Estimation of Annual One Day Maximum Rainfall for Design the Water Harvesting Structure and Check Dams in UP West Region, India

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ABSTRACT

The daily rainfall data of 36 years (1975-2010) were analyzed to determine the annual one day maximum rainfall of UP west region, India. The observed values were estimated by Weibull's plotting position and expected values were estimated by two well-known probability distribution functions viz., *normal and Gumbel. The expected values were compared with the observed values and goodness of fit was determined by chi-square (c2) test. The results showed that the Gumble distribution was the best fit probability distribution to forecast annual one day maximum rainfall for different return periods, based on the best fit probability distribution. The minimum rainfall 68.19 mm in a day can be expected to occur with 97 per cent probability and one year return period. However; the maximum rainfall 265.5 mm received with one per cent probability and 100 year return period. The results of this study may be very useful for agricultural scientists and civil engineers, decision makers, policy planners and researchers for agricultural development, construction and planning of soil and water conservation structures, irrigation and drainage systems in UP west region.*

***Key words**: Water deficiency; One day maximum rainfall; Probability distribution; Return period;*

Rainfall is one of the most important natural input resources to crop production and its occurrence and distribution is erratic, temporal and spatial variations in nature. Most of the hydrological events occurring as natural phenomena are observed only once. One of the important problem in hydrology deals with the interpreting past records of hydrological event in terms of future probabilities of occurrence. Analysis of rainfall and determination of annual maximum daily rainfall would enhance the management of water resources applications as well as the effective utilization of water resources. Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various return periods (*Bhakaret al., 2008*). Such information can also be used to prevent floods and droughts, and applied to planning and designing of water resources related to engineering such as reservoir design, flood control work and soil and water conservation planning. Though the rainfall is erratic and varies with time and space, it is commonly possible to predict return periods using various probability distributions. Therefore, probability analysis of rainfall is necessary for solving various water management problems and to access the crop failure due to deficit or excess rainfall. Scientific prediction of rains and crop planning done analytically may prove a significant tool in the hands of farmers for better economic returns (*Bhakaret al., 2008*). Frequency analysis of rainfall data has been attempted for different return period (*Bhakaret al., 2006*). Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances. The probability distribution functions most commonly used to estimate the rainfall frequency by methods norma and Gumbel distributions. There is no widely accepted procedure to forecast the one day maximum rainfall. In the present study, an attempt was made to determine the statistical parameters and annual one day maximum rainfall (ADMR) at various probability levels using two probability distribution functions..

METHODOLOGY

The area UP west situated at 27‡40´ N latitude and 80‡00' E longitude in India. As per record, the maximum rainfall was 406.2mm in 1989. The minimum rainfall was 57 mm in 1986. The whole calculation is based on these rainfall data. In this chapter, there is detailed explanation of various equation and method uses for computing the beneficial data which required for this study.

Daily rainfall data for the UP west region were collected from the established rain gauge stations have been used for the present investigation. The Time series rainfall records for the period of 36 years (1975 to 2010) have been collected from Water Resource Department. Annual maximum daily rainfall (ADMR) were sort out from these data (Table 1) and used statistical techniques for data analysis. The statistical behavior of any hydrological series was described on the basis of certain parameters. The commonly used procedures of statistical analysis as followed by *Gupta and Kapoor (2002)* have been followed. The computation of statistical parameters includes mean, standard deviation; coefficient of variation and coefficient of skewness were taken as measures of variability of hydrological series. All the above parameters have been used to describe the variability of rainfall in the present study.

Return period or recurrence interval is the average interval of time within which any extreme event of given magnitude will be equaled or exceeded at least once (*Patra, 2001*). Return period was calculated by Weibull's plotting position formula (*Chow, 1964*) by arranging one day maximum daily rainfall in descending order giving their respective rank.

$$T = \frac{N+1}{R}$$

Where, N - the total number of years of record and R- the rank of observed rainfall values arranged in descending order. Weibull's plotting position formula was used for computation of observed ADMR amounts at the return periods of 1.2, 1.05, 1.121, 1.233, .94, 2.46, 4.11, 5.28, 9.25 and 37 years.

