Estimation of Consecutive Days Maximum Rainfall using Different Probability Distributions and Their Comparsion

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Abstract—*Rainfall is a scarce and an important hydrological variable in dry land areas. The need for water in these areas increases daily due to population growth, economic development, urbanization and consequently, water management using all available resources is becoming increasingly crucial. 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 rain and crop planning may prove a significant tool in hands of farmers for better economic returns. Frequency analysis of rainfall data has been attempted for different rainfall period. Frequency analysis helps us determined expected rainfall at various chances. A major step in frequency analysis of precipitation involves selection of a suitable distribution for representing precipitation depth to investigate the extremes. Four distributions namely Gumbel, Log Pearson Type III, Log Normal and Van Te Chow can be applied for prediction of annual maximum rainfall. The daily rainfall data of 26 years of Rorkee, Uttarakhand collected from National Institute of Hydrology have been used in this study. The paper tries to fit various theoretical probability distributions to annual maximum rainfall for one day, two consecutive days, three consecutive days, four consecutive days; and to select the best probability distribution for annual maximum rainfall prediction for daily, two consecutive days, three consecutive days, four consecutive days.*

Keywords*: Gumbel, Log Pearson Type III, Log Normal, Van Te Chow.*

1. INTRODUCTION

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 (Subudhi, 2007). Probability and frequency analysis of rainfall data enables us to determine the expected rainfall at various chances (Bhakar et 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 (Agarwal et al., 1988 and Dabral et al., 2009). Though the rainfall is erratic and varies with time and space, it is commonly possible to predict return periods using various probability distributions (Upadhaya and Singh, 1998). 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 (Bhakar et al., 2008). Frequency analysis of rainfall data has been attempted for different return period (Bhakar et al., 2006; Barkotulla et al., 2009; Nemichandrappa et al., 2010; Manikandan et al., 2011 and Vivekanandan, 2012). 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 are normal, log-normal, log-Pearson type-III and Gumbel distributions. There is no widely accepted procedure to forecast one day, two consecutive days, three consecutive days, four consecutive days maximum rainfall . In the present study, an attempt was made to determine the statistical parameters and annual one day, two consecutive days, three consecutive days, four consecutive days maximum rainfall using various probability levels using four probability distribution functions, viz., normal, log-normal, log-Pearson type-III and Gumbel distribution and to select the best probability distribution system.

2. MATERIALS AND METHODS

The rainfall data for 26 years (1987-2012) were collected from National Institute of Hydrology (NIH), Roorkee which is located at 29° 51' N and 77°. 53' on the south bank of Solani River and 274 meters above the mean sea level. The Upper

Ganges Canal is the most important feature and adds beauty to the city. Running from north to south, it divides the city in two distinct parts.

The city receives an annual average rainfall of 1068 mm out of which the average monsoon rainfall is 878 mm.

The four probability distributions that are adopted for analysis are the Gumbel, Log Pearson Type III, Log Normal and Van Te Chow distributions. These distributions are elaborated in the upcoming sections.

2.1 Plotting position method

The purpose of frequency analysis of an annual series is to obtain a relationship between the magnitude of the event and its probability of exceedence. The probability analysis may be made either by empirical or by analytical methods. A simple empirical technique is to arrange the given annual extreme series in descending order of magnitude and to assign an order number m. thus for the first entry m - 1, for the second entry m = 2, and so on. till the last event for which ni - Number of years of record. The probability P of an event equaled to or exceeded is given by the Weibull formula.

$$P = m/ (N+1) \quad \text{….(3.1)}$$

$$T= 1/P$$

where T is recurrence interval in years.

The empirical formulae, i.e. equation (3.1) was used to calculate the exceedence probability of the event, equation (3.1) is considered to be the most popular and frequently used. The plot of daily maximum rainfall vs return period, T yields the probability distribution. A logarithmic scale period for T is often advantageous. This simple empirical procedure can give good results for small extrapolations and the errors increase with the amount of extrapolation. For accurate work, various analytical calculation procedures using frequency factors are available. These methods include Gumbel's extreme value distribution, Log Pearson Type III, Log Normal and Van Te Chow distributions. The methods of fitting these distributions are described further.

