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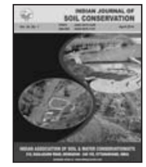

Estimation of probable maximum precipitation for one day duration in Jhalarapatan region of Rajasthan

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ABSTRACT

Daily rainfall data for a period of 51 years (1961-2011) were collected from Jhalarapatan meteorological station and the annual one day maximum rainfall was sorted from the data base to estimate the probable maximum precipitation (PMP) for one day duration. The Hershfield technique and Gumbel's theory of extreme values were used for estimation of PMP for one day duration based on an appropriate frequency factor. The value of the frequency factor was found to be 6.12 for one day duration. This frequency factor was used to estimate one day PMP values. It was observed that PMP for one day duration over the region was found as 509.11 mm and the ratio of the one day PMP to highest one day rainfall was found to be 1.24. The maximum one day rainfall for different return periods were also estimated which could be useful in appropriate designing of soil and water conservation, irrigation and drainage plans.

1. INTRODUCTION

The knowledge of probable maximum precipitation (PMP) for a given region or area is a prerequisite for planning and designs of structures such as check dams, storage reservoirs, drainage works, irrigation tanks, building, highway bridges, *etc.* Also, a high density of rainfall causes large scale flooding, claiming several lives and causing property damage on enormous scale. Therefore, accurate estimates of PMP should be essential for a design engineer or a hydrologist to prevent re-recoverable losses. Huge sums are invested each year on structures all around the world. It is, therefore, quite essential that these structures should be designed based on sound rainfall data. PMP is a common way to synthesize corresponding probable maximum floods in short-data cases (Ghahraman, 2008).

Probable maximum precipitation (PMP) is defined as '*the highest precipitation for a given duration at a particular location at a particular time of year, with no allowance made for long-term climatic trends*' (WMO, 1986). Hydrologists use the PMP magnitude and its spatial and temporal distributions to calculate the probable maximum flood (PMF), which is one of several conceptual flood events used in the design of hydrological structures, for maximum reliability and safety. Typically, PMF is estimated for the catchment area of a dam in order to design a spillway to minimize the risk of overtopping.

Procedures for determining the PMP are admittedly inexact: results are estimates and a risk statement has to be assigned to them. Quoting Koutsoyiannis (1999), the PMP approach 'by no means implies zero risk in reality'. The National Research Council (1994) estimates the return period of the PMP in USA as between 105 and 109 years. Koutsoyiannis (1999) developed a method for assigning a return period to PMP values obtained using the frequency factor method (Hershfield, 1961 and 1965). To estimate the PMP in a place a variety of procedures based on the location of the project basin, availability of data and other considerations have been proposed (e.g. WMO, 1986;

Rakhecha *et al.*, 1992; Collier and Hardaker, 1996). Most of them are based on meteorological analysis, whereas few based on statistical analysis. Casas *et al.* (2011) estimated PMP in Barcelona from 5 minutes to 30 hours. They used two techniques and compared where the first one was associated with a physical method based on the maximization of actual storms and the Hershfield' statistical method (Hershfield, 1961 and 1965; Chow *et al.*, 1988). The PMP results calculated based on two techniques were very similar for both cases. Among the statistical methods for estimating the PMP, the most widely used is the method of Hershfield (1961), based on the frequency analysis of the annual maximum rainfall data registered at the site of interest. The statistical method is more useful when there is insufficient meteorological data for storm maximization (Rakhecha and Soman, 1994). Pandey and Bisht (2006) analysed the annual maximum daily rainfall to estimate the probable maximum rainfall for Hawalbagh and found that Gumbel's distribution fitted well for observed data. Durbude (2008) determined the probable maximum precipitation by using the Hershfield technique and Gumbel's theory of extreme values for planning of soil and water conservation structures. Probability analysis is one of the reliable tools for predicting the rainfall behaviour and has been used extensively by many researchers for successful crop planning (Subudhi *et al.,* 2012; Sharma and Dubey, 2013). Tingsanchali and Tanmanee (2012) performed the hydrological assessment by estimating the PMP over Mae Sruai River Basin using two techniques, where the first PMP method is based on statistical approach while the second one is based on storm maximization and transposition approach to calculate the 1-day, 2-day and 3-day PMPs. In the present study, an attempt has been made to estimate the probable maximum precipitation (PMP) for one day duration by using Hershfield technique and Gumbel's theory of extreme values for Jhalarapatan rain guage station located in Jhalawar district of Rajasthan.

