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Estimation of Annual Maximum Rainfall for Central Meghalaya

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ABSTRACT

Daily rainfall data for 28 years (1983-2010) of Central Meghalaya, Nongstoin station has been collected and frequency analysis for maximum daily rainfall has been attempted. The annual maximum daily rainfall data has been fitted to five different probability distribution functions i.e. Normal, Log-normal, Pearson Type-III, Log Pearson Type-III and Gumbel Type-I extreme. The probable rainfall value for different return periods has been estimated. These estimated values have been compared with the values obtained by Weibull's Method. The analysis indicates that, the Gumbel distribution gives the closet fit to the observed data. Hence, Gumbel distribution may be used to predict maximum rainfall, which will be a great importance for economic planning and design of small and medium hydraulic structures.

Keywords: Rainfall analysis, Maximum daily rainfall, Rainfall and probability distribution

INTRODUCTION

The study place, Nongstoin station is located at 25° 10′ to 25° 51′ North Latitude and 90° 44′ to 91° 49′ East Longitude at an altitude of 1,200 m above mean sea level. The behavioral pattern of rainfall with reference to the amount of rainfall and number of rainy days in a week at Nongstoin, Meghalaya from historic daily rainfall records (1983-2010) were calculated using probabilistic approach. For Nongstoin, the normal annual rainfall ranges from 180 - 600 cm, which is highly erratic and occurrence of high intensity rainfall is somewhat common. Under such circumstances, probable maximum rainfall value is of great importance while designing hydraulic structures. Generally, areas with low rainfall are having high rainfall variability, the North East Hilly (NEH) region, by virtue of receipt of heavy rainfall the value ranges from 8-15%.

Hydraulic and design engineers require maximum daily rainfall of different return periods for safe planning and design of small and medium hydraulic structures such as small dams, bridges, culverts drainage works, etc. This would also be useful for forecasting the floods to downstream towns and villages. Prediction of maximum daily rainfall for higher return periods is usually done by a probability distribution function which fit the observed rainfall data better. Probability analysis of one day rainfall has been attempted for different places (Sharda and Bhusan 1985; Prakash and Rao 1986; Aggarwal et al. 1988; Bhatt et al. 1996 Mohanty et al. 1999; Kumar 1999 and 2000; George and Kolappadan 2002; Suresh 2003; Dingre and Atre 2005; Pandey and Bisht 2006; Ray et al. 2012a; Ray et al. 2012b). An attempt has been made in this present study to estimate the probable maximum daily for different return periods for Nongstoin, Meghalaya by five different probability distribution functions and to select the best one.

MATERIALS AND METHODS

Annual maximum daily rainfall data of Nongstoin, for 28 years (1983-2010) were fitted to five probability distribution functions i.e. Normal, Log normal, Pearson type-III, Log Pearson type-III and Gumbel type-I extreme distribution to predict one day maximum rainfall. The five different probability distributions (Chow et al. 1988) for fitting hydrologic data are given as follows:

Normal Distribution

The probability density function of this distribution is given by:

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$$f_x = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \quad (1)$$

Where μ and σ are mean and standard deviation of variate 'x' respectively (Singh 1994)

Log Normal Distribution

The probability density function of this distribution is given by:

$$f_x = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu_y)^2}{2\sigma_y^2}\right] \quad \ldots (2)$$

where y = log x, μ_y and σ_y are mean and standard deviation of variate 'x' respectively (Singh 1994)

Pearson type-III Distribution

$$f_x = \frac{\lambda^n}{\Gamma(n)}(x-A)^{n-1} e^{-\lambda(x-A)} \quad \ldots (3)$$

where λ = scale parameter; η is the shape parameter; Γ is gamma function and A = location parameter.

Log Pearson type-III Distribution

$$f_x = \frac{\lambda^n}{\Gamma(n)}(\ln x - A)^{n-1} e^{-\lambda(\ln x - A)} \quad \ldots (4)$$

where λ = scale parameter; η is the shape parameter; Γ is gamma function and A = location parameter.