2.1.1 Gumbel's extreme value distribution

The Gumbel's extreme value distribution was introduced by Gumbel (1941) and is commonly knownn as Gumbel's distribution. It is one of the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for the prediction of flood peaks, maximum rainfalls, maximum wind speed etc.

Chow (1951) showed that most frequency distribution functions applicable in hydrologic studies can be expressed by the following equation known as equation of hydrologic frequency analysis:

$$X_T=\bar{X} + K\sigma_n$$

Where X_T is the value of the variate X of random hydrologic series with a return period of T, $\bar{X}$ is the mean of the variate, σ is the standard deviation of the variate and K is the frequency factor.

Since practical data series of extreme events of rainfall depth have finite length records, equation (3.3) is modified to account for finite sample size N for practical use as given below:

$$X_T=\bar{X} + K\sigma_{n-1} \quad \ldots \quad (3.4)$$

In which σ_{n-1} represents the standard deviation of sample and is expressed by the equation

$$\sigma_{n-1}=\sqrt{\frac{(X-\bar{X})^2}{N}} \quad \ldots (3.5)$$

The frequency factor K, is expressed by the equation as,

$$K= \frac{Y_T-\bar{Y}}{S_n} \quad \ldots(3.6)$$

Where Y_T is the reduced variate that depends on recurrence interval T and is expressed by the equation-

$$Y_T =-[\ln(\ln T/(T-1))] \quad \ldots(3.7)$$

in which Y is the reduced mean in equation(3.6), and depends on the sample size N. S_n is the reduced standard deviation in equation (3.6). Yn and Sn corresponding to sample size N are selected.

The equations (3.4 to 3.7) are used to estimated extreme rainfall magnitude corresponding to given recurrence interval based on annual rainfall series

1. The 26 years rainfall is assembled for the sample size N in the present study. Annual maximum rainfall value is considered as the variate X, the mean of the variate $\bar{X}$ and standard deviation of the sample, σ_{n-1} for given data is calculated.
2. Tables from appendix of Subramanyam(2009) are used to find the reduced mean $\bar{Y}_n$ and the reduced standard deviation $\bar{S}_n$ corresponding to sample size N equal to 26.
3. The reduced variate, Y_T for a given return period, T is given by the equation (3.7).
4. The frequency factor is computed by equation (3.6).
5. The required value of variate X of random annual maximum rainfall series with return period T is computed by equation (3.4)

2.1.2 Log Pearson Type III

This distribution is extensively used in USA for the projects sponsored by the US government. In this the variate is first transformed into the logarithmic form (base 10) and transformed data is then analyzed. If X is the variate of a random hydrologic series, then the series of variates where

$$Z=\log X \quad \ldots(3.8)$$

For this series determined by the eqution (3.8), the equation (3.3) can be expressed as:

$$Z_T = \bar{Z} + K_z\sigma_z \quad \ldots(3.9)$$

in which Kz is the frequency factor which depends on recurrence interval T and coefficient of skewness, Cs, Z is the mean of Z values and σ_z is standard deviation of Z value sample, σ_z can be expressed as-

$$\sigma_z = \sqrt{\frac{\sum(Z-\bar{Z})^2}{N-1}} \quad \ldots(3.10)$$

Coefficient of skewness is

$$C_s = \sqrt{\frac{N\sum(Z-\bar{Z})^2}{(N-1)(N-2)(\sigma^3)}} \quad \ldots(3.11)$$

After finding Z_T using equation(3.9), the corresponding value of variable, X_T is obtained using the equation:

$$X_T = \text{antilog } Z_T \quad \ldots(3.12)$$

2.1.3 Log Normal distribution

Log normal distribution is a special case of Log-Pearson type III distribution. When the skew is zero, i.e. C_S =0, Log Pearson type III distribution reduces to Normal distribution. The other statistics like $\bar{Z}$ is calculated for transformed rainfall data and σ_z can be calculated from equation (3.10), the value of K_Z for a given return period T and C_S =0 is read from appendix of Subramanyam(2009). A Log Normal plots a straight line on logarithmic paper.

