

Rainstorm characteristics of extremely humid area of the World-Cherrapunjee

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ABSTRACT

The paper highlights the rainstorm characteristics of Cherrapunjee area to understand the monsoon mechanism in the area of globally extreme humid conditions. The paper analyses four major aspects of rainstorm characteristics, namely; the identification of rainstorms, its trends and probability of occurrences, intensity (or depth)-duration relationship and the nature of storm advancement. These aspects of rainstorm are analysed by collecting daily rainfall data from the Regional Office, Indian Meteorological Department, Guwahati for the period of 13 years (1986 to 1998). The details of rainstorm patterns, their advancement coefficients and rates are interpreted by generating hourly data of the pre-monsoon periods of the rainstorms for the year 1999. Further, the trend and magnitude of rainstorms are analysed by establishing magnitude-rank relationship. The least square method of regression is applied for estimation of parametric relationship.

The results of the study show that the longer-duration storms of more than 8-days follow 'normal' pattern with their peak of 620 mm/day; if daily precipitation is considered for highlighting pattern of such rain storm. Decreasing magnitude of rainstorm follows concavity in its general trend. The magnitude-duration relationship is log-based and is positive because increasing duration of storm increases its rainfall magnitude ($b = 1.2564$). The intensity-duration relationship is expected to be negative as observed by many hydrologists. But it is observed to be positive even on log-based regression with the higher degree of its scatterness. It confirms that the rainstorm intensity increases marginally by their duration in the most extreme humid conditions. On account of such relationship, the area receives more rain. The hourly hyetographs of pre-monsoon rainstorm follow the increasing trend of rainfall intensity with decreasing advancement ratio. It shows that the peak of rainstorm shifts as intensity increases specially during May to July period of time.

1. Introduction

The extreme rainfall conditions are complex phenomena of great interests defined differently by scientists of different disciplines such as climatologists, hydrologists and agronomists. Thus, the study of rainfall characteristics acquires great significance. The rain bearing mechanism of North-East area specially in Cherrapunjee, which lies between the Himalayan mountains in the North and Bangladesh plains in the South, is controlled by the North-South movement of Inter-Tropical Convergence Zone (ITCZ), the shifting of S-W monsoon and the orographic effects (O' Hare¹). These factors cause the seasonality, alter the rainfall pattern, and create extreme conditions of rain, which may be understood by studying rainstorm pattern of the area.

In general, the landforms of an area are controlled by its geological structure and lithology. However, the micro land-features are evolved by its erosional characteristics and hydrological processes which are accelerated by rainfall

intensity. For example, the action of water forms talus on the debris slopes of upper cretaceous Shillong series of rocks prevailing on the scarp slopes of the valley heads at the Mawsmai falls in Cherrapunjee (Starkel²). Inversely, the local conditions of forest and lake ecology alter the climate and influence the rainfall pattern (Blazejezyk³ and Blazejezyk and Grzybowski⁴). Broadly, it may be said that relief features of landscape are major determining factors as an orographic effect on determining rainfall characteristics. On account of the location of Cherrapunjee area in the transitional zone of high hill plateau topography in its North (Shillong peak of about 2000 m elevation from m.s.l.) and the Bangladesh plains of very low elevations in the South, the direct effect of S-W summer (June) monsoon (ocean-to-land) can be observed over the North-East part of India in relation to the movement of the ITCZ. Regional variations in rainfall distribution occurring in the Meghalaya plateau has a great significance in understanding the causes of storm occurrences. The extreme wet conditions prevailing in the Southern slopes of the plateau (as a record of over 12,000 mm average

annual rainfall received in Cherrapunjee area) are because of orographic effects and wind-ward movements of S-W monsoon (Fig. 1). The Northern slopes of the plateau come