Gumbel type-I extreme Distribution

$$f_x = \alpha \exp[-\alpha(x-\beta) - \exp\{-\alpha(x-\beta)\}] \quad \ldots (5)$$

where α = scale parameter and β = location parameter (Singh 1994)

All the five different probability distribution functions were compared by chi-square (χ^2) test of goodness of fit by the following equation

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \quad \ldots (6)$$

RESULTS AND DISCUSSION

Central Meghalayan district i.e. West Khasi Hills district is the largest district in the state with a geographical area of 5,247 km^2 with district headquarters located at Nongstoin. It has a population of 3,85,601 with a population density of 73 (Census 2011). Agriculture is the prime occupation of the district which is mostly rainfed. The monthly normal and extreme rainfall (number of rainy days) along with SD, CV and percentage contribution at Nongstoin station is presented in Table 1. More than 60% of the rainfall is contributed between June to September. The annual average rainfall of Nongstoin is calculated to be 3,529.4 mm with 118 numbers of rainy days. The maximum and minimum rainfall of central Meghalaya is 6,189.2 and 1,825.0 during 1988 and 1998, respectively. A decreasing rainfall is found for the Nongstoin station. From Table 1 it may be noted that the standard deviation (SD) is more than 100 mm for the month of April to October. The highest SD was found for the month of July i.e., 509.02; and it was the lowest for the month of December i.e., 21.94. Contrarily, the coefficient of variation (CV) is the highest for the non-rainy season. The highest CV was recorded for the month of December i.e. 128.55%. Percentage contribution of rainfall during the peak period (June to September) amounting to around 73.79%. For the rest eight months of the calendar year the quantum of rainfall is distributed very unevenly.

Analysis of rainfall data for the station was done for evaluating the start and end of rainy season using forward and backward accumulation of standard meteorological week (SMW) rainfall. It may be recorded that the monsoon almost starts at 21st SMW and ends at the end of 28th SMW. Similarly during monsoon the percentage of occurrence of drought is around 7% for the week 23rd, 26th, 34th and 37th week.

The probable rainfall values for different probability distribution functions and their comparison with the observed value have been presented in Table 2. The estimation of maximum annual rainfall for a region is of great importance so as to install and establish soil conservation or drainage structure in that place (Chow et al. 1988). Since these structures need to overcome the extreme weather events, their hydraulic design has to be made carefully considering maximum value of the rainfall with its recurring interval. The probabilities of occurrence of the extreme events have been done by Weibull method (Table 2). The return period of the extreme event is the reciprocal of the probability

Table 1: Monthly Normal and Extreme Rainfall (Number of Rainy Days) along with SD, CV and Percentage contribution at Nongstoin

Month	Normal (mm)	Extreme Value		Standard Deviation (mm)	Coefficient of Variation (%)	Percentage contribution (%)
		Minimum (mm)	Maximum (mm)			
January	16.43 (1.18)	0 (0)	152.7 (5)	29.92 (1.19)	182.09 (100.80)	0.47 (1.00)
February	25.50 (2.25)	0 (0)	104.7 (8)	24.50 (1.88)	96.08 (83.48)	0.72 (1.91)
March	76.12 (4.75)	11.5 (1)	257.2 (12)	65.63 (3.36)	86.23 (70.79)	2.16 (4.04)
April	196.09 (10.36)	17.3 (2)	467 (18)	104.37 (4.10)	53.22 (39.61)	5.56 (8.81)
May	350.44 (15.32)	135.4 (8)	990.1 (25)	195.26 (3.70)	55.72 (24.16)	9.93 (13.03)
June	641.40 (18.89)	159.9 (12)	1051.2 (25)	249.02 (3.79)	38.82 (20.08)	18.17 (16.07)
July	983.41 (20.93)	367.5 (13)	2655.5 (26)	509.02 (2.79)	51.76 (13.32)	27.86 (17.80)
August	570.73 (18.43)	240.4 (11)	2021 (28)	364.51 (3.47)	63.87 (18.82	16.17 (15.67)
September	409.15 (15.25)	0 (0)	931.2 (22)	237.31 (4.26)	58.00 (27.91)	11.59 (12.97)
October	212.01 (7.32)	24.4 (2)	619.2 (14)	167.23 (3.30)	78.88 (45.08)	6.01 (6.23)
November	31.03 (1.68)	0 (0)	204 (4)	47.97 (1.47)	154.59 (87.40)	0.88 (1.43)
December	17.07 (1.29)	0 (0)	65.6 (5)	21.94 (1.49)	128.55 (115.67)	0.48 (1.09)

