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Frequency Analysis of Flood Flow at Garudeshwar Station in Narmada River, Gujarat, India

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Abstract:

This paper presents a frequency distribution study on maximum monthly flood data in Narmada River at Garudeshwar station using widely used frequency distributions for periods from 1949 to 1979. The Normal, Lognormal, Log pearson type III and Gumbell extreme value type I are proposed and tested together with their single distributions to identify the optimal model for maximum monthly flood analysis. The selected model will be determined based on the minimum error produced by some criteria of goodness of-fit (GOF) tests. The results indicated that Normal distribution is better than the other distributions in modeling maximum monthly flood magnitude at Garudeshwar station in Narmada River. Hence frequency curve at Garudeshwar station is derived using Normal distribution method. However these results can vary between the flow gauge stations which are strongly influenced by their geographical, topographical and climatic factors. The following study can be used by planning and designing engineers for deciding the dimension of hydraulic structures such as bridges, dams, canals ,levees , and spillways etc. This study can be further extended into preparation of flood forecasting techniques and flood inundation maps for Narmada River.

Keywords: Flood, Frequency distribution, Garudeshwar station, Narmada River, Normal distribution method.

1.0 Introduction

India has a large network of rivers which are spread out over the country. These rivers are great source of prosperity and energy if properly harnessed. River can be extrememly disastrous when it flows over it bank. Floods are natural hazards causing loss of life, injury, damage to agricultural lands, and major property losses (Fill & Stedinger, 1995). One method of decreasing flood damages and economic losses is to use flood frequency analysis for determining efficient designs of hydraulic structures. In hydrology, estimation of peak discharges for design purposes on catchments with only limited available data has been a continuing problem (Blazkovaa & Beven, 1997). A promising and elegant approach to this problem is the derived flood frequency curve. Reliable estimates of flow statistics such as mean annual flow and flood quantities are needed, however, historical data that are needed to estimate these statistics are not always available at the site of interest or available data may not be representative of the basin flow because of the changes in the watershed characteristics, such as urbanization (Pandey & Nguyen, 1999; Ouarda, *et al.* 2006). In practice, design floods often are estimated on the basis of a single site and/or regional flood-frequency analysis (Burn, 1990). An optimum design can be achieved with proper flood frequency and risk analyses (Saf, 2008). However design floods estimated by fitted distributions are prone to modelling and sampling errors (Alila & Mtiraoui, 2002). Several researchers have investigated different distributions for application to flood-frequency analysis (Cunnane, 1989; Grehys, 1996; Blazkova & Beven, 1997; Saf, 2008). The available historical hydrometric data especially in developing countries can be short, limited or non-existent (Fill and Stedinger, 1995) to the extent that it is far from being representative of the region under consideration, or getting it may be expensive, difficult, or time consuming (Oztekin *et al.* 2007; Patel, 2007). Most frequent uses of statistics in hydrology all over the world have been that of frequency analysis, which were largely in the area of flood flow estimation. Best probability distributions that can be used in various situations are based on certain properties of such distributions (Haan, 1994). Hydrologist finds it difficult to make accurate prediction of flood estimates using limited historic information of runoff, rainfall, river stages. (Adeboye and Alatise, 2007). The distributions suggested for fitting flood extremes data have been many (Singh & Strupczewski, 2002). (Oztekin *et al*. 2007) applied parameter estimation methods to a comprehensive list of different distributions. Different studies were undertaken on distribution selection for flood data all over the world. The three-parameter log-pearson type 3 distribution is the most frequently used distribution in the USA, whereas the generalized extreme value distribution in Great Britain, the lognormal distribution in China (Singh & Strupczewski, 2002). Several flood distributions have also been studied, for example in USA (Wallis, 1988; Vogel *et al.,* 1993); UK, Australia, Italy Scotland, Turkey and Kenya (Haktanir, 1991; Mutua, 1994; Abdul Karim & Chowdhury, 1995). There is no question that hydro-climatic regimes may be different for different regions, but the differences in regimes should serve as a hydro-physical basis for choosing a particular distribution. Therefore, selection of an appropriate distribution needs closer attention.

