Vol. 45, No. 3, pp 331-337, 2017

Indian Journal of Soil Conservation

Online URL : http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Prediction of annual extreme rainfall events and probable maximum precipitation (PMP) for planning of soil and water conservation structures

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ARTICLE INFO

Article history:

Received : November, 2016
Revised : September, 2017
Accepted : October, 2017

Key words:
One-day maximum rainfall,
Probability distribution models,
Probable maximum precipitation

ABSTRACT

The prediction of probable maximum precipitation (PMP) and annual one-day maximum rainfall at different return periods were carried out for providing necessary information required for designing of various soil and water conservation structures like field bunding, vegetative waterways, field diversions, check dams, gully control structures etc. for the drought prone region of Dhasan basin coming under Bundelkhand region. It has been estimated that the one day PMP varies from the highest 682.8 mm at Sagar to the lowest 290.4 mm at Banda, whereas it lies at about 334.7 mm for Khurai region. The analysis of one-day maximum rainfall data revealed that the Generalised Pareto distribution was the best-fit distribution with minimum Chi-square value among other probability distribution methods considered for comparison followed by Log Pearson and Log normal distributions. The Chi-square values for Generalised Pareto distribution are 6.3, 9.64 and 6.2 for Sagar, Khurai and Banda region, respectively. This study will be helpful for engineers, policy makers, planners, agriculturalists, farmers etc. while designing various conservation structures.

1. INTRODUCTION

Drought is an extreme hydrological event which affects the livelihood and socio-economic development of people. The scenario of drought frequency and severity have changed over the last decade in the Bundelkhand region and ranging between once in three years to once in five years and also there is a decreasing trend in the seasonal rainfall and number of rainy days in a number of blocks (Thomas *et al.,* 2015). The region is under the influence of drought during most of the time (Kar *et al.,* 2016) so it raises the necessity to conserve the available water potential and utilize it properly for which, the estimation of maximum one-day rainfall for various return periods is essential. The return periods of several consecutive rainfall events in India may be predicted using various probability distribution methods although its pattern is uneven throughout year (Upadhaya *et al.,* 1998 and Bhakar *et al.*, 2006). The erratic distribution and spatiotemporal variation of rainfall is the measure cause for crop failure in rainfed and drought-prone areas (Panigrahi *et al.*, 2002 and Kumar, 2009). Detailed knowledge of rainfall pattern helps in designing of different water conservation structures to meet the irrigation requirement for crop during drought period (Ray *et al.,* 1987; Panigrahi *et al.*, 2001 and Sharma *et al.,* 2013).

Analysing return period of rainfall is a vital tool for planning and designing of various structural measures, such as check dams, spillways, ponds etc. Determination of annual maximum daily rainfall and thus peak runoff will be used for the hydrologic design of several hydraulic structures which will enhance and improve the effective utilization of water resources (Bhatt *et al.*, 1996; Subudhi, 2007 and Khatua *et al.*, 2014 and Kumar *et al.,* 2007). Rakhecha *et al.* (1992) had estimated the PMP of 2-days duration for designing of costly and large hydraulic structures in Indian peninsula region by Hershfield technique. Adequate availability of water for meeting the requirements of crop is of prime importance in rainfed agriculture. Tiwari *et al.* (1998) estimated drought using rainfall data for Bundelkhand region and proposed that water harvesting by constructing

embankment cum dugout ponds or stop dams across ephemeral streams is necessary to solve the drought problem in the region. Effective interventions of a watershed in Bundelkhand region by integrated watershed development works *viz.,* field bunding, contour bunding and contour cropping, check dams and gully control structures etc. have shown tremendous impact on hydrological components such as reduced runoff, increased base flow, groundwater recharge, water productivity and yield (Singh *et al.,* 2014b).

The crop yield in the region is very less due to drought and irregular rainfall pattern which makes the farmer less profitable. So it is necessary to construct conservation structures and select proper cropping pattern so that it can aid required amount of water by retaining more soil moisture. This will also make to grow a second crop in that area, by utilizing the stored water in the pond. Hence, in the present study, an attempt has been made to find the best fit probability distribution method to predict one-day maximum rainfall pattern at different probability levels which has been suggested for the design of appropriate conservation structures in the area and to find the PMP using Hershfield technique for Dhasan basin in Bundelkhand region.