Frequency or probability distribution helps to relate the magnitude of extreme hydrologic events like floods, droughts and severe storms with their number of occurrences such that their chance of occurrence with time can be predicted successfully. Observed values of ADMR can be obtained statistically through the use of the Chow's general frequency formula. The formula expresses the frequency of occurrence of an event in terms of a frequency factor (K_t) which depends upon the distribution of particular event investigated. *Chow (1951)* has shown that many frequency analyses was reduced to the following forms

$$X_t = \bar{x}(1 + C_v K_t)$$

Where, X_t is maximum value of event corresponding to return period T; X is mean of the annual maximum series of the data of length N years, C_v is the coefficient of variation and K_t is the frequency factor which depends upon the return period T and the assumed frequency distribution. The expected value of annual maximum daily rainfall for the same return periods were computed for determining the best probability distributions. Calculations of frequency factor by the two distributions namely normal and Gumbel are discussed as below.

Normal distribution: For normal distribution, the frequency factor 'K_t' was expressed by following equation (*Chow, 1988*),

$$K_T = \frac{x_{t-\mu}}{\sigma}$$

This is the same as the standard normal vitiates z. The value of z corresponding to accidences of p (p = 1/T) can be calculated by finding the value of an intermediate variable w:

$$w = [\ln \frac{1}{p2}]^2 \quad (0<p \leq 0.50)$$

Then z calculated by using the following equation:

$$z = w - [\frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}]$$

When, p > 0.5, 1-p is substituted for p in equation (4) and the value of z is computed by equation (5) is given a negative sign (*Bhakaret al., 2006*). The frequency factor K_t for the normal distribution is equal to z, as mentioned above.

Gumbel distributions: In Gumbel distribution, the expected rainfall X_t was computed by the following formula:

$$X_t = \bar{x}(1 + C_v K_t$$

Where, x is mean of the observed rainfall, C_v is the coefficient of variation; Kt- frequency factor which is calculated by the formula given by *Gumbel (1958)* as

$$K_t = -\frac{\sqrt{6}}{\pi}\{0.5772 + \ln[\ln\left(\frac{T}{T-1}\right)]\}$$

Testing the goodness of fit of probability distribution: The expected values of maximum rainfall were calculated by four well known probability distributions, *viz.*, normal and Gumbel distribution at different selected probabilities *i.e.* 97, 95, 90, 80, 50, 40, 25, 20, 10, 2.7, 2, 1 and 0.5 per cent levels. Among these two distributions, the best fit distributions decided by chi-square test for goodness of fit to observed values. The chi-square test statistic is given by the equation

$$X^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)}{E_i}$$

Where, O_i observed rainfall and E_i is the expected rainfall.

The best probability distribution function was determined by comparing Chi-square values obtained from each distribution and selecting the function that gives smallest Chi-square value (*Agrawal et al. 1988*).

RESULTS AND DISCUSSION

One day maximum daily rainfall corresponding date for the period of 36 years (1975 to 2010) is presented in Table 1. The maximum (406.6 mm) and minimum (57 mm) annual one day maximum rainfall was recorded during the year 1989 and 1986, respectively. This indicates that the mostly fluctuations was observed during the decade 1989-1986. The average for these 36 years rainfall was found to be 153.6 mm. However, no general trend in rainfall occurrence was observed during the study period. The distribution of one day maximum rainfall received during different months in a year is presented in fig.5. From the figure, it can be seen that July received the highest amount of one day maximum rainfall (48%) followed by August (41%) and September (9%) and January (2%).

Computation of ADMR by Gumbel method and effect of probability : The average ADMR found from the taken data is 153.56mm. However the computed ADMR by Gumbel method found to be 149.83mm at average probability and return period, 39 per cent and 31.89 respectively. As evident from visual observation the ADMR computed by Gumbel method and found to be 292.06, 265.5, 238.83, 227.18, 172.59, 149.44, 138.57, 114.77, 102.31, 70.29, 59.25, 48.88, 68.18 mm. As per result when the probability is increasing then the return period and ADMR values are decreasing. It means at high probability Percentage, the ADMR having low values and occurrence of events having with more frequency. In the case of long return period events having low probability percentage with the high value of ADMR. Long return period means, the frequency of occurrence of events should be low, is given in Table1 and shown in fig1. However; the relationship of probability and observed data with computed value of Gamble distribution are shown in fig. 2.

