APPLICATION OF INNOVATIVE TREND ANALYSIS METHODOLOGY AND DISTRIBUTION FITTING: STUDY ON ANNUAL PEAK INFLOW INTO UKAI DAM, GUJARAT, INDIA

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ABSTRACT

Trends in annual peak inflow into Ukai reservoirs, Gujarat has been detected using innovative trend analysis methodology recently proposed by Şen (2012)[1], which is independent of the trend in time-series, pre-assigned significance level, magnitude of trend, sample size and the amount of variation within the time series. Annual peak inflow (in m^3s^{-1}) into the reservoir, from commencement of Ukai dam in year 1972 to 2009 (38 years), were collected and used in present study to explore the possibility of any change in extreme flow in the recent past. The statistical parameters of the said time series have been worked out. Also, the adequacy of data for flood frequency analysis has been checked for their serial correlation (data independency) and computation of threshold values of high and low outliers. The Gumbel Extreme Value (GEV) distribution has been fitted for the said data using maximum likelihood method through χ^2 as evaluation criteria. Also, the Gringorten plotting positions have been obtained to find the suitability of fitted distribution. Flood event with higher return period can be obtained by extrapolating said GEV distribution. The maximum annul peak inflow into Ukai reservoir after commencement of Ukai dam occurred in year 2006 has been found to have a return period of 70 years.

KEYWORDS: Innovative trend analysis methodology, Annual peak inflow, frequency analysis, trend, GEV distribution, Ukai reservoir.

INTRODUCTION

Time series analysis has become a major tool in hydrology to detect the trends and its shifts (Salas 1992)[2]. Management of reservoir for flood control mainly depends upon likelihood or probability of extreme floods (Stedinger et al., 1992)[3]. Non-parametric test like Mann-Kendall (MK) and Spearman's Rho (SR) tests are widely used for detection of trends in hydrologic time series (Yue et al., 2002b)[4]. Strength of such non-parametric test depends upon pre-assigned significance level, magnitude of trend, sample size and the amount of variation within time series. Şen (2012)[1] presented innovative trend analysis methodology on basis of sub-section time series plots derived from a given time-series on cartesian coordinate system which is independent of the trend in time series, pre-assigned significance level, magnitude of trend, sample size and the amount of variation within time series. Frequency distribution is generally fitted to historical time series data to obtain probability of occurrence of different magnitude event while checking its suitability from probability plotting position. Present study has been carried to detect trend and to fit distribution to annual peak inflow into the Ukai reservoir. In recent past, major flood of year 2006 having discharge about 34500 m^3s^{-1}, strikes into the Ukai reservoir. The flood have created havoc in the downstream, Surat city, with loss of about Rs.21000/- crore. This study is part of the global efforts to reduce the impact of climate change and create resilience against such adverse condition in the developing countries like India.

METHODOLOGY

The innovative trend analysis methodology has recently been presented by Şen (2012)[1]. The basis of this methodology is the scatter plot of sub-series in the ascending order from the original time series on the cartesian coordinate system. The 45° straight line implies no trend but any plot appearance above (below) this line implies

increasing (decreasing) trends. Increasing or decreasing trends occupy upper or lower triangular areas of the square plots respectively. In interpretation, it is better to think of the annual flow in three clusters as low, medium and high peak annual flows and scatter diagram of 1:1 line (45˚ straight-line) divided into three clusters. Trend in the high, medium and low magnitude can be detected using this simple but still powerful innovative trend analysis methodology.

Gumbel Extreme Value (GEV) distribution is the most suitable distribution for the extreme value hydrologic time series. The adequacy of fitted distribution can be arrived through the maximum likelihood method using as χ^2 as evaluation criteria. The fitted distribution further can be checked through suitable plotting positions methodologies.