2. MATERIALS AND METHODS

Study Area

This study has been carried out in Dhasan basin up to Patan village with a catchment area of 2054.39 sq. km and falls in Bundelkhand region of Madhya Pradesh, India. Dhasan river flows through the study area to join river Betwa which is a tributary of the Yamuna and it is extended between $23^0 28' 56''$N to $24^0 16' 20''$N Latitude and $78^0 23' 24''$E to $78^0 57' 03''$ E Longitude. The area is under the hold of the recurrent occurrence of droughts since decades due to abnormality in the arrival and removal of rainfall along with scanty rainfall which eventually affect livelihoods. The average maximum, minimum and mean daily temperatures for Sagar district are 45.6^0C, 1.1^0C and 23.3^0C, respectively. Eight soil groups have been identified in the study area namely, deep clayey soils, deep calcareous clayey soils, moderately deep calcareous clayey soils, slightly deep clayey soils, very shallow clayey skeletal soils, deep loamy soils, slightly deep loamy soils and very shallow loamy soils based on the classification system of ICAR-NBSS&LUP, Nagpur and most of the area is covered by deep calcareous clayey soils. The average annual rainfall of Dhasan basin is around 1117.2 mm and seasonal rainfall is about 1020.2 mm. The maximum rainfall is obtained during the month of August followed by July. The entire study area is comprised of hard rock formations. Rainfed agriculture is the main livelihood of the farmers in this region. Maize, oil seeds, sorghum etc. are the major crops cultivated during *kharif* season and wheat, pulses, chickpeas etc. are cultivated during *rabi* season. Three rain gauge stations (Sagar, Khurai and Banda) are considered for carrying out the study and the daily rainfall data is collected for Sagar, Khurai from the year 1976 to 2009 and rainfall data from 1981 to 2009is taken for Banda station.

Probability Distribution Methods

The different probability distribution methods *viz.,* Normal distribution, Log normal distribution, Gamma distribution, Log Pearson (LP) method, Gumbel, Generalised Extreme Value (GEV), Generalised Pareto (GP) method, Log Normal (3 parameter) and Weibull were used for fitting hydrologic data and given in Table 1 (Chow *et al.,* 1988; Panda *et al.,* 2005 and Tilahun, 2006).

Testing the Goodness of Fit of Probability Distribution Methods

The Chi-square test (Haan, 1994) as given in eq. 1, is used to test the goodness of fit between two methods and to check whether any significant difference exist between observed frequencies computed by Weibull's formula and estimated frequencies obtained by various distribution methods. The observed values are estimated using Weibull's plotting position formula by applying it to the rainfall data for comparing with expected values (Kar *et al.*, 2002 and Sabarish *et al.*, 2015). While comparing the observed rainfall at different probability levels, the Weibull's method was considered as nearly equal to observed distribution and the expected rainfall value is estimated at different probability levels by using various probability distribution methods. The distribution which gives the smallest Chi-square value was considered and recommended as best fit probability distribution function for the study area (Bhatt *et al.*, 1996; Agarwal *et al.,* 1998 and Kar *et al.*, 2002).

$$\chi^2 = \sum_{i=1}^{N} \frac{(O_i - E_i)^2}{E_i} \quad ...(1)$$

Where, χ^2= Chi-square, O_i = Observed value and E_i = Expected value.

Determination of Probable Maximum Precipitation (PMP)

The PMP is defined as the theoretical maximum depth of precipitation which is meteorologically possible for a given duration and over a specified area (WMO, 2009).