Table 1.Observed and expected one day maximum rainfall at different Probability levels.

Probability (%)	Return Period (Years)	Observed Rainfall (mm)	Expected Rainfall (mm)	
			Gumbel	Normal
97	1.2077	57	68.19	14.91
95	1.0571	69.4	48.88	29.77
90	1.1212	74.8	59.25	31.52
80	1.233	92.8	70.29	90.26
50	1.9473	147.8	102.31	153.6
40	2.4666	157.2	114.77	267.83
25	4.11	184	138.57	204.43
20	5.285	188.4	149.44	216.93
10	9.25	197.7	172.59	250.06
2.7	37	406.2	227.18	298.65
2	50	-	238.83	308.20
1	100	-	265.5	328.64
0.5	200	-	292.06	347.49

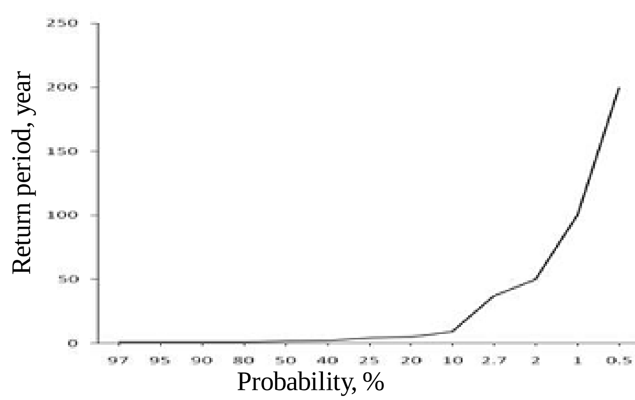

Fig. 1. Graphical presentation between probability and return period.

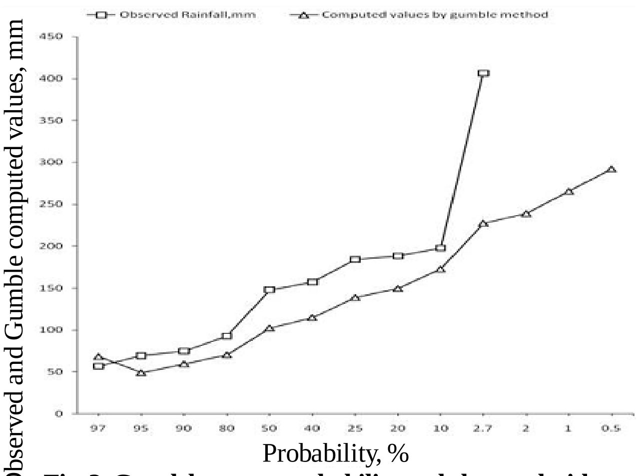

Fig. 2. Graph between probability and observed with computed Gumbel values

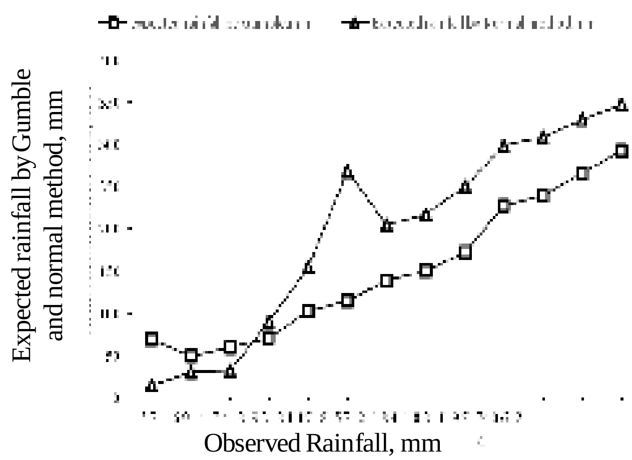

Fig. 4. Graphical presentation of Gumbel and Normal ADMR with observed ADMR

ADMR: The average ADMR was chosen from the observed data is 153.56 mm. However; it is shown in fig. 3. As evident from the Table 1 and fig 3, as the value of probability percentage increasing, the value of ADMR by normal distribution method is decreasing with the low value of return period. As per comparison of *Comparison between Normal distribution and observed values and effect of probability with ADMR:* The average ADMR was chosen from the observed data is 153.56 mm. However; it is shown in fig. 3. As evident from the table 1 and fig 3, as the value