This paper tries to evaluate the magnitude of flood for various return periods. In this paper, focus will be given on two and three parameters distributions in order to find the best model in fitting maximum annual flood data. In order to verify the suitable distribution that best describes the maximum monthly flood, the goodness-of-fit tests (GOF) will be performed as given by (Zhang, 2002). The best fitting distribution will be used for further frequency analysis.

2.0 Materials and methods

2.1 Study area description

The Narmada also called the Rewa, is a river in central India and the fifth longest river in the Indian subcontinent. It is the third longest river that flows entirely within India, after the Godavari and the Krishna. It is also known as "Life Line of Madhya Pradesh" for its huge contribution to the state of Madhya Pradesh in many ways. The river travels a distance of 1,312 km before it falls into Gulf of Cambay in the Arabian Sea near Bharuch in Gujarat (NVDA, 1985). The Narmada River basin extends over an area of 98,796 sq. km and lies between longitudes 72° 32' E to 81° 45' E and latitudes 21° 20' N to 23° 45' N (Narmada basin, 2005). Most of the basin is at an elevation of less than 500 meters above mean sea level. A small area around Panchmarhi is at a height of more than 1,000 meters above mean sea level (HWRIS, Narmada basin). The location and its catchments have been shown in Figure I.

Figure I: Location of Narmada River (maps of India, 2103)

2.2 Stream Gauging Network:
Systematic observations of gauge and discharge were started in Narmada basin only in 1947 by the then Central waterways, irrigation and navigation commission. The main river Narmada is now gauged at nine sites at Manot, Mandla, Jamtara, Bermanghat, Hoshangabad, Mortakka, Mandleshwar, Barwani, and Garudeshwar, where daily gauge and discharge observations and hourly gauge observations during monsoon season from June to October are made (HWRIS, Narmada basin). The data has been collected with courtesy from Centre for Sustainability and Global Environment web site. The discharge site is Garudeshwar (21.92 N, 73.65 E) and has been shown in Figure II.

Figure II: Location of Flow gage at Garudeshwar station

3.0 Modeling maximum monthly flood flow at Garudeshwar station:

Models of maximum monthly flood amount are described with their probability density functions f(X) and cumulative distribution functions F(X). Note that X is the random variable representing the maximum monthly flood magnitude. The maximum monthly flood at Garudeshwar station has been shown in Figure III.

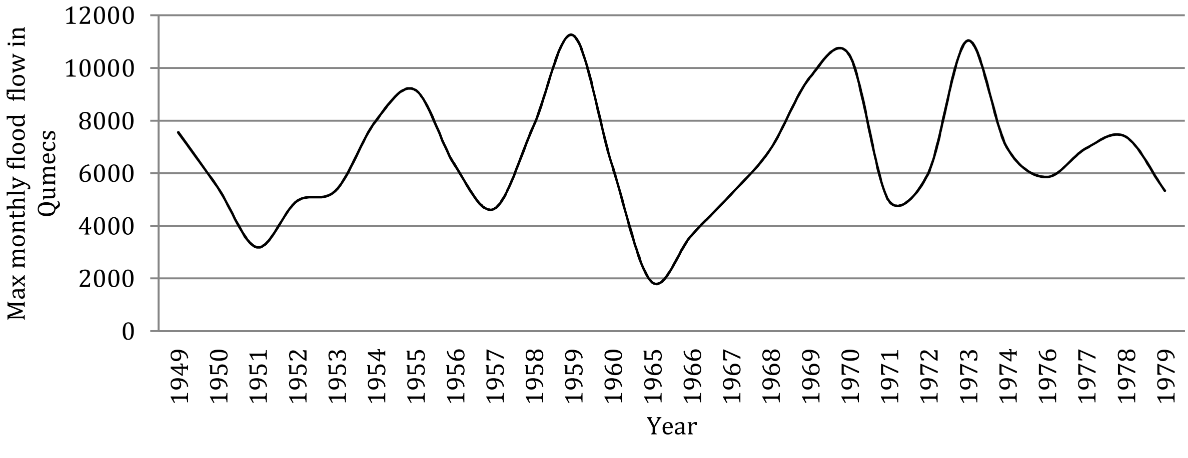

Figure III: Maximum Monthly flood at Garudeshwar station

The model distribution was chosen on the basis of their relative advantage for analysis of monthly flood magnitude data. The chosen distribution has been described in the Table I. The description of model can be found in any basis statistics books. The Table 1 shows the properties of selected distributions.