Table: 1
Various probability distribution methods and their equation

Probability distribution methods	Equations	Probability distribution methods	Equations
Normal	$f_x = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left[\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]}$	Log normal	$f_x = \frac{1}{\sigma_y\sqrt{2\pi}} e^{-\left[\frac{1}{2}\left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]}$
Gamma	$f_x = \frac{x^{\alpha-1}}{\beta^{\alpha}\,\Gamma_{(\alpha)}} e^{\left(-\frac{x}{\beta}\right)}$	Log Pearson	$f_x = \frac{1}{\lvert a\rvert\, x\, \Gamma(b)}\left(\frac{y-c}{a}\right)^{b-1} e^{-\left(\frac{y-c}{a}\right)}$
Gumbel	$f_x = \frac{1}{\alpha} e^{\left[-\frac{x-\mu}{\alpha}-e^{\left(-\frac{x-\mu}{\alpha}\right)}\right]}$	Generalised Extreme Value	$f_x = e^{\left[-e^{\left(-\frac{x-\beta}{\alpha}\right)}\right]}$
Generalised Pareto	$f_x = 1 - \left[1 - \frac{k(x-\varepsilon)}{\alpha}\right]^{\frac{1}{k}}$	Log normal (3 Parameter)	$f_x = \frac{1}{(x-\gamma)\,\sigma\sqrt{2\pi}} e^{\left[-\frac{\{\ln(x-\gamma)-\mu\}}{2\sigma^2}\right]}$
Weibull	Probability (P) = $\frac{m}{N+1}$ and Return period (T) = $\frac{1}{P}$		

Hershfield technique (Hershfield, 1965 and Casas *et al.*, 2011) is based on a general frequency equation given by Chow (1951) for determination PMP and uses parameters like mean, standard deviation and the frequency factor of the annual maximum one-day rainfall series. The mathematical representation of Hershfield method for estimation of PMP (Rakhecha *et al.*, 1992 and Singh *et al.*, 2014a) of any duration can be estimated from the eq. 2.

$$PMP = P_N + K_f.\{SDV(P)_N\} \quad ...(2)$$

Where, PMP is the estimated one-day maximum rainfall, P_N and $SDV(P)_N$ are the mean and standard deviation of annual one-day maximum rainfall series having N observations, K_f is the frequency factor which depends upon the number of observations. The value of K_f can be obtained from eq. 3.

$$K_f = \frac{P_{max} - P_{N-1}}{SDV(P)_{N-1}} \quad ...(3)$$

Where, P_{max} is the maximum rainfall value in annual one-day maximum rainfall series, P_{N-1} and $\{SDV(P)_{N-1}\}$ are the mean and standard deviation of annual one-day maximum rainfall series having (N-1) observations excluding the maximum rainfall value.

Return Period for Design of Structures

The hydrologic design of various soil and water conservation structures comprise of estimating peak runoff rate for a given return period which the structure can pass through safely. The return period of various soil and water conservation structures like field bund, terrace outlets, vegetative waterways, field diversions, small permanent masonry gully control structures, check dams, drainage line treatment (DLT) structures, stock water dams, earthen storage dam with natural spillways, storage and diversion dams having spillways etc. are presented in Table 7 (Durbude, 2008 and Sharma *et al.*, 2015). Based on the return period, determination of PMP for respective structure is made.

3. RESULTS AND DISCUSSION

One-day maximum daily rainfall data for the period of 34 years (1976 to 2009) is presented in Table 2. Results revealed that the highest observed rainfall (HOR) was found to be 475.4 mm for Sagar, 309.6 mm for Khurai and 260.5 mm for Banda during the year 2005, 1982 and 2005, respectively. The lowest observed one-day maximum rainfall was 63 mm, 65.2 mm and 47 mm for Sagar, Khurai and Banda during the years of 1986, 1984 and 1981, respectively.