2.1.3 Van Te Chow distribution

In the Van Te Chow distribution, the plotting position is assigned to each annual maximum rainfall value arranged in decreasing order of magnitude. If rank of X value is m, its plotting position for return period

$$T = \frac{N+1}{m} \quad \ldots(3.13)$$

Where N is equal to total number of years of observation

$$Z_V = \log[\log T - \log(T-1)] \quad \ldots(3.14)$$

$$Z_V = \log\log \frac{T}{T-1} \quad \ldots(3.15)$$

On substitution of value of T

$$Z_V = \log\log \frac{N+1}{N+1-m} \quad \ldots(3.16)$$

The regression analysis between variable X and Y computed through equation

$$X_T = A + BZ \quad \ldots(3.17)$$

In which A and B are constants, which can be determined by the following equation-

$$A = \left(\sum \frac{xi}{N}\right) - \left(B\sum\frac{Z_i}{N}\right) \quad \ldots(3.18)$$

$$B = \frac{\sum ZiXi - \sum Zi\frac{Zi}{N}}{\sum Zi^2 - \frac{\sum Zi^2}{N}} \quad \ldots(3.19)$$

When the constants A and B are determined, the equation (3.17) can be used to determine X_T for any desired return period T. The theoretical extreme rainfall magnitudes were computed based on equation (3,17), corresponding to slected recurrence intervals of 1.05, 1.11, 1.25, 2, 5, 10,25, 50 and 100 years.

2.2 Goodness of Fit Criteria

2.2.1 Chi-Square test

Chi –square test is a statistical hypothesis test in which the sampling distribution of the statistic is a chi-squared distribution when the null hypothesis true. The following equation can be used to calculate the Chi-Square values

$$X^2 = \left(\frac{(RO - RE)^2}{Ro}\right) \quad \ldots(3.20)$$

R_o and R_E are the observed and estimated rainfall magnitudes, respectively. The distribution with the least average value of the Chi- Square values is adjusted to be the best.

2.2.2 Percentage absolute deviation

The goodness of the fit of the computed and observed rainfall magnitudes can also tested using percentage absolute deviation (PAD) which can be expressed as:

$$PAD = \left|\frac{Ro-Re}{Ro}\right| * 100 \quad \ldots(3.21)$$

Where PAD is the percentage absolute deviation of the compound extreme rainfall values with respect to the observed values

2.2.3 Integral square error

The integral square error (I.S.E) was used to measure the goodness of fit between the observed and estimated extreme rainfall. The integral square error values of distribution were estimated as