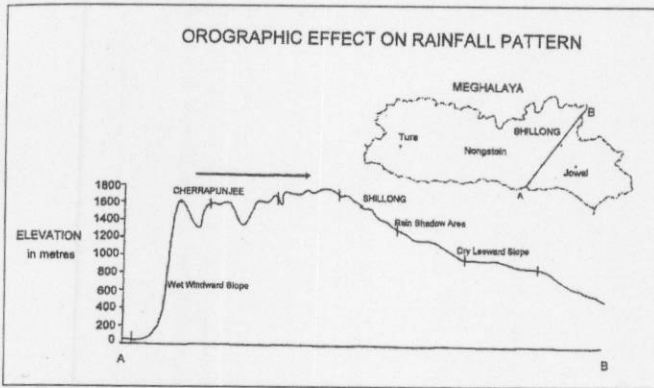


Fig. 1 : Orographic effect on rainfall pattern

under 'rain shadow' areas of less rainfall as Shillong which is only 60 km Northward from Cherrapunjee, receives only 1,000 mm of annual rain on the plateau (Starkel⁵ and Singh⁶). Such rainfall distribution has important bearings on water resources and variations in vegetal cover (Martin⁷).

Keeping these aspects in mind, the present paper highlights the rainstorm characteristics of Cherrapunjee area to understand the monsoon mechanism in the area of globally extreme humid conditions. The paper analyses four major aspects of rainstorm characteristics, namely, the identification of rainstorms, its trends and probability of occurrences, intensity (or depth)-duration relationship and the nature of storm advancement. These aspects of rainstorm are analysed by collecting daily rainfall data from the Regional Office, India Meteorological Department, Guwahati for the period of 13 years (1986 to 1998). The details of rainstorm patterns, their advancement coefficients and rates are interpreted by generating hourly data of the pre-monsoon periods of the rainstorms for the year 1999. The average rainfall intensity of rainstorms (I_s) is calculated simply by dividing the total magnitude of precipitation (P_s) by its total duration (D) as $I_s = (P_s/D)$. Further, the trend and magnitude of rainstorms are analysed by establishing magnitude-rank relationship. The least square method of regression is applied for estimation of parametric relationship.

2. Criteria for identification of stormy days

There are numerous studies on the estimation of extreme rainfall conditions (Maheras & Kolyva-Machera⁸; Chambers *et al.*; Mooley & parthasarathy¹⁰ and Parthasarathy *et al.*¹¹). A long time-series rainfall data of 100 years or more was

compiled and its mean and standard deviations were computed to find out extreme conditions of rainfall characteristics of Eastern Mediterranean region of Europe. The dry/wet years were identified by using Standard Score Technique of the distribution (Kutial *et al.*¹²). A significant exercise of estimating extreme Indian monsoon rainfall was made by Reeve¹³ to test the validity of various statistical tests of rainfall distribution, considering time series data of 306 well-distributed raingauge stations in India for the period 1871-1991. Reeve¹³ calculated best-fit distribution parameters for various families of rainfall distribution: normal, log-normal, gamma, exponential, Gumbel and General Extreme Value (GEV) distributions and concluded that GEV distribution should give 'best-fit' results.

It may be noted here that the dimension and time-series data for the present study are based on daily rainfall records and hence are different from the above studies. A simple criterion of 'standard z score' for identifying the stormy days has been adopted for the present study. There are two main steps of the procedure for identification of stormy days. These are:

- (a) According to the definition given by Indian Meteorological Department (IMD) Pune and its standard classification for the Wet days, a day is considered rainy day when it receives an amount of rainfall equal to or more than 2.5 mm. A significant temporal fluctuation is seen from the distribution of total rainy days of above 2.5 mm daily in Cherrapunjee. The year 1986 was recorded as low-magnitude year since it recorded only 60.58 mm rainfall per rainy day. On the other hand, rainfall of about 116.62 mm per rainy day with moderate number of rainy days (i.e., 158) was recorded in 1988. The degree of annual variation of daily rain of rainy days is recorded more than 100% in each year. It means that there is a significant temporal fluctuation in daily rainfall at Cherrapunjee. The higher degree of rainfall variability ($CV=195.08\%$) with moderately high mean rain per rainy day (84.21 mm) was recorded in the year 1995 when total number of rainy days are enumerated as 169 and the few days have extreme conditions as the 15th and 16th of June of this year received the highest rain during the last 13 years. It raises the coefficient of variability for this year (Table 1).
- (b) The Daily Average Effective Rainfall (DAER) is the criteria for identifying stormy days. The entire domain