2. MATERIALS AND METHODS

Study Area

The study area is situated under humid south-eastern plain under Zone V of the Jhalawar district of Rajasthan state covering an area of 1282 km^2. The mean annual rainfall is 921.5 mm which remains distributed in 38 rainy days. Jhalarapatan region is fertile plain having rich black-cotton soil and is watered dominantly by *Ahu* and *Kalisindh* rivers. Heavy rains are likely to occur during southwest monsoon. The annual mean, maximum and minimum monthly mean daily temperatures in the district are 27.5, 48.8 (May) and 5.5 °C (February), respectively.

Data Collection and Analysis

Daily rainfall data of Jhalarapatan station (24°33' N and 76°10' E) have been used for the present investigation. Time series rainfall records for the period of 51 years (1961 to 2011) have been collected from Water Resource Department, Government of Rajasthan, Sinchai Bhawan, Jaipur. Annual maximum daily rainfall was sorted out from these data and presented in Fig. 1. Hershfield technique was used to find the probable maximum precipitation and Gumbel's method was used to compute one day maximum rainfall for return period *viz.,* 2, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90 and 100 years for the Jhalarapatan raingauge station.

Hershfield Technique

Hershfield (1961 and 1965) was a pioneer who developed a statistical method for estimating PMP values for small area around the world. Required input in this method are a series of maximum annual daily rainfall at an observation point, yet the partial duration series Ghahraman and Khalili (2004) may be an alternative. Hershfield (1961 and 1965) technique for estimating PMP is based on Chow's (1951) general frequency equation:

$$PMP = \overline{X}_n + K_m\sigma_n \quad (1)$$

and $$K_m = \frac{X_m - \overline{X}_{n-1}}{\sigma_{n-1}} \quad (2)$$

Where X_m, $\overline{X}_n$, σ_n are the highest, mean and standard deviation for a series of *n* annual maximum rainfall values of a given duration; $\overline{X}_{n-1}$ and σ_{n-1} are the mean and standard deviation, respectively, for this series excluding the highest value from the series; and K_m is a frequency factor, with K_m varying between 5 and 20 depending on the rainfall duration and the $\overline{X}_n$ mean (WMO, 1986).

Gumbel's Method

Chow (1951) derived specific relationship of K and the return period (T) for different probability distributions. The theoretical value of annual maximum daily rainfall for different return periods was computed by Gumbel's method. In case of Gumbel's extreme value distribution (Gumbel, 1958), it was computed by the following equation:

$$f(x) = \frac{1}{\sigma}\exp\left[-\frac{x-\mu}{\sigma} - \exp\left(-\frac{x-\mu}{\alpha}\right)\right] \quad (3)$$

Where, $\alpha = \frac{\sigma\sqrt{6}}{\pi}$ and $u = \bar{x} - 0.5772\alpha$

Now, Chow's formula becomes

$$X_T = \overline{X} + K_T\sigma \quad (4)$$

Where, X_T Maximum value of event corresponding to return period of T years; $\overline{X}$ = Mean of the annual maximum series of the data of length N years, σ = standard deviation of the variate; K = frequency factor which depends upon the return period T, given by

$$K_T = 1.00\text{-}1.75 \log\log [T/(T\text{-}1)] \quad (5)$$

Regression Model

Regression models were developed for estimating the one day annual maximum rainfall to return periods in the present study and found the coefficient of determination (R^2).

Rainfall data were thoroughly checked and any doubtful observations were discarded. The annual maximum series of a one day maximum amount of rainfall was selected and an array of annual maximum values of rainfall was formed. The homogeneity of the series was checked by a nonparametric Mann-Kendall rank test (WMO, 1966). The statistic is computed from

$$\iota = \frac{4\sum n_i}{N(N\text{-}1)} \text{-}1,$$ (n_i is s the number of values larger than i^{th} value in the series subsequent to its position in the series of N values). Its expected value in a random series is 0 and standard deviation (σ_r) is given by $\sqrt{(4N+10)/9N\,(N-1)}$

The ratio of τ to σ_τ is considered an indication of a possible trend in the data. For no trend in the data series, this value lies within the limits of ±1.96 at the 5% level significance. Afterwards K_m value and the corresponding one day PMP value were determined using (2) and (1), respectively.