Comparison of Observed and Expected One Day Maximum Rainfall

The expected annual one-day maximum rainfall by several probability distribution methods were calculated for different return periods and the results are shown in Table 3, Table 4 and Table 5 for Sagar, Khurai and Banda region, respectively. The analysis of one-day maximum rainfall data

Table: 2
Annual one-day maximum rainfall (mm) data for Dhasan basin

Year	Sagar		Khurai		Banda	
	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)	Date
1976	92.4	11-Jul	112	31-Aug		
1977	146.2	6-Aug	127.4	5-Jul		
1978	143.2	10-Aug	170	10-Aug		
1979	102.8	29-Nov	88	13-Jul		
1980	114.4	27-Jul	118	27-Jul		
1981	74	2-Aug	91.4	2-Aug	47	6-Aug
1982	191	2-Aug	309.6	16-Aug	111.8	20-Aug
1983	264.1	9-Sep	174.8	10-Sep	183.6	9-Sep
1984	95.7	10-Aug	65.2	10-Aug	118.4	23-Aug
1985	173.1	8-Aug	146.2	8-Aug	76.2	8-Aug
1986	63	21-Jul	279.4	21-Jul	68.2	19-Jun
1987	178.4	25-Aug	185.8	25-Aug	180.5	25-Aug
1988	71	26-Jul	247	4-Jul	98.6	21-Jul
1989	84.8	25-Aug	94.8	7-Aug	64.6	21-Jul
1990	257.2	3-Jul	100.4	3-Jul	106.6	1-Aug
1991	90.8	24-Aug	122	18-Jul	136.2	19-Aug
1992	142.2	12-Sep	84.6	24-Aug	174.2	12-Sep
1993	99.7	18-Sep	69.4	20-Aug	128	18-Sep
1994	126.4	23-Jun	179	5-Aug	214	5-Aug
1995	94.8	29-Jul	183	22-Aug	64.2	22-Aug
1996	130	20-Aug	140	20-Aug	84	4-Aug
1997	125.6	7-Aug	94.4	1-Aug	96.2	7-Aug
1998	115	22-Aug	133	11-Jul	132	26-Sep
1999	88.3	19-Sep	113.8	18-Sep	178.4	7-Aug
2000	176.4	20-Jul	296.6	20-Jul	130.2	20-Jul
2001	154	16-Jun	112.8	10-Jul	73.6	1-Jul
2002	68.8	16-Aug	68	30-Aug	55.4	19-Aug
2003	70.6	30-Aug	77.4	23-Jul	78.8	16-Jul
2004	87.2	17-Jun	170.4	15-Aug	110.1	17-Jun
2005	475.4	4-Jul	166	4-Jul	260.5	3-Jul
2006	103.2	27-Jul	110	31-Jul	59.1	31-Jul
2007	68.6	8-Jul	122	8-Jul	53.3	15-Jul
2008	97.5	20-Jun	148	20-Jun	128	10-Aug
2009	143.6	12-Aug	93.2	10-Sep	96	10-Sep

revealed that the Generalised Pareto distribution was the best-fit distribution with minimum Chi-square value among other probability distribution methods considered. The second and third best-fit distributions were Log Pearson and Log normal distributions. The Chi-square values for Generalised Pareto distribution are 6.3, 9.64 and 6.2 for Sagar, Khurai and Banda, respectively. The gradual increase of observed and expected annual one-day maximum rainfall with respect to different return periods are represented in Fig. 1, Fig. 2 and Fig. 3 for Sagar, Khurai and Banda region, respectively. The trend line is drawn for the expected one-day maximum rainfall given by Generalised Pareto method. A regression model is also developed from the expected