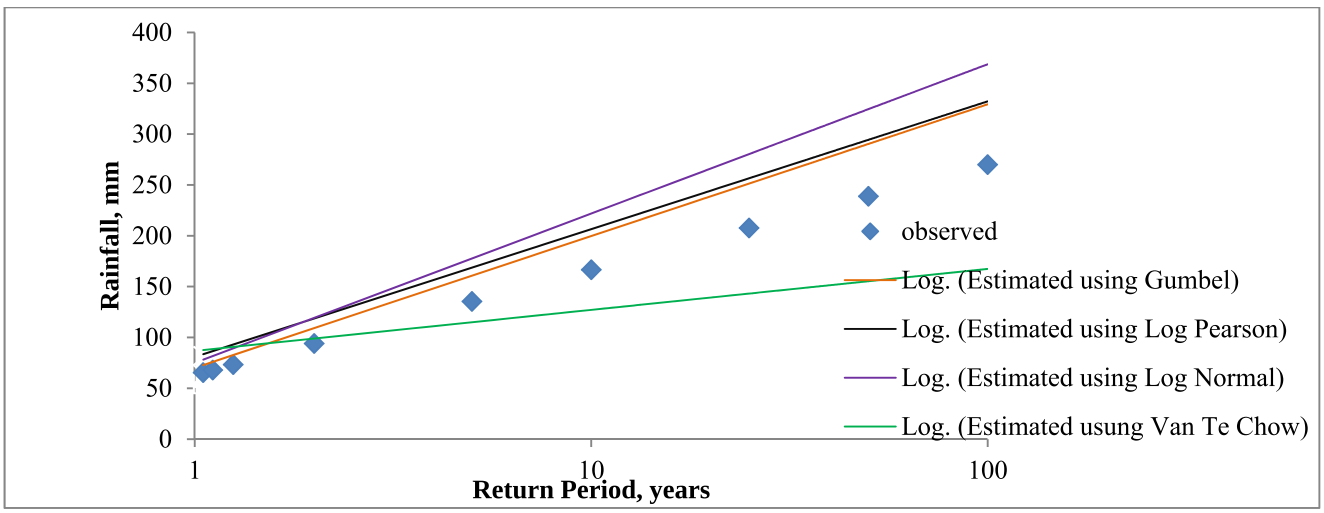
$$ISE = \frac{\sqrt[2]{\sum(REi-Roi)^{\ 2}}}{\sum Roi} \quad \ldots(3.22)$$

R_{oi} and R_{ei} are the observed and estimated values of the extreme rainfall magnitudes illustrated in the upcoming tables