3. RESULTS AND DISCUSSION

One day maximum daily rainfall for the period of 51 years (1961 to 2011) is presented in Fig. 1. Results revealed that the maximum (410.7 mm) and minimum (45.6 mm) annual one day maximum rainfall was recorded during the year 1969 and 2008, respectively. The distribution of one day maximum rainfall received during different months in a year is presented in Fig. 2. It can be seen that July-August received the highest amount of one day maximum rainfall (78%). This is due to the fact that the study area received most of its rain from southwest monsoon (93% of annual rainfall) during monsoon (June-September) season.

Hershfield (1961 and 1965) technique was used to estimate the PMP and Gumbel's method (1958) was used to compute one day maximum rainfall for return period *viz.,* 2 years, 5 years, 10 years, ... for the study area. The statistical parameters like mean, standard deviation, coefficient of variability were computed. The values of $\overline{X}_{n-1}$ and σ_{n-1} were also calculated. The frequency factor (K_m) and corresponding PMP were determined using Equations (1) and (2), respectively. The observed one day maximum rainfall during the period of analysis is presented in Table 1 for comparison with the corresponding PMP value. It is evident from Table 1 that the average annual one day maximum rainfall of the region is 117.12 mm with standard deviation and coefficient of variation 64.05 mm and 0.55, respectively. The value of the frequency factor (K_m) was