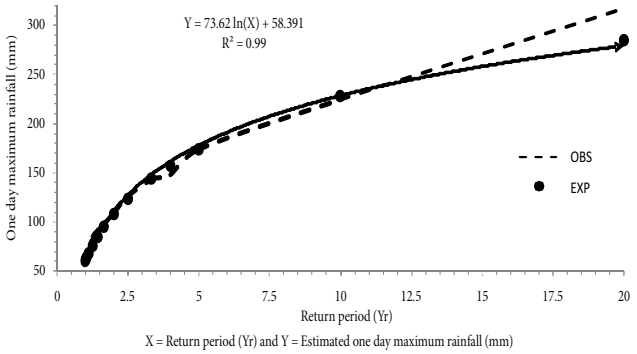

Fig.1. Observed and estimated one-day maximum rainfall for Sagar region

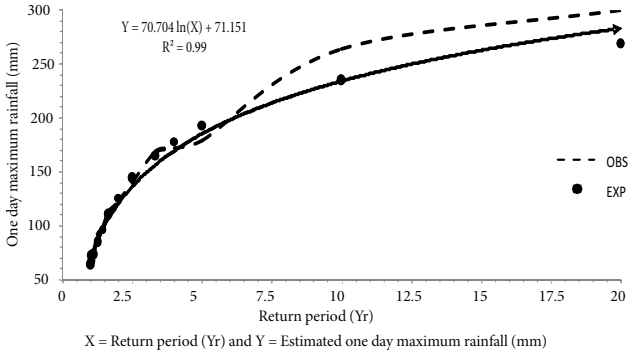

Fig. 2. Observed and estimated one-day maximum rainfall for Khurai region

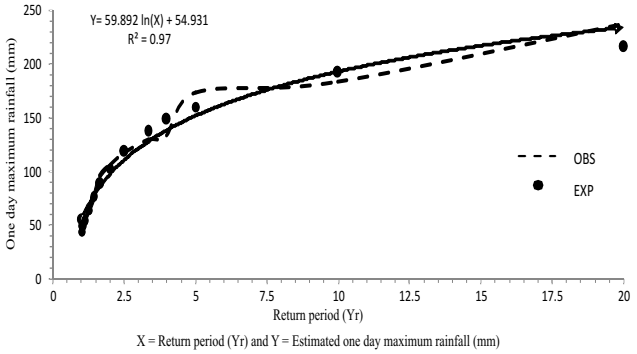

Fig. 3. Observed and estimated one-day maximum rainfall for Banda region

annual one-day maximum rainfall against different return periods.

Probable Maximum Precipitation (PMP) by Hershfield Technique

Hershfield technique was used to estimate the PMP. The parameters of probable maximum rainfall of one-day duration are given in Table 6. The statistical parameters like average, standard deviation and coefficient of variation were computed for the observed one-day maximum rainfall series for the period of 1976-2009 for the regions of Sagar, Khurai, and Banda. The average annual one-day maximum rainfall is highest (140.99 mm) for the Khurai region and lowest (114.06 mm) for the Banda region. The coefficient of variation varies from 0.445 at Khurai to 0.581 at Sagar. The value of the

Table: 3
Observed and expected one-day maximum rainfall for Sagar region

Return period (Yr)	Observed rainfall (mm)	Expected rainfall (mm)							
		GP	Log Pearson	Log normal (3P)	GEV	Log normal	Normal	Gumbel	Gamma
1.01	59.35	61.72	59.39	49.28	36.44	42.36	0	0	18.2
1.05	66.73	64.44	66.72	58.54	51.99	57.27	0	0	34.83
1.11	69.7	68.02	72.39	65.61	62.08	67.27	32.45	30.68	47.37
1.25	84.8	75.87	81.58	76.96	76.56	81.75	66.84	76.41	66.59
1.43	91.6	84.86	90.29	87.61	88.97	94.09	91.65	104.99	83.5
1.67	97.5	95.36	99.53	98.77	101.21	106.1	112.84	126.88	100.14
2	108.8	107.95	110.06	111.3	114.33	118.71	132.66	145.48	117.62
2.5	126.4	123.62	122.87	126.27	129.41	132.83	152.47	162.48	137.06
3.33	143.4	144.24	139.83	145.5	148.2	149.79	173.67	179.12	160.1
4	148.14	157.56	151	157.83	160	160.1	185.42	187.72	173.88
5	173.1	174.13	165.24	173.17	174.53	172.42	198.5	196.81	190.12
10	224.1	227.55	214.46	223.31	221.31	209.6	232.94	218.64	237.45
20	316.74	284.06	273.28	278.18	272.18	246.32	261.43	234.67	281.71
40		343.83	344.33	338.67	328.53	283.47	286.21	247.35	324.02
50		363.8	370.28	359.51	348.02	295.62	293.61	250.93	337.31
100		428.18	462.16	428.96	413.32	334.2	315.26	260.87	377.84
200		496.28	574.04	506.89	486.61	374.65	335.41	269.42	417.41
400		568.31	710.45	595.6	568.98	417.82	354.66	276.91	456.47
Chi-square values		6.3	8.27	10.48	29.33	32.78	86.48	123.48	152.3