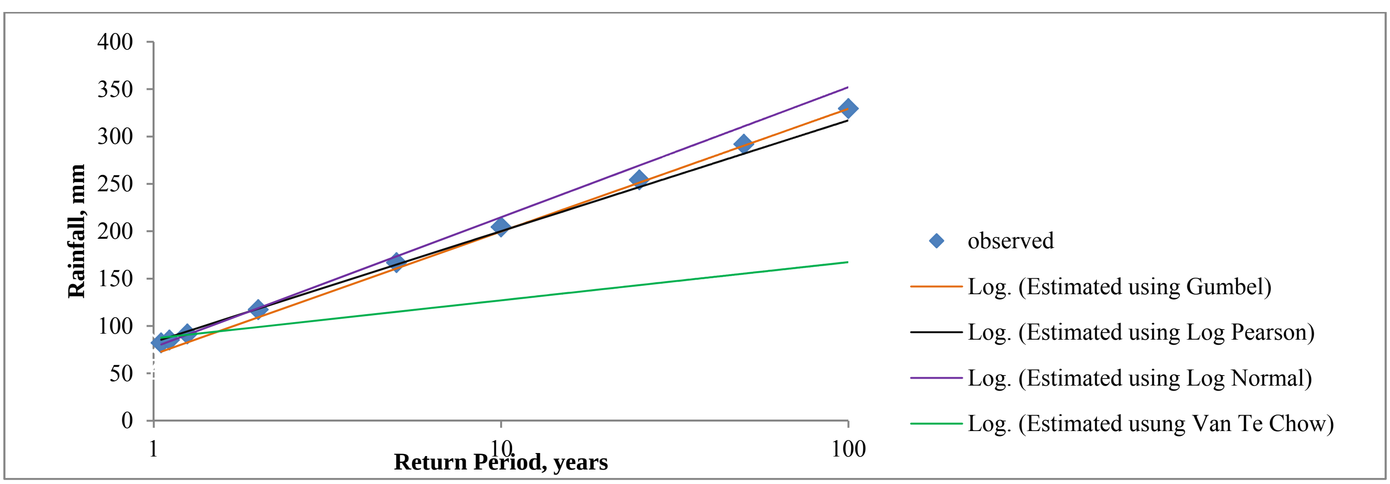
3. RESULTS AND CALCULATIONS

Return Period(T), years	Probability	Observed	Gumbel	Log Pearson	Log Normal	Van Te Chow	Chi Square Test				PAD				I.S.E			
							Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow
1.05	95	65.321	54.333	60.496	63.524	81.869	2.222151	0.384829	0.050834	3.344811	16.82154	7.386598	2.75103	25.33335	0.168215	0.073866	0.02751	0.253334
1.11	90	67.816	66.889	73.281	74.475	85.828	0.012847	0.407558	0.595398	3.780027	1.366934	8.05857	9.819217	26.5601	0.013669	0.080586	0.098192	0.265601
1.25	80	73.15	83.665	91.443	90.308	91.028	1.321523	3.65948	3.259921	3.511259	14.37457	25.00752	23.45591	24.44019	0.143746	0.250075	0.234559	0.244402
2	50	94.025	122.696	134.743	130.599	103.172	6.699699	12.30458	10.24248	0.810953	30.49295	43.3055	38.89817	9.728264	0.30493	0.433055	0.388982	0.097283
5	20	135.397	175.211	189.828	188.863	119.498	9.047118	15.60746	15.13591	2.115334	29.40538	40.20104	39.48832	11.74251	0.294054	0.40201	0.394883	0.117425
10	10	166.521	209.98	223.498	229.017	130.115	8.994593	14.52531	17.05441	10.18635	26.09821	34.2161	37.5304	21.86271	0.260982	0.342161	0.375304	0.218627
25	4	207.664	253.912	262.543	281.382	143.986	8.423696	11.47128	19.31305	28.16168	22.27059	26.42682	35.49869	30.66396	0.222706	0.264268	0.354987	0.30664
50	2	238.788	286.503	289.411	321.187	154.107	7.946588	8.85484	21.13907	46.53177	19.98216	21.19998	34.50718	35.46284	0.199822	0.212	0.345072	0.354628
100	1	269.911	318.855	314.491	361.836	164.194	7.512867	6.319343	23.35369	68.06634	18.13338	16.51656	34.05752	39.16736	0.181334	0.165166	0.340575	0.391674
						MEAN	**5.797898**	8.170521	12.23831	18.50095	**19.88286**	24.70208	28.44516	24.9957	**0.198829**	0.247021	0.284452	0.249957