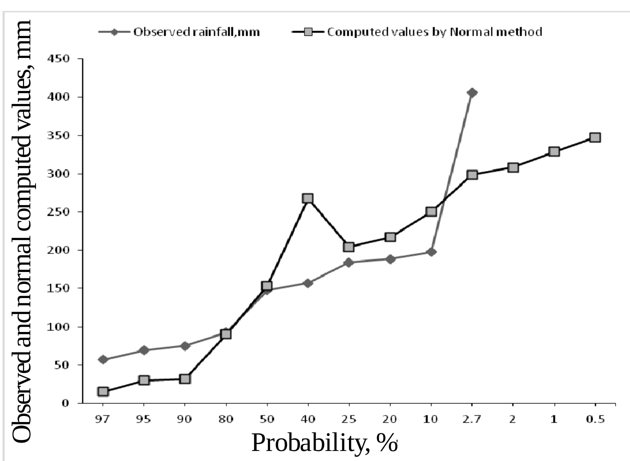

Fig. 3. Graph between probability and observed and computed values by Normal method.

of probability percentage increasing, the value of ADMR by normal distribution method is decreasing with the low value of return period. As per comparison of results the results the observed and computed ADMR value is inversely proportional to probability percentage and return period is also on the inverse trend of probability.

Comparison of Gumbel and Normal distribution with observed ADMR: Comparison of Gumbel and normal distribution with observed ADMR as per Table 1 and fig. 4, there is no similarity between Gumbel and Normal distribution ADMR with observed ADMR values, the probability is increasing but the computed and observed values of ADMR are decreasing. However in the case of deceasing probability percentage, the computed and observed ADMR values are increasing and similar trend is followed by the return period. It means if ADMR values are too high then the probability percentage is too low and return period is too long. As per Table.1, it may conclude that the high ADMR values having low probability percentage and long return period or the long ADMR values events occurs rarely or after a long period

Statistical Measures: To verify the effectiveness of the applied models, the several statistical parameters were used to decided the model goodness. In statistical measures average, standard deviation, coefficient of variation and coefficient of skewness has been computed. The computed values are given in Table 2.

Table 2. Computation of statistical parameters of annual one day Maximum rainfall

Statistical Parameter	Compute Value
AVERAGE ($\overline{X}$)	153.6
Standard Deviation (σ)	75.30
Coefficient of variation (CV)	0.49027
Coefficient of skewness (Ck)	1.80434

To find the best fit model, Chi-square test applied and the quantitative result of Chi-square test for the Gumbel and Normal distribution method were computed and are given in Table 3. The values of Chi-square for Gumbel and Normal distribution methods were found to be 227.420 and 332.410 respectively. The value of Gumbel distribution method is lower than Normal distribution method. In Chi-square test the lower value is considered for the goodness of model. So the Gumbel distribution method is best fit model.

Table 2. One day maximum rainfall for the period of 1975 to 2010.

Year	Date	Rainfall (mm)	Year	Date	Rainfall (mm)
1975	03 Sept	94.6	1993	03 Sep	157.2
1976	*13 Aug*	167.1	1994	23 July	118.0
1977	27 Aug	184.0	1995	06 Aug	130.6
1978	30 July	160.8	1996	25 June	305.8
1979	09 July	71.8	1997	10 Sept	76.0
1980	09 July	147.8	1998	09 July	120.6
1981	25 June	365.8	1999	03 Sept	190.4
1982	20 Aug	187.2	2000	20 Aug	90.4
1983	23 July	188.4	2001	24 Sept	158.0
1984	27 Aug	166.8	2002	10 Sept	197.7
1985	23 July	178.6	2003	09 July	116.1
1986	11 June	57.0	2004	02 July	104.8
1987	27 Aug	92.8	2005	09 July	196.4
1988	06 Aug	117.8	2006	23 July	148.1
1989	27 Aug	406.2	2007	27 Aug	74.8
1990	16 July	154.4	2008	13 Aug	124.9
1991	03 Sep	69.4	2009	01 Oct	153.0
1992	06 Aug	139.8	2010	13 Aug	115.2

Table 3. Observed and expected one day maximum rainfall at different Probability levels