Table I: Probability Density functions for selected distributions (Chow, 1964)

SN	Distributions	f(X)	F(X)
1	Normal	$\frac{\exp(\frac{-1}{2}(\frac{x-\mu}{\sigma})^2}{\sigma\sqrt{2\pi}}$	$\emptyset(\frac{x-\mu}{\sigma})$
2	Lognormal	$\frac{\exp(\frac{-1}{2}(\frac{\ln(x)-\mu}{\sigma})^2}{x\sigma\sqrt{2\pi}}$	$\emptyset(\frac{\ln(x)-\mu}{\sigma})$
4	Gumbell	$\frac{1}{\sigma}\exp(-z-\exp(-z))$	exp (-exp(-z))
6	Log pearson Type III	$\frac{1}{xI\beta I\,\mathcal{T}(\alpha)}(\frac{\ln(x)-\gamma}{\beta})^{\alpha-1}\exp(-\frac{\ln(x)-\gamma}{\beta})$	$\frac{\mathcal{T}\,(\ln(x)-\gamma)/\beta^{\alpha}}{\mathcal{T}\,(\alpha)}$

3.1 Estimation of parameters:

Many methods are available for parameter estimations, which include the method of moments (MM), maximum likelihood estimation (MLE), the least squares method (LS), L-moments and generalized probability weighted moments (GPWM).The MLE method is considered in this study because it provides the smallest variance as compared to other methods. The idea of this method is to find a set of parameters that will maximize the likelihood function. The parameters are obtained by differentiating the log likelihood function with respect to the parameters of the distribution. The all parameters was estimated by creating formulas in Microsoft excel 2010 and have been shown in Table II.

Table II: Parameters of selected distributions

SR NO	Distributions	Parameters				
		μ	σ	α	β	ϒ
1	Normal	6617	2343	--	--	--
2	Lognormal	8.7309	0.39971	--	--	--
4	Gumbell maximum value	5574.6	1860.7	--	--	--
6	Log Pearson Type III	--	--	4.0067	- 0.2038	9.5475

Table III: GOF value for selected probability distributions

SR NO	Distributions	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Normal	0.09151	1	0.29344	1	0.23655	2
2	Log Pearson Type III	0.09837	3	0.30591	2	0.43869	3
3	Gumbell maximum value	0.09232	2	0.36037	3	0.188	1
4	Lognormal	0.12417	4	0.40303	4	0.60535	4

4.0 Goodness-of-fit tests (GOF):

Three different mostly used GOF tests have been used in this study to identify the best fit models. The chosen distribution that best fits the maximum monthly flood amount is based on the minimum error indicate by all these seven tests. The description of all tests can be found in any basic statistics books. The results have been shown in Table III.

5. Results and discussions:

The excel sheet was developed for calculation of all statistics and result were prepared. The results have been summarized in Table II and III. The Goodness of fit test was done for all distribution using three methods. The rank has been given on the basis of minimum value of error given by GOF test. First, we will proceed to give comments on the results of fitting distributions that are based on GOF criteria. Finally the remarks on the estimated parameters for the best model will be made.

5.1 Descriptive statistics:

The frequency analysis is performed on 26 years of usable flood record. The flood missing data between 1961 to 1964 and 1975 to 1976 were deleted from calculation. The basic parameters of flood record have been shown in Table IV. An observed data shows that a maximum flow of 11246 cumec was recorded at Garudeshwar station on the 1973 and a minimum of 1861 cumec on the June 1965 (River discharge data base, 2010) .The lower value of C_s indicates that data is almost symmetrical and it can be easily fit by normal distribution method. The low value of kurtosis is indication non peakedness of flood which shows that river flow throughout year. The average value of flood at Garudeshwar station is about 6617 cumecs.