For 1 day maximum rainfall



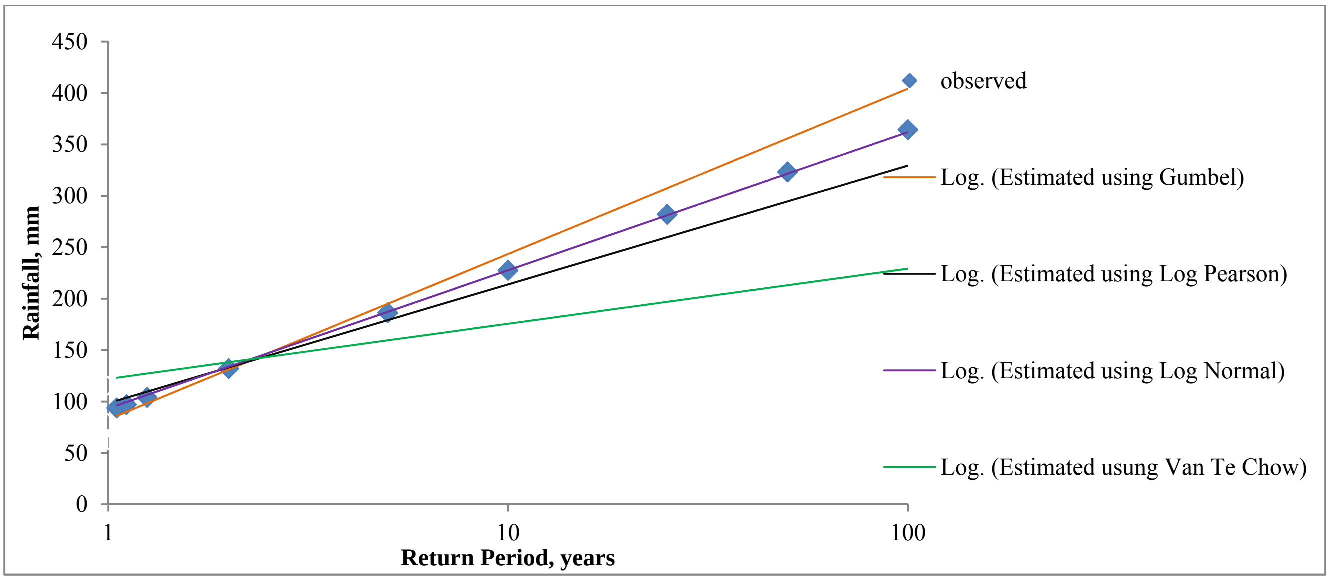
For 1day maximum rainfall



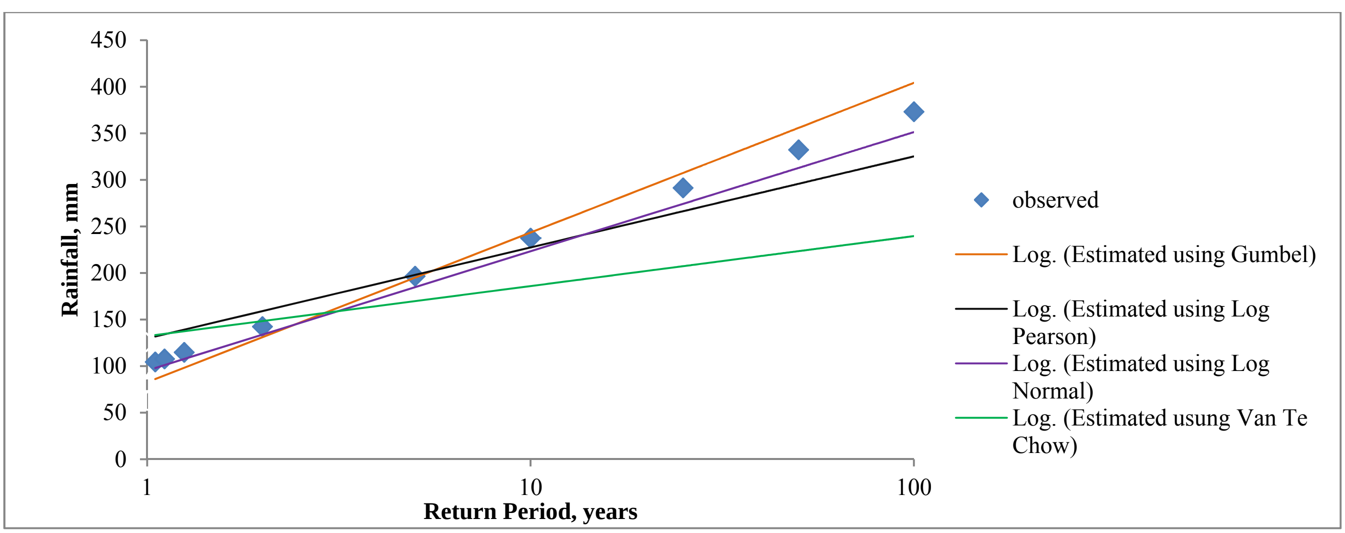
For 2 dayonsecutive maximum rainfall

Return Period(T), years	Probability	Observed	Gumbel	Log Pearson	Log Normal	Van Te Chow	Chi Square Test				PAD				I.S.E			
							Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow
1.05	95	82.273	54.333	62.384	65.533	81.869	14.36776	6.340926	4.27613	0.001994	33.96011	24.1744	20.34689	0.491048	0.339601	0.241744	0.203469	0.00491
1.11	90	85.289	66.889	75.058	76.2662	85.828	5.06152	1.394566	1.067457	0.003385	21.57371	11.99569	10.57909	0.631969	0.215737	0.119957	0.105791	0.00632
1.25	80	91.737	83.665	92.825	91.6592	91.028	0.778787	0.012752	6.6E-05	0.005522	8.799067	1.185999	0.084808	0.772862	0.087991	0.01186	0.000848	0.007729
2	50	117.249	122.696	134.45	130.307	103.172	0.241816	2.200628	1.308536	1.920695	4.645669	14.67049	11.13698	12.00607	0.046457	0.146705	0.11137	0.120061
5	20	166.986	175.211	186.28	185.25	119.498	0.386109	1.998381	1.800668	18.87153	4.925563	11.55426	10.93744	28.43831	0.049256	0.115543	0.109374	0.284383
10	10	204.611	209.98	217.219	222.64	130.115	0.137281	0.731804	1.459957	42.65192	2.624004	6.161937	8.811354	36.4086	0.02624	0.061619	0.088114	0.364086
25	4	254.348	253.912	252.711	270.951	143.986	0.000749	0.010604	1.017378	84.58997	0.171419	0.643606	6.527671	43.39016	0.001714	0.006436	0.065277	0.433902
50	2	291.973	286.503	276.806	307.392	154.107	0.104435	0.831044	0.773428	123.3366	1.873461	5.194658	5.280968	47.21875	0.018735	0.051947	0.05281	0.472187
100	1	329.598	318.855	299.225	344.39	164.194	0.361958	3.083028	0.635336	166.6229	3.259425	9.215165	4.487891	50.18356	0.032594	0.092152	0.044879	0.501836
						MEAN	2.382268	1.844859	**1.370995**	48.66717	9.092491	9.421799	**8.688122**	24.39348	0.090925	0.094218	**0.086881**	0.243935