STUDY AREA

Ukai reservoir situated in the lower Tapi basin having catchment area of 62225 km^2 as shown in Fig. 1 (Timbadiya et al., 2011)[5]. During the monsoons, the Tapi River is frequently flooded and cause havoc in the plains in of lower reaches like the Surat city which is situated about 103 km downstream of the Ukai dam.

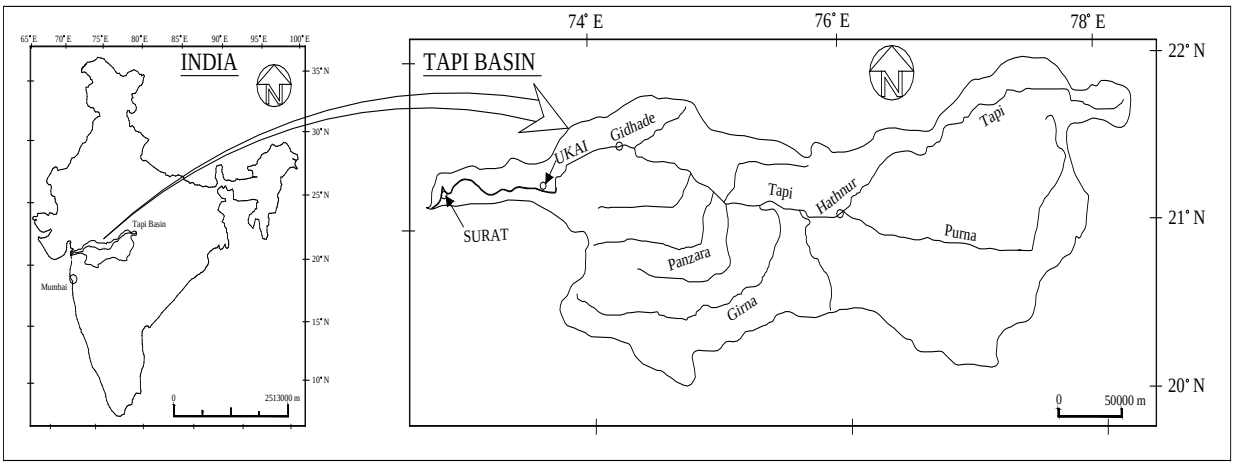

Fig.1 Map of Tapi River Basin (Timbadiya et al, 2011)[5]

The salient features of Ukai reservoir project are included in Table 1.

Table 1: Salient features of Ukai Project

River	Tapi
State/Country	Gujarat/India
Length of dam	
a) Length of masonry section including-spillway	868.83 m
b) Length of earthen dam section	4057.96 m
Max. height of dam	
a) Earth dam above river bed	68.58 m
b) Masonry dam above deepest foundation	80.77 m
Gross Storage Capacity	7414.29 Mm^3
Full Reservoir Level	105.15 m
Design Flood Discharge	49497 m^{3}s^{-1}
Cultivable Command Area	331557 ha.

The Ukai reservoir project system is a multipurpose major irrigation project which mainly serves the purposes like irrigation, power generation, water supplies to industries and drinking, partial flood control and fisheries in state of Gujarat, India with 21˚15' N latitude and 73˚35' E longitude. The Ukai reservoir project has gross storage capacity of 7414.29 Mm^3 with 684.39 Mm^3 as dead storage.

TREND ANALYSIS AND EXTREME VALUE DISTRIBUTION FITTING

The aforesaid methodology has been applied to the annual peak flow data of Ukai reservoir, Gujarat, India. Total 38 (n) year annual peak inflow (in m^3s^{-1}) time series data, from commencement of Ukai dam in year 1972 to 2009, were collected and used in present study to explore the possibility of any change in extreme flow in the recent past has been shown in Fig.2.

