indus River. Sources of the Indus River are rainwater and melted water from glacier through the Himalayas. High flow season is apparent in Kharif season (i.e. 6 months from April to September) due to snowmelt and heavy rainfall to the river runoff. Therefore, the annual peak flow (*Q*) has been recorded in the Kharif season for 36 years (1977-2012).

2.2. *Methods of Gumbel Distribution (Analytical and Frequency Factor)*

The statistical approach that is used to analyze the data related to extreme events such as flood, called the Gumbel distribution may be applied to predict flood event. In this section ,Gumbel formula[13]is used to determine the return period of high ,very high and extremely very high flood and compare them with given discharge capacity of river structure , whereas, for this purpose return period are assembled and ranked (in descending order). We compute the return period (*T*) by

$$T=(N+1)/m \qquad (1)$$

Where N is the numbers of annual flood peak discharge and m is termed to be rank of flood arranged in descending order. P stands for exceedance probability :

$$P=\frac{1}{T}\times 100 \qquad (2)$$

According to [8], Gumbel's distribution is often applied when:

a. Maximum upstream data are independent and homogenous.

b. Observed upstream data was more than 10 years.

c. The river is not as much of regulated i.e. not affected by human water demand such as basin diversion and urbanization.

According to Gumbel the probability of occurrence of flood event is expressed as [10]:

$$P(Q\geq q)=1-e^{-e^{-z}} \qquad (3)$$

Where z is another dimensional variable given as;

$$z=\alpha(Q-\beta) \qquad (4)$$

$$\alpha=\frac{1.28255}{S_y} \qquad (5)$$

$$\beta=\bar{Q}-0.45005S_Q \qquad (6)$$

, where S_Q=Standard deviation of Q

$$z=\frac{1.2825}{S_y}(Q-\bar{Q})+0.577 \qquad (7)$$

For any given data, the value of $\bar{Q}$ for a given probability (p) is required; therefore, Equation (3) is transpose as:

$$Y_p=-ln[-ln(1-p)] \qquad (8)$$

$$Y=-[ln(ln\frac{T}{T-1})] \qquad (9)$$

Also, Equation (2) will now become $Q_T$from Gumbel analytical method.

$$Q_T=\bar{Q}+0.45S_Q-(0.7797)S_Q.Z \qquad (10)$$

, where $Z=[-ln\left(ln\frac{T-1}{T}\right)]$ and Q_T is a value of peak discharge (Q) for a return period of T.

$$Q_T=\bar{Q}+K.S_Q \qquad (11)$$

$$K=\frac{Y-0.577}{1.2825} \qquad (12)$$

Where K is a frequency factor and can be written as:

$$K=\frac{Y-\bar{Y}_n}{\sigma_n} \qquad (13)$$

Equation (11) is solution of Q_T from frequency factor method.

Steps of Method:

The requirement for estimating the design flood return period applying Gumbel distribution [2] areas follow:

1. Assemble the data of annual peak flood from 1977-2012.
2. Compute mean $\bar{Q}$ and standard deviation S_y using maximum flood data of n years.
3. Use the maximum value for both reduced mean of $\bar{Y}_n$=*0.577* and reduced standard deviation of σ_n=1.2825.
4. The reduced variant Y is computed using equation (9) from the return period given as T
5. The frequency factor K is computed using equation (13) when Y, $\bar{Y}_n$ and σ_n are obtained.
6. The magnitude for flood is obtained using equation (11).

3. Results Presentation

3.1 *Flood Frequency Analysis*

The peak flood data of Guddu barrage for last 36 years have been used for flood frequency analysis. Theoretical flood frequency curves have been derived by using Gumbel methods. Hydrological data of the Guddu barrage is compiled and analyzed by the above mention and the results which obtained are talk about in subsequent paragraph. The data of maximum discharge measurement of Guddu barrage have been collected from the irrigation department of Sindh since 1977-2012 in ft^3/s .All data have been convert into m^3/s due to S.I units display in Table 1.