For 2 day consecutive maximum rainfall



For 3 day consecutive maximum rainfall



For 3 days consecutive maximum rainfall

Return Period(T), years	Probability	Observed	Gumbel	Log Pearson	Log Normal	Van Te Chow	Chi Square Test				PAD				I.S.E			
							Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow
1.05	95	93.736	63.121	75.562	78.987	115.484	14.84891	4.371169	2.754035	4.095593	32.66088	19.3885	15.73462	23.20133	0.326609	0.193885	0.157346	0.232013
1.11	90	97.036	78.694	89.2554	90.547	120.745	4.275154	0.678253	0.465031	4.655403	18.90226	8.018261	6.687209	24.4332	0.189023	0.080183	0.066872	0.244332
1.25	80	104.092	99.5	108.075	106.85	127.655	0.211924	0.14679	0.071189	4.34934	4.411482	3.826423	2.649579	22.63671	0.044115	0.038264	0.026496	0.226367
2	50	132.01	147.9	150.885	146.683	143.795	1.707181	2.361173	1.46777	0.965863	12.03697	14.29816	11.11507	8.927354	0.12037	0.142982	0.111151	0.089274
5	20	186.437	213.038	202.375	201.362	165.492	3.321535	1.255194	1.106245	2.650841	14.26809	8.548732	8.005385	11.23436	0.142681	0.085487	0.080054	0.112344
10	10	227.609	256.16	232.403	237.62	179.868	3.182228	0.09889	0.421766	12.67153	12.54388	2.106244	4.398332	20.97501	0.125439	0.021062	0.043983	0.20975
25	4	282.036	310.644	266.338	283.589	198.037	2.634584	0.925242	0.008505	35.62886	10.14339	5.565956	0.550639	29.78308	0.101434	0.05566	0.005506	0.297831
50	2	323.208	351.064	289.102	317.718	211.487	2.2103	4.02356	0.094864	59.0182	8.618599	10.55234	1.698597	34.56629	0.086186	0.105523	0.016986	0.345663
100	1	364.38	391.188	310.107	351.959	224.893	1.837144	9.498523	0.43835	86.51502	7.357155	14.89462	3.408804	38.28064	0.073572	0.148946	0.034088	0.382806
						MEAN	3.803218	2.595422	**0.758639**	23.39452	13.43808	9.688803	**6.027581**	23.782	0.134381	0.096888	**0.060276**	0.23782