Table IV: Basic Parameters for flood record

Parameters	Symbol	Values
Average	$\bar{X}$	6617
Standard Deviation	s	2343
Variance	s^2	5491953
Coefficient of Skew	C_s	0.31
Kurtosis	C_k	-0.07
Maximum	X_{max}	11246
Minimum	X_{min}	1861

5.2 Estimation of best fitting based on GOF Criteria:

The Figures IV and V shows the Probability distribution function f(x) and Cumulative distribution function for all selected probability distribution functions. The all distribution seems to be covering the histogram by observation hence GOF test was performed to obtain the best fit. The values of three goodness-of-fit criteria have been calculated and the best distribution was chosen based on the minimum error of GOF tests. The distributions were then ranked in ascending order based on those values. Unfortunately, when many criteria are used to identify the best distribution, it is more difficult to for the same data may be different for different analysis. In this study, we chose the best fitting distribution based on the majority of the tests, since we did not investigate which is the most effective test. Based on the results, Log Pearson Type III distribution was found to be best fitting curve for Maximum Monthly flood data at Garudeshwar.

5.3 Estimation of Flood magnitude for various design return period:

The Normal distribution method has been adopted for frequency analysis of flood data. The Flood magnitude at various return periods were calculated using following formula.

$Q_T = Q_{avg} + Z*\sigma$

Where,

Q_T , flood magnitude at return period T and Q_{avg}, Avergae flood magnitude.

Z, normal variate derived using standard normal variate table, σ standard deviation of flood magnitude.

The results obtained have been shown in Figure VI for design return periods of 200, 100, 50, 25, 10, 5, 2, and 1.25 years.