Probability (%)	Return Period (Years)	Observed Rainfall (mm)	Expected Rainfall (mm)	
			Gumbel	Normal
97	1.2077	57	68.19	14.91
95	1.0571	69.4	48.88	29.77
90	1.1212	74.8	59.25	31.52
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50	1.9473	147.8	102.31	153.6
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20	5.285	188.4	149.44	216.93
10	9.25	197.7	172.59	250.06
2.7	37	406.2	227.18	298.65
2	50	-	238.83	308.20
1	100	-	265.5	328.64
0.5	200	-	292.06	347.49

According to Gumbel distribution, in a day the minimum rainfall of 68.19 mm rainfall can be expected to occur with 99 per cent probability and one]\ year return period and maximum of 265.5 mm rainfall can be received with one per cent probability and 100 year return period. A maximum of 102.31 mm rainfall is expected to occur at every 2 years which is approaching average ADMR. 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 (*Bhakar et al., 2006*)

Table 4. Chi-square values at different probability levels for different distributions.

Probability (%)	Return Period (years)	Gumbel	Normal
97	1.2077	1.836	118.8174
95	1.0571	8.6143	52.755
90	1.1212	4.0810	59.4276
80	1.233	7.2087	.007147
50	1.9473	20.2261	.2190
40	2.4666	15.6861	45.6968
25	4.11	14.8941	2.04170
20	5.285	10.1517	3.752
10	9.25	3.6532	10.9636
2.7	37	141.0694	38.730
	X^2_{cal}	227.420	332.4102

As per computed and observed data The various graphical relationships between are like probability and computed values of rainfall by Gumbel method, probability and computed values by normal method, return period and expected rainfall values by Gumbel method, return period and expected rainfall values by normal method and one day maximum annual rainfall (mm) distribution are shown in fig. 5-9 respectively. The Fig. 5 and Fig. 6 are presenting the relationships between probability and computed rainfall buy Gamble and Normal

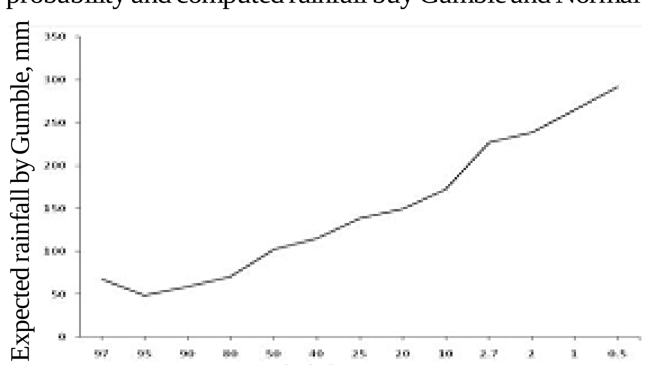

Fig. 5. Graphical Presentation between probability and computed values by Gumbel.

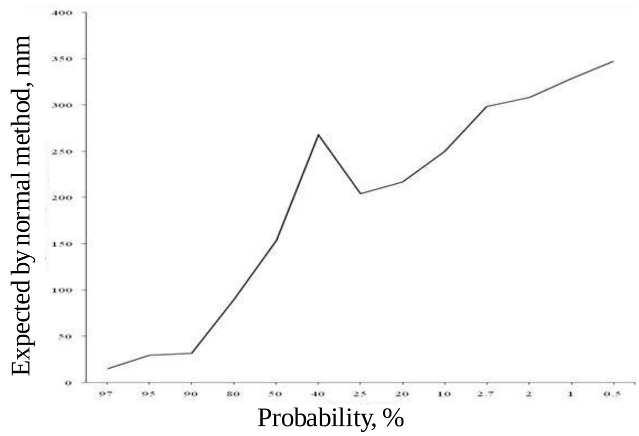

Fig. 6. Graphical Presentation between probability and computed values by normal method.