Table1: Annual Peak Discharges of Guddu barrage (1977-2012)

Years	Annual Peak(Q) (ft^3/s)	Annual Peak(Q) (m^3/s)	Years	Annual Peak(Q) (ft^3/s)	Annual Peak(Q) (m^3/s)
1977	471324.0	13346.40	1995	747058.0	21154.32
1978	605011.7	17132.02	1996	598719.5	16953.84
1979	304342.0	8618.00	1997	569195.26	16117.81
1980	373025.6	10562.90	1998	498987.4	14129.74
1981	403037.0	11412.73	1999	262681.0	7438.29
1982	228507.0	6470.59	2000	113141.0	3203.79
1983	321145.0	9093.81	2001	155662.0	4407.85
1984	453776.0	12849.50	2002	176532.6	4998.84
1985	308427.5	8733.69	2003	264116.3	7478.94
1986	962887.4	27265.93	2004	82941.0	2348.62
1987	167083.3	4731.27	2005	379289.7	10740.28
1988	866493.0	24536.34	2006	456534.0	12927.60
1989	779796.7	22081.38	2007	198619.2	5624.26
1990	441145.4	12491.84	2008	218926.0	6199.29
1991	454610.7	12873.14	2009	135545.0	3838.20
1992	551495.7	15616.61	2010	898557.0	25444.30
1993	487214.3	13796.37	2011	134305.0	3803.09
1994	544837.0	15428.06	2012	124039.0	3512.39

It is important to verify whether the Gumble's distribution can be applied to flood data or not. For achieving this, arrange the collected flood data in descending order and assign the number, which represent the rank as the return period to each value, compute reduced variants applying equation (9). Now plot the observed flood data and corresponding reduce variants and observe the behavior of graph. If the graph reveals straight-line pattern then it is the verification for the applicability proposed model (Fig. 1).

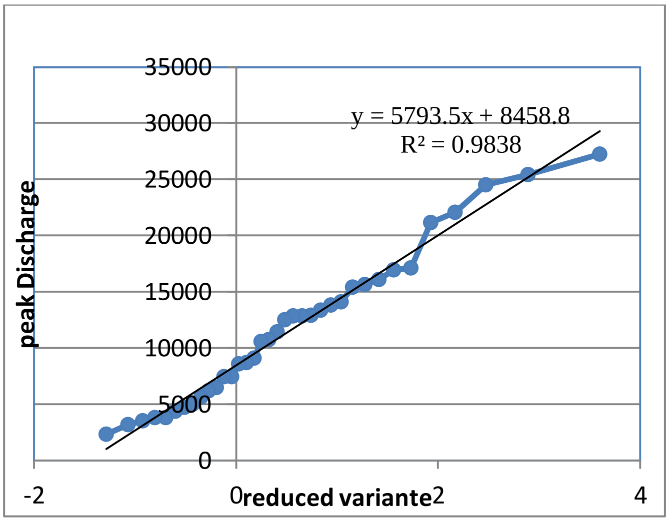

Fig. 1: Plot of Guddu Barrage Discharge.

3.2 Estimation of Return Period

Recorded peak flow data of 36 years has been arranged in descending order in Table 3 from column numbers 1-3. Return period (T) and probability (P) calculated from equation (1) and (2).

Following the methodology stated above, the parameters are obtained for analysis in Table 2, whereas, Table 3&4 represent two method of expected flood peaks according to corresponding return periods. Fig 2 depicted comparison between Gumbel analytical and Gumbel frequency factor method which shows that frequency factor method's results are superior over Gumbel analytical method.