Table: 4
Observed and expected one-day maximum rainfall for Khurai region

Return period (Yr)	Observed rainfall (mm)	Expected rainfall (mm)							
		GP	Log Pearson	Log normal	Log normal (3P)	Gamma	GEV	Normal	Gumbel
1.01	63.37	63.29	56.29	49.58	43.02	35.49	31.8	0	0
1.05	67.3	67.37	69.17	65.64	60.78	54.97	53.37	36.36	22.34
1.11	73.4	72.64	77.96	76.25	72.38	68.04	66.68	59.47	58.03
1.25	91.4	83.86	90.92	91.41	88.83	86.64	84.93	87.46	95.24
1.43	97.6	96.17	102.26	104.19	102.59	102.07	99.84	107.64	118.5
1.67	112.8	109.85	113.54	116.51	115.79	116.67	113.96	124.89	136.31
2	122	125.33	125.67	129.34	129.46	131.54	128.49	141.01	151.44
2.5	140	143.28	139.6	143.59	144.55	147.64	144.5	157.13	165.28
3.33	168	164.91	156.9	160.58	162.46	166.24	163.48	174.39	178.82
4	171.5	177.79	167.7	170.84	173.23	177.18	174.92	183.94	185.81
5	179	192.72	180.9	183.05	186	189.9	188.52	194.59	193.21
10	263.2	233.87	222.64	219.52	223.92	226.18	229.18	222.62	210.97
20	299.84	268.12	266.69	255.11	260.64	259.27	268.89	245.8	224.02
40		296.61	314.03	290.72	297.12	290.33	308.51	265.96	234.34
50		304.73	330.08	302.3	308.94	299.99	321.32	271.99	237.26
100		327.08	382.82	338.86	346.1	329.29	361.39	289.6	245.34
200		345.68	440.34	376.86	384.54	357.57	401.99	306	252.3
400		361.16	503.21	417.12	425.03	385.02	443.21	321.66	258.39
Chi-square values		9.64	13.94	21.99	24.56	40	45.96	57.91	153.43

frequency factor (K_f) was found to be 7.14, 3.09 and 3.40 for Sagar, Khurai and Banda, respectively. This frequency factor was used to estimate PMP. It has been estimated that PMP for one-day maximum rainfall data series varies from 682.83 mm at Sagar to 290.38 mm at Banda, whereas it is about 334.69 mm over the Khurai region. The ratio of PMP and HOR was also calculated and the lowest value (1.08) and highest value (1.44) were found Khurai and Sagar, respectively.

Estimated Probable Maximum Precipitation (PMP) for Design of Structures

The PMP for design of various soil and water

Table: 5
Observed and expected one-day maximum rainfall for Banda region

Return period (Yr)	Observed rainfall (mm)	Expected rainfall (mm)							
		GP	Log Pearson	Log normal	Gamma	Log normal (3P)	Normal	GEV	Gumbel
1.01	42.59	44.65	38.14	36.49	27.48	25.59	0	16.56	0
1.05	50.15	48.64	50.38	49.51	43.21	43.41	27.38	37.11	15.76
1.11	55.4	53.78	58.66	58.26	53.84	54.61	46.52	49.58	45.33
1.25	64.6	64.6	70.77	70.96	69.06	70.01	69.71	66.43	76.16
1.43	76.2	76.28	81.22	81.8	81.74	82.52	86.43	79.98	95.43
1.67	96	89.02	91.51	92.37	93.77	94.25	100.72	92.65	110.18
2	106.6	103.14	102.42	103.48	106.05	106.16	114.08	105.51	122.72
2.50	118.4	119.09	114.77	115.93	119.37	119.07	127.43	119.48	134.19
3.33	130.2	137.71	129.86	130.91	134.79	134.07	141.73	135.79	145.4
4	134.1	148.46	139.15	140.02	143.88	142.94	149.64	145.49	151.19
5	174.2	160.62	150.36	150.93	154.45	153.34	158.46	156.89	157.33
10	183.6	192.27	184.89	183.88	184.66	183.5	181.69	190.17	172.04
20	237.25	216.4	219.97	216.5	212.26	211.81	200.89	221.55	182.85
40		234.78	256.32	249.55	238.22	239.23	217.59	251.82	191.39
50		239.72	268.36	260.37	246.29	247.97	222.59	261.39	193.81
100		252.56	306.98	294.77	270.77	275.07	237.18	290.68	200.51
200		262.34	347.67	330.87	294.48	302.53	250.77	319.4	206.27
400		269.8	390.64	369.46	317.42	330.91	263.74	347.59	211.32
Chi-square values		6.2	7.39	8.24	16.49	19.84	34.28	50.92	111