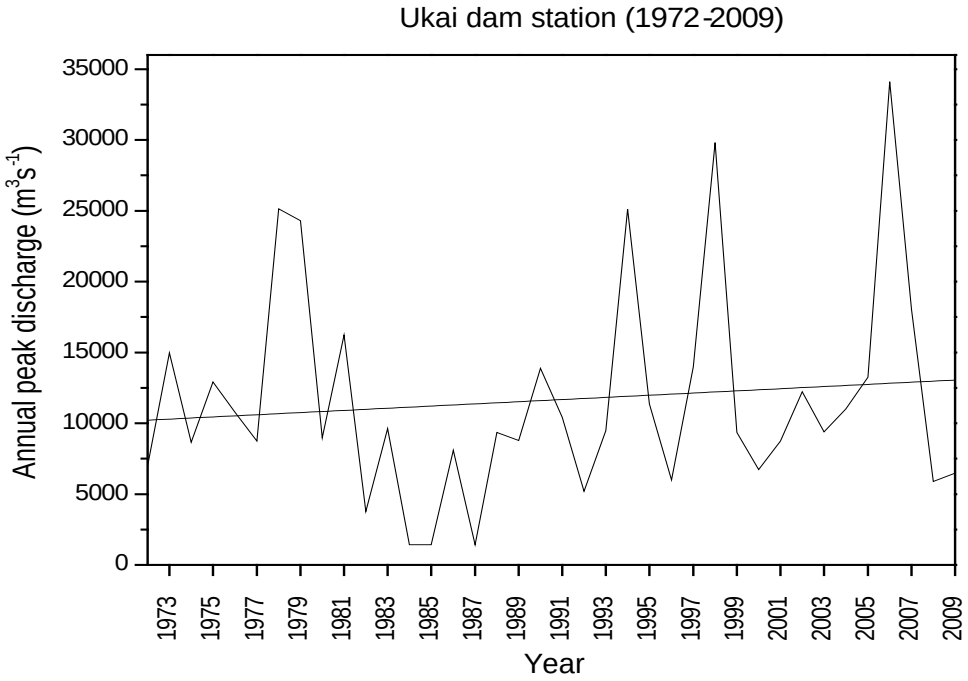

Fig. 2 Observed annual peak inflow into Ukai Reservoir

The statistical parameters, i.e. mean, standard deviation, coefficient of skewness and coefficient of kurtosis of original data were computed and found to be 11634.89 m^3s^{-1}, 7507.95 m^3s^{-1}, 1.3419 and 1.7789 respectively. The trend analysis, as suggested by Şen (2012)[1] and described above, have been applied for inflow of annual extreme flow into Ukai reservoir, as shown in Fig.3.