Table 2: Return Period Computation method

Year of peak flood event	Peak in descending order (m^3/s)	Rank (m)	Return Period $T_r = \frac{n+1}{m}$	Probability (P in %)	Reduce variant $Y = -lnln\frac{T_r}{T_r - 1}$
1986	27266	1	37.00	2.70	3.60
2010	25444	2	18.50	5.41	2.89
1988	24536	3	12.33	8.11	2.47
1989	22081	4	9.25	10.81	2.17
1995	21154	5	7.40	13.51	1.93
1978	17132	6	6.17	16.21	1.73
1996	16954	7	5.29	18.90	1.56
1997	16118	8	4.63	21.60	1.41
1992	15617	9	4.11	24.33	1.28
1994	15428	10	3.70	27.03	1.15
1998	14130	11	3.36	29.76	1.04
1993	13796	12	3.08	32.47	0.94
1977	13346	13	2.85	35.09	0.84
2006	12928	14	2.64	37.88	0.74
1991	12873	15	2.47	40.49	0.65
1984	12850	16	2.31	43.29	0.57
1990	12492	17	2.18	45.87	0.49
1981	11413	18	2.06	48.54	0.41
2005	10740	19	1.95	51.28	0.33
1980	10563	20	1.85	54.05	0.25
1983	9094	21	1.76	56.82	0.18
1985	8734	22	1.68	59.52	0.10
1979	8618	23	1.61	62.11	0.03
2003	7479	24	1.54	64.94	-0.04
1999	7438	25	1.48	67.57	-0.12
1982	6471	26	1.42	70.42	-0.19
2008	6199	27	1.37	72.99	-0.27
2007	5624	28	1.32	75.76	-0.35
2002	4999	29	1.28	78.13	-0.43
1987	4731	30	1.23	81.30	-0.51
2001	4408	31	1.19	84.03	-0.60
2009	3838	32	1.16	86.21	-0.69
2011	3803	33	1.12	89.29	-0.80
2012	3512	34	1.09	91.74	-0.92
2000	3204	35	1.06	94.34	-1.07
2004	2349	36	1.03	97.09	-1.28

Table 3: Expected Flood Computation by Gumbel frequency factor method

Return Period (T) in years	probability (P in %)	Reduce variant $Y = -\ln(\ln\frac{T}{T-1})$	Frequency Factor $K = \frac{Y - \bar{Y}_n}{\sigma_n}$	Expected Peak Flood $Q_T = \bar{Q} + K.S_Q$
2	50	0.366513	-0.16412	10493.57
5	20	1.49994	0.719641	16415.95
10	10	2.250367	1.30477	20337.09
25	4	3.198534	2.044081	25291.47
50	2	3.901939	2.592545	28966.91
100	1	4.600149	3.136958	32615.20
200	1/2	5.295812	3.679386	36250.20
400	1/4	5.990213	4.220829	39878.59

Table 1

Mean=$\bar{Q}$ =11593.39 and S.D =S_Q= 6701.337

Table 4: Expected Flood Computation by Gumbel's analytical method

Return Period (T) in years	probability (P in %)	$Z = \ln(-\ln(\frac{T-1}{T}))$	Expected Peak Flood $Q_T = \bar{Q} + 0.45S_Q - (0.7797)S_Q.Z$
2	50	-0.36651	16524.03
5	20	-1.49994	22446.22
10	10	-2.25037	26367.22
25	4	-3.19853	31321.42
50	2	-3.90194	34996.73
100	1	-4.60015	38644.90
200	1/2	-5.29581	42279.76
400	1/4	-5.99021	45908.02