Table: 6
Rainfall characteristics and parameters of probable maximum precipitation (PMP) in study area

Parameter	Values		
	Sagar	Khurai	Banda
Average one day maximum rainfall (mm)	132.63	140.99	114.06
Standard deviation	77.02	62.68	51.79
Coefficient of variation	0.581	0.445	0.454
Highest observed rainfall (HOR), mm	475.4	309.6	260.5
Probable maximum precipitation (PMP), mm	682.83	334.69	290.38
Frequency factor	7.14	3.09	3.40
Ratio of PMP to HOR	1.44	1.08	1.11

conservation structures have been presented in Table 7 along with their respective return period. It can be seen from the Table 7 that expected PMP for structures like field bunding, terrace outlet, vegetative waterways, field diversion and small permanent gully control structures was found to vary between 174 mm to 256 mm for Sagar, 193 mm to 251 mm for Khurai and 150 mm to 198 mm for Banda region. The expected PMP for structures like check dam, DLT, earthen dams, storage and diversion dams was found to be between 299 mm to 428 mm for Sagar, 275 mm to 327 mm for Khurai and 221 mm to 253 mm for Banda. These computed PMP's can be used to design various soil and water conservation structures to aid irrigation in the semi-arid region of Bundelkhand.

Table: 7
The probable maximum precipitation (PMP) and return period for design of different soil and water conservation structures

Types of soil and water conservation structures	Return period (Yr)	PMP (mm)		
		Sagar	Khurai	Banda
Field bunding	5	174	193	150
Terrace outlets and vegetative waterways	10	228	234	185
Field diversions	15	256	251	198
Small permanent masonry gully control structures	10-15	228-256	234-251	185-198
Check dams, Drainage Line Treatment (DLT) structures, Stock water dams	25	299	275	221
Earthen storage dam with natural spillways	25-50	299-364	275-305	221-240
Storage and diversion dams having spillways	50-100	364-428	305-327	240-253

4. CONCLUSIONS

This study gives an idea about the prediction of PMP and annual one-day maximum rainfall at different return periods to design various soil and water conservation structures. It was observed that the Generalised Pareto distribution was the best method among other distributions considered based on statistical analysis of Chi-square test for annual maximum daily rainfall at all stations (Sagar, Khurai, and Banda) under study for Dhasan basin. In overall,

Generalised Pareto followed by Log-Pearson distribution are recommended for estimation of annual maximum daily rainfall for the Dhasan river basin on a priority basis. The average annual one-day maximum rainfall is highest (140.99 mm) for the Khurai region and lowest (114.06 mm) for the Banda region whereas the PMP varies from 682.83 mm at Sagar to 290.38 mm at Banda. Regression model and trend line is developed from the expected annual one-day maximum rainfall using the best probability distribution method to determine the rainfall at different return periods. These findings will help in designing proper water harvesting structures based on PMP expected for that region which will be utilized for supplemental irrigation to crops during water scarcity periods and to mitigate the effect of dry spells during critical periods of crop growth. The results of this study would be useful for engineers, agricultural scientists, decision makers and researchers for agricultural development and construction of soil and water conservation structures for the study area.

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