(Murthy 2002). The best probability distribution function was determined by comparing the Chi-square ($\div^2$) value (Bhatt et al. 1996; Chow et al. 1988). The chi-square values calculated for Normal, Log normal, Pearson type-III, Log Pearson type-III and Gumbel extreme distribution are 77.98, 51.87, 74.85, 55.14 and 45.35, respectively. This suggests that Gumbel distribution gives a better fit to the observed data (Table 2). Similar trend of distribution for maximum annual rainfall was reported by Ray et al. (2012a) for Barapani station, Ri-Bhoi district of Meghalaaya. Gumbel extreme distribution generally fits well for extreme rainfall events of hilly areas like Srinagar (Dingre and Atre 2005), Ooty (Jeevarathnam and Jaykumar 1979), Pantnagar (Kumar 1999), Ranichauri (Kumar 2000), Almora (Pandey and Bisht, 2006), etc. However, the distribution patterns are different for valley, river basin and plain regions (George and Kolappadan 2002).

CONCLUSIONS

Gumbel probability distribution has been found approropriate on the basis of the Chi-square ($\div^2$) goodness of fit test for describing the data set under study and is the most suitable for predicting maximum daily rainfall in Nongstoin, Meghalaya condition. Thus Gumbel distribution can safely be used for the design of small and medium hydraulic structures in mid altitude regions of Central Meghalaya.

Table 2: Annual maximum daily rainfall of Nongstoin for five different probability distribution functions

Sl. No.	Probability (%)	Return period	Observed value (O)	Estimated value (E)				
				Normal	Log Normal	Pear -III	Log Pearson-III	Gumbel
1.	0.01	100.0	-	500.67	578.56	613.79	579.47	599.72
2.	0.02	50.0	-	473.8	525.62	549.22	524.37	543.32
3.	0.03	29.0	600	450.62	483.86	498.68	481.43	498.73
4.	0.07	14.5	450.2	417.58	429.99	434.44	426.73	441.29
5.	0.10	9.7	360.5	395.75	397.73	396.76	394.34	407.04
6.	0.14	7.3	344.4	378.73	374.28	369.89	370.97	382.25
7.	0.17	5.8	340.3	364.43	355.64	348.93	352.5	362.63
8.	0.21	4.8	340.2	351.86	340.02	331.69	337.09	346.25
9.	0.24	4.1	315	340.48	326.48	317	323.79	332.08
10.	0.28	3.6	303	329.95	314.43	304.18	312	319.51
11.	0.31	3.2	300	320.06	303.51	292.77	301.34	308.14
12.	0.34	2.9	297	310.64	293.47	282.47	291.57	297.69
13.	0.38	2.6	282	301.57	284.11	273.06	282.48	287.97
14.	0.41	2.4	280.4	292.75	275.31	264.38	273.96	278.83
15.	0.45	2.2	275	284.11	266.94	256.31	265.87	270.15
16.	0.48	2.1	275	275.58	258.92	248.75	258.14	261.83
17.	0.52	1.9	265	267.07	251.18	241.61	250.69	253.79
18.	0.55	1.8	259.4	258.54	243.63	234.83	243.44	245.96
19.	0.59	1.7	247.3	249.9	236.23	228.34	236.35	238.28
20.	0.62	1.6	234	241.08	228.90	222.11	229.34	230.68
21.	0.66	1.5	220.5	232.01	221.61	216.1	222.37	223.11
22.	0.69	1.5	220.4	222.59	214.27	210.26	215.38	215.49
23.	0.72	1.4	220.4	212.7	206.83	204.57	208.3	207.74
24.	0.76	1.3	220	202.17	199.20	198.98	201.05	199.77
25.	0.79	1.3	186	190.79	191.27	193.46	193.52	191.46
26.	0.83	1.2	183.2	178.22	182.87	187.95	185.57	182.61
27.	0.86	1.2	183.2	163.92	173.76	182.42	176.96	172.96
28.	0.90	1.1	147	146.9	163.51	176.77	167.29	162.01
29.	0.93	1.1	140.5	125.07	151.25	170.88	155.73	148.73
30.	0.97	1.0	107.2	92.03	134.41	164.5	139.89	130.11
Chi-square (÷^{2}) value		77.98	51.87	74.85	55.14	45.35		

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