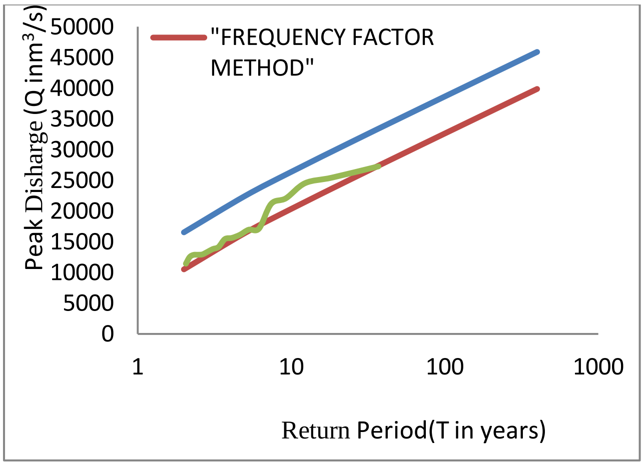

Fig. 2: Comparison between Gumbel frequency factor and analytical method

4. Conclusion

Flood frequency analysis of Guddu Barrage has been computed using annual peak discharge of 36 years, the behavior of observed data which verifies the applicability of Gumbel's distribution because the plot reveals the straight line pattern and suggests that applied distribution (Gumbel distribution) can explain a highly significant variation in the peak flow discharge (about 98.3%). Frequency factor method's results are superior over Gumbel analytical method. The expected peak flood for various years shows that the expected peak is likely to occur once in a corresponding year i.e. the peak of 20337.09 m^3/s is expected to occur once in 10 years. Thus we can say that Guddu barrage will be on the risk of very high flood against 10 years and will remain extremely very high risky against 200 and 400 years. The finding of this study suggests to increase the design capacity of dam and small reservoirs having different capacities to be constructed and stock up water can be used for agriculture, power energy generation and household purpose.

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Compliance with ethical standards

Conflict of interest No conflict of interest is confirmed

References:

1. BORBDA, (2005), "Benin Owena River Basin Development Authority Hydrological year Book", 1989 to 2008.
2. Chow, V. T., Maidment, D.R., Mays, L. W. (1988), "Applied Hydrology". McGraw Hill Book Company, Singapore
3. Han, C. T., (1977), "Statistical Methods in Hydrology",Iowa State University Press, Iowa.
4. Izinyon, O. C. and Igbinoba E., (2011), "Flood Frequency Analysis of Ikpoba River Catchment at Benin Cityusing Log Pearson Type III Distribution", (JETEAS) 2 (1): 50-55.
5. Khan, G., (2007), "Flood hazard assessment and mitigation along River Indus from Chashma Barrage to Sukkur Barrage using satellite image .*M.Phil thesis"*, Institute of Space and Planetary Astrophysics, University of Karachi.
6. Khan B., Iqbal M. J &Yousufzai M.A, (2011), " Flood Risk Assessment of River Indus of Pakistan",*Arabian Journal of Geosciences* 4(12):doi 10.1007/s12517-009-0110-9, 115-122.
7. Pegram, G and Parak, M. , (2004), "A review of the regional maximum flood and rational formula using geomorphological information and observed floods", Water SA 30 (3), 377-388.
8. Iqbal M.J. Baig M.J and Naz S., (2011), "Dominant Impact of South Asian Low Heat on Summer Monsoon Rainfall over Central India", Arabian Journal of Geoscience vol 6, no.6. DOI: 10.1007/s12517-011-0458-5.
9. Mujere, N., (2006), "Impact of River Flow Changes on Irrigation Agriculture", A case Study of Chimanimani District MPhil Thesis, University of Zimbabwe, Harare.
10. Nawaz, F., (2003),"Role of GIS and RS for flood hazard management in Pakistan: A case study of Jhelum,Pakistan",MAPAsia,(http://www.gisdevelopment.net/proceedings/mapasia/003/disaster/index.htm.
11. Reddy, J.A.,((2006), "A textbook on hydrology".Laxmi Publications, New Delhi India,.
12. Shaw, E.M.,(1983)., "Hydrology in Practice". Van Nostrand Reinhold, UK
13. Solomon Okonofua* and Ogbeifun Prince,(2013) " Flood Frequency Analysis of Osse River Using Gumbel's Distribution ", Civil aEnvironmental Research, vol.3,no.10.