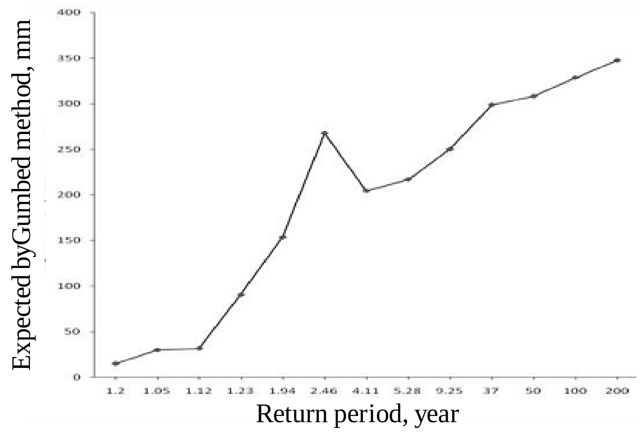

Fig. 8. Graphical Presentation between return period and expected rainfall values by normal method.

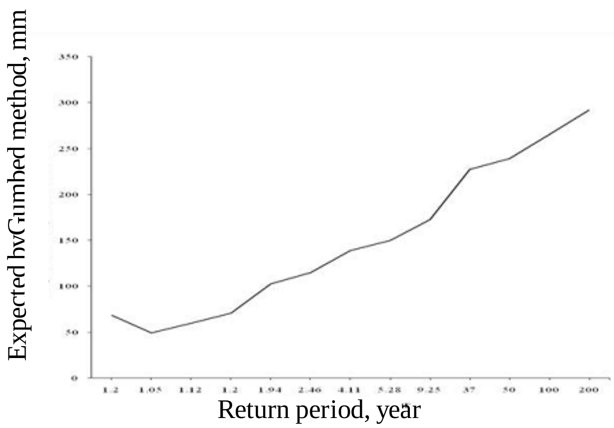

Fig. 7. Graphical Presentation between return period and expected rainfall values by Gumbel method.

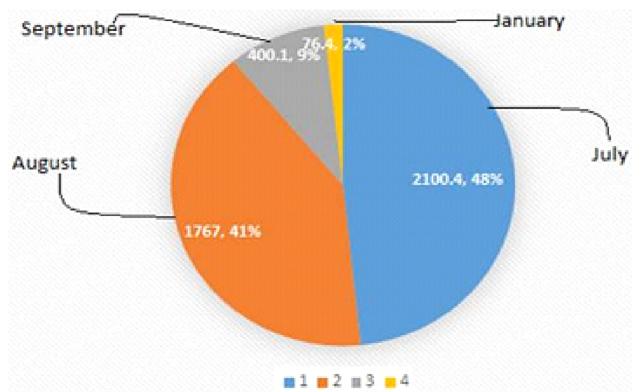

Fig. 9. Distribution of one day maximum annual rainfall (mm) in a year.

distribution methods and the Fig. 7 and Fig. 8 are presenting the relationships between returned period and computed rainfall by Gamble and Normal distribution methods. However; the fig.9 is representing the distribution pattern of q one day maximum annual rainfall (mm).

CONCLUSION

The study was conducted for the flood frequency analysis of any area and last 36 years data were analysed. Gumbel and Normal distribution two methods were used to find the expected rainfall values. These methods needed various parameters to compute the expected rainfall values like; mean, standard deviation, coefficient of variation and coefficient of skewness.

The best fitness decided by Chi-square test between Gumbel and Normal distribution methods. The computed mean value of ADMR was found to be 153.6 mm with standard deviation and coefficient of variation of 75.30 and 0.49, respectively. The coefficient of skewness was observed to be 1.80. The month of July received one day maximum rainfall (48%) followed by August (41%), September (9%) and January (2%). However; the frequency analysis of ADMR for identifying the best fit probability distribution was studied for four probability distributions such as normal and Gumbel by using by the test of Chi-square goodness of fit. It was observed that all the two probability distribution functions fitted significantly, except the normal distribution. Gumbel distribution was found to be the best fit to ADMR data by Chi-square test for goodness of fit. A maximum of 102.31 mm rainfall is expected to occur at every 2 years and 50 per cent probability which is approaching means ADMR. For a recurrence interval of 100 years one per cent probability, the one day annual maximum rainfall was found to be 265.5 mm. However; the p probability percentages were found to be 227.78 and 298.65 for

Gumbel and Normal distribution method respectively. This study gives an idea about the prediction of ADMR rainfall to design the small and medium hydraulic and soil and water conservation structures, irrigation, drainage works, vegetative waterways and field diversions. This study also helps in developing cropping plan and estimating design flow rate for maximizing crop production.

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