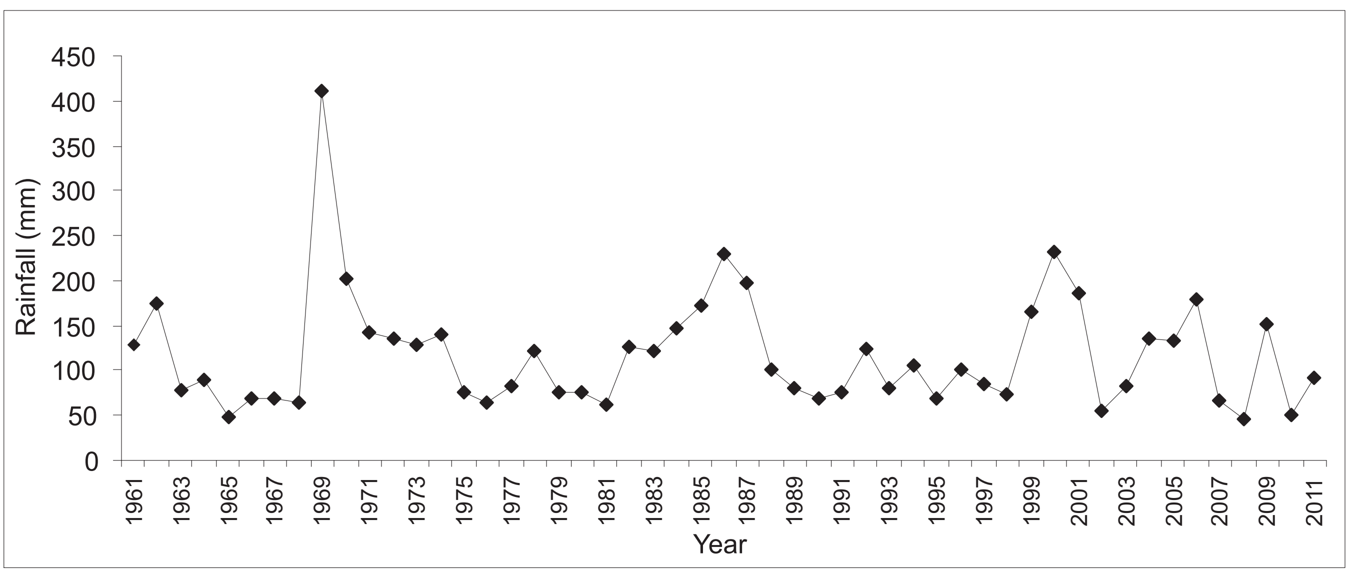

Fig. 1. One day maximum daily rainfall for the period of 1961 to 2011

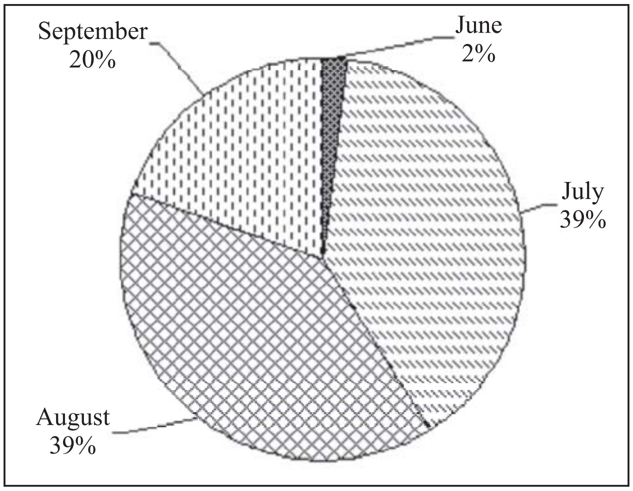

Fig. 2. Monthly distribution of one day maximum rainfall during 1961-2011

Table: 1
Rainfall characteristics and PMP (1961-2011)

S.No.	Parameter	Computed value
1	Average one day maximum rainfall (mm), $\overline{X}_N$	117.12
2	Standard deviation (mm), σ_N	64.05
3	Coefficient of variation (C_V)	0.5468
4	Highest observed rainfall (mm)-HOR	410.70
5	Probable maximum precipitation (mm)-PMP	509.11
6	Frequency factor (K_m)	6.12
7	Ratio, PMP/HOR	1.24

found to be 6.12 for one day duration. This frequency factor was used to estimate one day PMP values. It was observed that PMP for one day duration over the region was 509.11 mm and the ratio of the one day PMP to highest one day rainfall was found to be 1.24. The results are in conformity to the norm laid by WMO (1986). Regression model was developed from the estimated annual one day maximum rainfall for different return periods by Gumbel's method and it appeared that the logarithmic trend line had the better coefficient of determination (R^2 = 0.9983) as per the equation:

$$Y=77.402\ Ln(X) + 113.36 \qquad (6)$$

Where, Y = annual one day maximum rainfall, mm and X = Return period, Year.

Using equation (6), the expected maximum one day rainfall for different return periods for the study area is shown in Table 2. The expected maximum one day rainfall for 50 and 100 years return period was 416.16 and 469.81 mm, respectively. A maximum of 167.1 mm rainfall is expected to occur at every 2 years (Table 2). It is generally recommended that 2 to 100 years is sufficient return period for soil and water conservation measures, construction of dams, irrigation and drainage works (Singh *et al.*, 2012).

The major dams throughout the world are based on the PMF which comes out from the PMP. Its estimates have been used for many years to provide the rainfall values used to compute the PMF for drainage basins. In the design of hydrological structures, the structures have to be designed to carry maximum runoff expected in a specified recurrence interval. In a study, various designs of hydrological structures have been used at different return periods (Durbude, 2008). Accordingly, the PMP for various

Table: 2
Estimated maximum one day rainfall for different return period

Sl.No.	Return period (Year)	Estimated maximum one day rainfall (mm)
1	2	167.01
2	5	237.93
3	10	291.58
4	15	322.97
5	20	345.24
6	25	362.51
7	30	376.62
8	40	398.89
9	50	416.16
10	60	430.27
11	70	442.20
12	80	452.54
13	90	461.65
14	100	469.81

Table: 3
The return period and PMP for design of different structures

S.No.	Type of soil and water conservation structure	Return Period (Year)	PMP (mm)
1	Terrace outlets and vegetated waterways	10	292
2	Field diversions	15	323
3	Small permanent masonry gully control structures	10-15	292-323
4	Stock water dams	25	363
5	Earth fill dams-storage having natural spillways	25-50	363-416
6	Storage and diversion dams having spillways	50-100	416-470

hydrological structures were calculated and presented in Table 3. It was observed that the PMP with different return periods for various soil and water conservation structures like terrace outlets and vegetated waterways, field diversions and stock water dams were found as 292, 323 and 363 mm respectively. Also, PMP values for small permanent masonry gully control structures, earthfill dams-storage having natural spillways and storage and diversion dams having spillways were 292-323, 363-416 and 416-470 mm, respectively. The estimated values of PMP should be considered at the time of design of overflow arrangement of these structures for the effective planning of soil and water conservation activities.