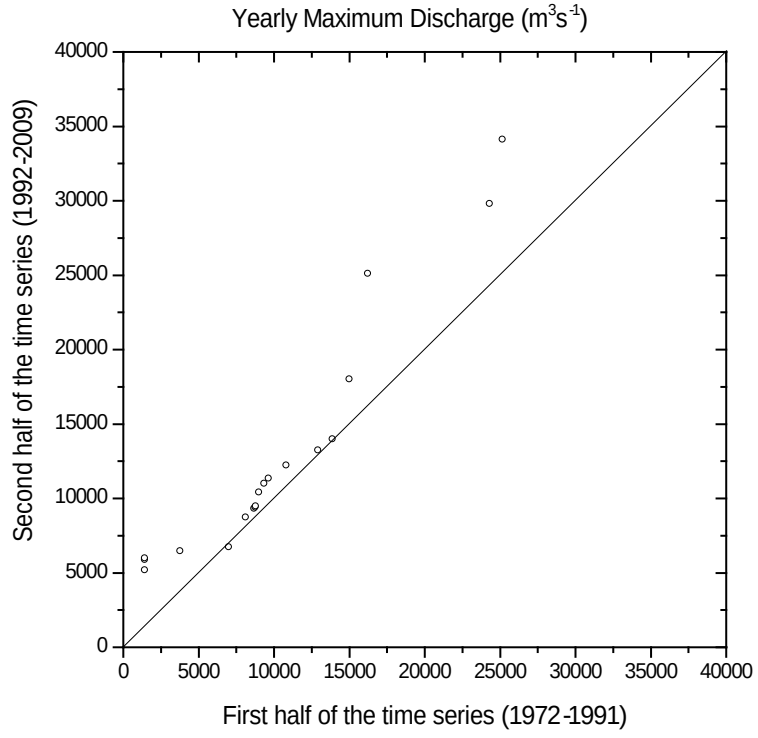

Fig. 3 Annual peak inflow trend analysis for Ukai reservoir

From Figs. 2-3, it is clearly seen that extreme inflow (flood) situation in Ukai reservoir is increasing in the recent past (1992-2009) as compared to the situation during (1972-1991), particularly in medium and high peak annual flow conditions. This indicates that, at this station, floods are bound to increase in future.

The adequacy of data for flood frequency analysis has been checked for their serial correlation (data independency) and computation of threshold values of high and low outliers. Checking serial correlations of hydrological time series is a prerequisite for taking up further their statistical analyses. The statistical analyses, without checking serial correlation of hydrological data, may be misuse of statistical analysis as reported by von Storch (1995)[6] and Clarke (2010)[7] According to Yue et al., (2002a)[8], the lag-*k* serial correlation coefficient, r_k can be computed as,

$$r_k = \frac{\frac{1}{n-k}\sum_{t=1}^{n-k}[(X_t - E(X_t)][X_{t+k} - E(X_t)]}{\frac{1}{n}\sum_{t=1}^{n}[X_t - E(X_t)]^2} \quad (1)$$

$$E(X_t) = \frac{1}{n}\sum_{t=1}^{n} X_t \quad (2)$$

where r_k is the lag-k serial correlation coefficient of the sample data X_t and $E(X_t)$ is the mean of the sample data. The lag-one auto correlation coefficient, r_1 has been computed as 0.2248 for the present data series. Since $((-1-1.645\sqrt{(n-2)})/(n-1)) \le r_1 \le ((-1+1.645\sqrt{(n-2)})/(n-1))$, i.e. -0.45 ≤ 0.2248 ≤ 0.4022, which indicates that the data are independent at 10% significance level and no pre-whitening is required for further analysis. The data were also checked for outliers, which are points that depart significantly from the trend of the remaining data point. According to procedure given by Chow et al. (1988)[9], the computed threshold values of high outlier and low outlier are 70680 m^3s^{-1} and 1135 m^3s^{-1} respectively, which are within corresponding observed maximum and minimum annual peak discharge of 34121 m^3s^{-1} and 1415 m^3s^{-1} respectively. The results show that the annual peak flow time series, between 1972 to 2009, is fit to carry out further flood frequency analysis. The GEV distribution has been fitted for the said data using maximum likelihood method through χ^2 evaluation criteria (Chow et al. (1988)[9]). Also, the Gringorten plotting positions have been obtained and superimposed on the fitted distribution to check suitability of the GEV distribution. The fitted distribution, its 90 % confidence limits and corresponding Gringorten plotting are shown in Fig.4. From the figure, it is evident that, Gringorten plotting positions are within 90 % confidence limits of GEV distribution. Hence, the said distribution is suitable for frequency analysis.