For 3 days consecutive maximum rainfall

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Return Period(T), years	Probability	Observed	Gumbel	Log Pearson	Log Normal	Van Te Chow	Chi Square Test				PAD				I.S.E			
							Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow	Gumbel	Log Pearson	Log Normal	Van Te Chow
1.05	95	104.456	63.121	96.83	80.771	125.711	27.06836	0.600598	6.945305	3.593759	39.57169	7.300682	22.67462	20.34828	0.395717	0.073007	0.226746	0.203483
1.11	90	107.732	78.694	115.066	92.138	130.98	10.71499	0.46745	2.639224	4.126351	26.95392	6.807634	14.47481	21.57947	0.269539	0.068076	0.144748	0.215795
1.25	80	114.734	99.501	147.83	108.08	137.902	2.33208	7.409492	0.409657	3.892302	13.2768	28.84585	5.799501	20.19279	0.132768	0.288459	0.057995	0.201928
2	50	142.441	147.9	175.927	146.683	154.07	0.201492	6.373736	0.122677	0.877742	3.832464	23.50868	2.978075	8.164082	0.038325	0.235087	0.029781	0.081641
5	20	196.456	213.03	232.33	199.072	175.803	1.289478	5.539293	0.034377	2.426275	8.436495	18.26058	1.331596	10.51279	0.084365	0.182606	0.013316	0.105128
10	10	237.317	256.16	242.851	233.518	190.203	1.386082	0.126107	0.061804	11.67032	7.940013	2.331902	1.600812	19.85277	0.0794	0.023319	0.016008	0.198528
25	4	291.332	310.644	271.497	276.92	208.402	1.200581	1.449103	0.750057	33.00057	6.628863	6.808384	4.946933	28.46581	0.066289	0.068084	0.049469	0.284658
50	2	332.193	351.064	289.477	308.976	221.875	1.014387	6.303287	1.744566	54.85098	5.680734	12.85879	6.989009	33.20901	0.056807	0.128588	0.06989	0.33209
100	1	373.054	391.188	305.086	341.013	235.304	0.840624	15.14212	3.010518	80.64063	4.860958	18.21935	8.588837	36.92495	0.04861	0.182193	0.085888	0.369249
						MEAN	5.116453	4.823465	**1.746465**	21.67544	13.02021	13.88243	**7.709355**	22.13888	0.130202	0.138824	**0.077094**	0.221389

For 4 days consecutive maximum rainfall

4. SUMMARY AND CONCLUSION

1. The minimum average values using three different goodness of fit criterion viz. Chi square test, Percentage Absolute deviation and Integral Square Error(ISE) were found 5.79,19.88 and .198 in case of Gumbel distribution for one day maximum rainfall and 1.370, 8.688 and .0868 in case of Log Normal distribution for two consecutive days.
2. The minimum average values using three different goodness of fit criterion viz. Chi square test, Percentage Absolute deviation and Integral Square Error(ISE) were found 0.758, 6.02 and .0602 in case of Log Normal distribution for three consecutive day maximum rainfall and 1.746, 7.709 and 0.077 in case of Log Normal distribution for four consecutive days.
3. The Gumbel distribution was found to be the best fit for one day annual maximum rainfall value of Roorkee based on performance evaluation criteria.
4. The Log Normal distribution was found to be the best fit for prediction of two, three and four consecutive day annual maximum rainfall values of Roorkee based on performance evaluation criteria.

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