4. CONCLUSIONS

The main objective of the present study was to introduce the simple statistical method for computation of probable maximum rainfall (PMP) and one day maximum rainfall for different return periods. This study gives an idea about the prediction of PMP and annual one day maximum rainfall to design the small and medium hydraulic and soil and water conservation structures, irrigation and drainage systems, vegetative waterways, storage reservoirs, check dams, building, highway bridges and field diversions. The study is also helpful in developing crop plan and estimating design flow rate for maximizing crop production.

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REFERENCES

Casas, M.C., Rodriguez, R., Prohom, M., Gazquez, A. and Redano, A. 2011. Estimation of the probable maximum precipitation in Barcelona (Spain). *Int. J. Climatol.,* 31: 1322-1327.

Chow, V.T. 1951. A general formula for hydrologic frequency analysis. *Trans. Am. Geophys. Union,* 32: 231-237.

Chow, V.T., Maidment, D.R. and Mays, L.W. 1988. *Appl. Hydrol.*, McGraw-Hill, USA.

Collier, C.G. and Hardaker, P.J. 1996. Estimating probable maximum precipitation using a storm model approach. *J. Hydrol.,* 183: 277-306.

Durbude, D.G. 2008. Estimation of probable maximum precipitation for planning of soil and water conservation structures. *J. Soil Water Cons., India,* 7(3): 31-35.

Gumbel, E.J (1958). Statistics of Extremes, Columbia University Press, New York.

Ghahraman, B. 2008. The estimation of one day duration probable maximum precipitation over Atrak watershed in Iran.**Iranian J. Sci. Tech., Transactions B: Engineering,* 32(B2):175-179.

Ghahraman, B. and Khalili, D. 2004. A re-visit to partial duration series of short duration rainfalls. *Iranian J. Sci. Tech., Transactions B: Engineering,* 28 (B5): 547-558.

Hershfield D.M. 1961. Estimating the probable maximum precipitation. *Proceedings Amer. Soc. Civil Engineers, J. Hydraul. Div.,* 87(HY5): 99-106.

Hershfield, D.M. 1965. Method for estimating probable maximum precipitation. *J. Am. Water Works Assoc.,* 57: 965-972.

Koutsoyiannis, D. 1999. A probabilistic view of Hershfield's method for estimating probable maximum precipitation. *Water Resour. Res.,* 35(4): 1313-1322.

National Research Council. 1994. *Estimating bounds on extreme precipitation events*. National Academy Press: Washington, DC.

Pandey, S.C. and Bisht, K.K.S. 2006. Probability analysis for prediction of annual maximum daily rainfall for Hawalbagh (Almora). *Ind. J. Soil Cons.,* 34(1): 75-76.

Rakhecha, P.R., Deshpande, N.R. and Soman, M.K. 1992. Probable maximum precipitation for a 2-day duration over the Indian Peninsula. *Theor. Appl. Climatol.,* 45(4): 277-283.

Rakhecha, P.R. and Soman, M.K. 1994. Estimation of Probable maximum precipitation for a 2-day duration: Part 2-North Indian Region. *Theor. Appl. Climatol.,* 49(2):77-84.

Sharma K.K. and Dubey, S.K. 2013. Probability analysis of nainfall for planning water harvesting and irrigation in semi-arid region of Uttar Pradesh. *Ind.J.Soil Cons.,* 41(1): 14-19.

Singh, B., Rajpurohit, D., Vasishth, A. and Singh, J. 2012. Probability analysis for estimation of annual one day maximum rainfall of Jhalarapatan area of Rajasthan. *Plant Archives*, 12(2): 1093-1100.

Subudhi, C.R., Sahoo, M. and Senapati, S.C. 2012. Rainfall probability analysis for crop planning in Kandhamal district of Orissa, India. *Ind.J.Soil Cons.,* 40(3): 247-251.

Tingsanchali, T. and Tanmanee, S. 2012. Assessment of hydrological safety of Mae Sruai Dam, Thailand. *Procedia Engineering*, 32: 1198-1204.

World Meteorological Organization. 1966. *Climate change*. WMO Tech. Note No. 79, 80 p.

World Meteorological Organization. 1986. Manual for estimation of probable maximum precipitation. *Operational hydrology, Report 1.* WMO-No. 332, pp. 1-269.