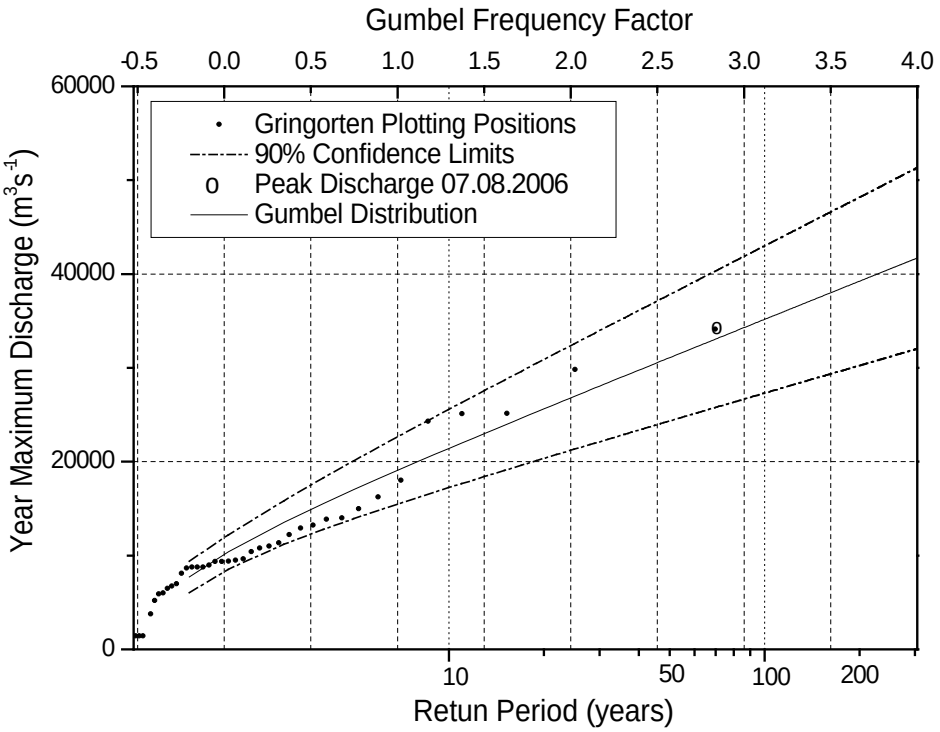

Fig. 4 GEV distribution based on Annual peak discharges (period 1972-2009) at Ukai dam

To obtain a flood event with higher return period, the discharge frequency distribution can be extrapolated by the said GEV distribution. The maximum annul peak inflow into Ukai reservoir after commencement of Ukai dam occurred in year 2006 has found to have a return period of 70 years, see Fig. 4.

CONCLUSIONS

From the present study, it can be concluded that, annual extreme inflows into the Ukai reservoir follow the Gumble Extreme Value distribution. The flood of year 2006 has been found to have the return period of 70 years. Also, from the said fitted distribution, one can calculate peak discharge of high return periods which may be helpful for effective management of the reservoir. Also, the trend analysis has indicated that, annual extreme inflow into Ukai reservoir follow the increasing trend as found from innovative trend analysis and observed trend on the past data. This indicates that, at this station, floods are bound to increase in future.

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"Dr. P.L.Patel pursued post graduate and doctoral degree from IIT -Roorkee (then University of Roorkee) in 1991 and 1995 respectively. He joined Border Road Organisation as Executive Engineer through Indian Engineering Services, where he handled project related to design of hydraulic structure and roads. He joined Department of Civil Engineering of Delhi College of Engineering as Assistant Professor in 1999. In year 2007, he joined Department of Civil Engineering of SVNIT-Surat as Professor. He is teaching subject of Water Resources and Hydraulic Engineering at undergraduate and post graduate level. He has guided 22 post graduation dissertation in Hydraulic Engineering. Presently, guiding seven PhD students and handling TWO major projects worth Rs.70 lakhs on 'Development of Water Resources and Flood Management Centre at SVNIT' and (Erosion of Nonuniform Unimodal and Bimodal Sediments'. At present, there are Fifty papers in his credit from Peer reviewed Journal /conference proceedings. Also, handled the responsibility of Dean (PG) and Dean (R&C) from July 2007-Oct.2011. He is also member of various Technical society, like IAHR, Indian Society for Hydraulics(Fellow member), Institution of Engineers India (Fellow Member) and Society for Technical Education. He is the reviewer of many prestigious journals, like Journal of Hydraulic Research (IAHR), International Journal of Sediment Research, Journal of Hydraulic Engineering (Indian society for Hydraulics)."

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