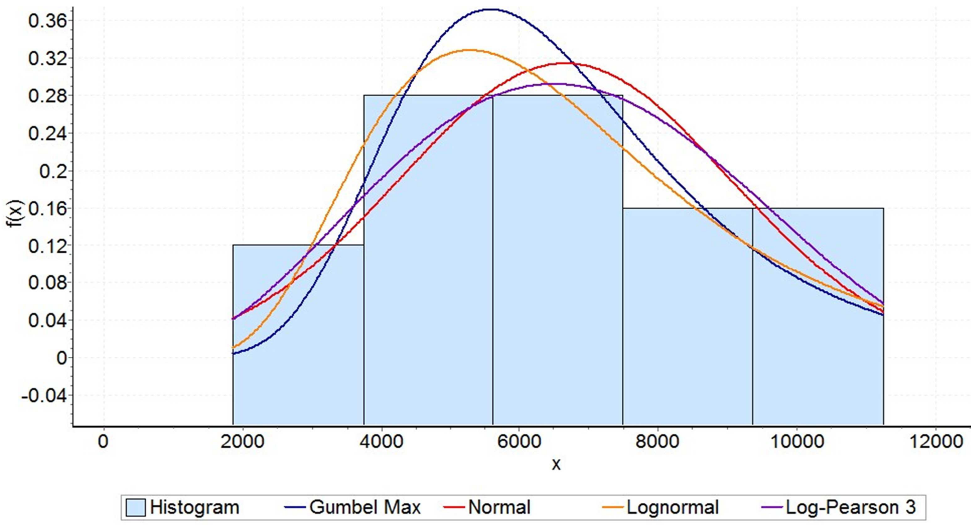

Figure IV: Probability density functions for selected distribution

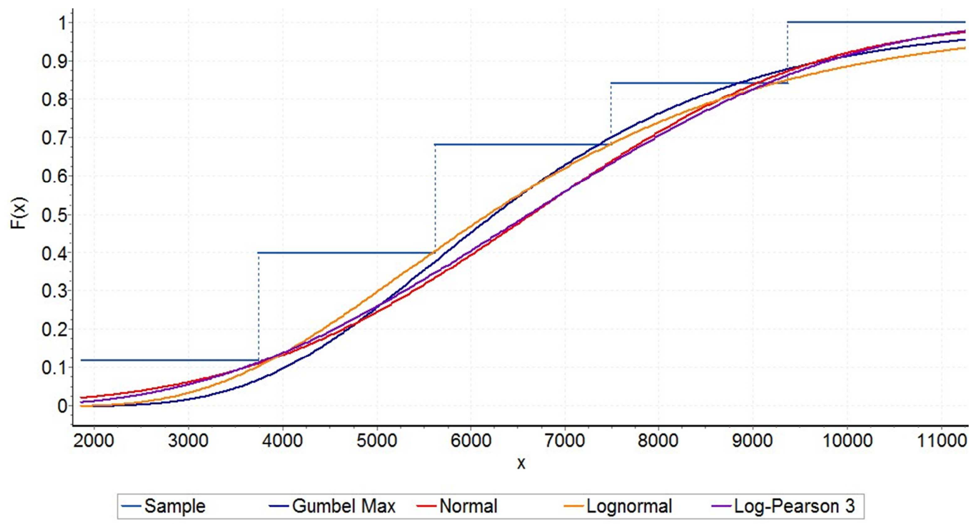

Figure V: Cumulative distribution functions for selected distribution

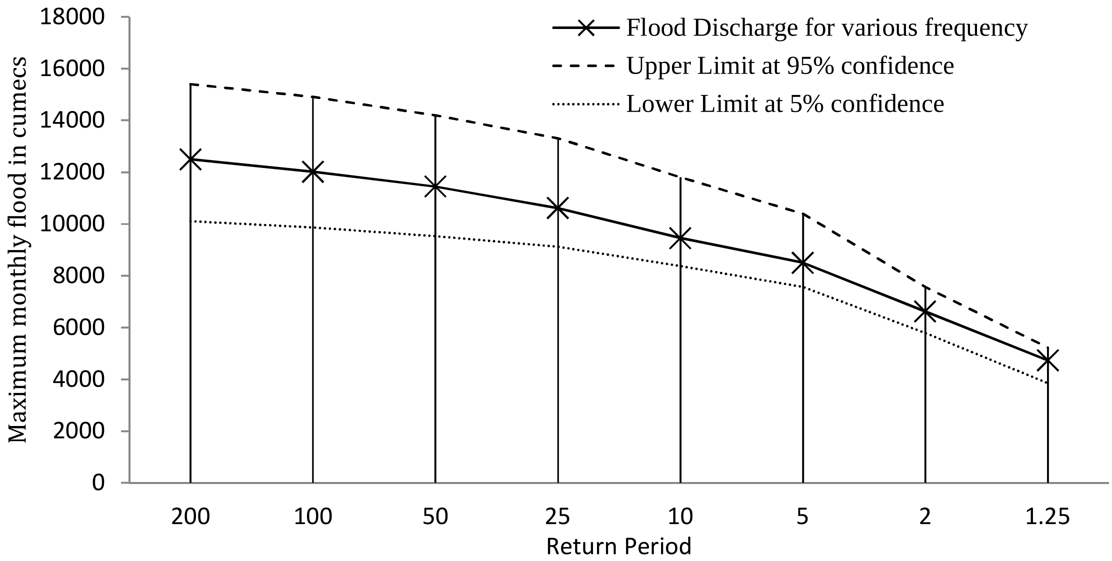

Figure VI: Flood magnitude for various design return period

6. Conclusions:

The estimation for the best fitting distribution for Maximum monthly 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. Different types of goodness-of-fit tests have been attempted in this study. the Normal distribution curve has been identified as the best fitting distribution for flood data in Narmada River at Garudeshwar station. However the flood data should be further analyzed and corrected for missing data, historical data and Zero flood values. The study should be further extended to account for outliers involved in the data. Based on this study the Normal distribution curve has been found as most suitable distribution for analysis of maximum monthly flood data of Narmada River at Garudeshwar station. 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.

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