Table 1: Temporal variability in number of rainy days, rainfall and DAER in Cherrapunjee

Years	No .of Rainy days (n)	Total Rainfall above 2.5 mm daily ($\sum x_i$)	mean Rain per Rainy day (in mm) (x^*)	S.D. (σ)	C.V. (%) (σ/x^*)	Stormy Rain (above DAER Norm)		No. of Stormy days
						Total	%	
1986	148	8966.8	60.58	94.517	156.00	5101.1	56.89	33
1987	165	13233.7	80.20	114.241	142.44	9476.0	71.60	47
1988	158	18427.2	116.63	150.230	128.81	15293.5	82.99	61
1989	163	13579.2	83.31	105.179	126.25	10293.5	75.80	52
1990	171	12807.8	74.90	125.354	167.36	7715.6	60.24	43
1991	169	13513.0	79.96	88.607	111.33	10271.4	76.01	54
1992	142	9675.9	68.14	100.949	148.15	5324.3	55.03	31
1993	166	13066.8	78.72	108.424	137.74	9970.3	76.30	52
1994	151	11445.1	75.79	95.768	126.35	7856.9	68.65	41
1995	169	14232.0	84.21	164.285	195.08	11474.2	80.62	43
1996	153	12867.5	84.10	106.979	127.20	10090.7	78.42	51
1997	156	8940.4	57.31	85.868	149.83	5663.9	63.35	28
1998	152	14527.5	95.57	112.300	117.50	11324.9	77.95	55
Average	159	12714.1	80.12	115.332	143.95	9225.2	72.56	45

Abbreviations: S.D.= Standard Deviations and, C.V.= Coefficients of Variation of daily rainfall of rainy days in the year.

of daily rainfall data of rainy days is transformed into standard z scores as $z = [(x_i - x^*) / \sigma]$ where x_i is the rain of a day, x^* = the mean and σ = the standard deviation of daily rain for 13 years. Infact, x^* must determine the normal wet days when $z = 0$ (80.12 mm; total number of days are counted 652 during study period of 13 years). The range of positive z scores is classified into four categories, namely, (i) the Stormy Days as $z \leq .05$ (above 85.88 mm daily rainfall; total number of days are counted 591), (ii) the Heavy Stormy Days as $z \leq .50$ (above 137.78 mm; total 355 days); (iii) the Very Heavy Stormy Days as $z \leq 1.50$ (the days receiving more than 253.11 mm rainfall; total 132 days) and (iv) the Extremely Heavy Stormy Days as $z \leq 2.50$ (days receiving more than 368.45 mm of rain; the total number of days are counted as 54 only during the period of 13 years. Thus, the days, which receive more than 85.8 mm of rain, are considered as stormy days in the domain of present study. The magnitude and share of total stormy rain also fluctuate temporally as the years 1988, 1989, 1991, 1995, 1996 and 1998 were considered the extreme stormy rain years when total amount of stormy rain was recorded

more than 10,000 mm, which shares more than 75% of total annual rainfall (Table 1).

3. Occurrence and severity of rainstorms

The rainstorm occurrence period, the total number of rainstorms occurred, the average length of rainstorm occurrences per storm, the severity, (i.e., interpreted by the magnitude and intensity of rainstorms) are major aspects of longevity and duration of rainstorms. Average storm longevity is the result of two attributes of storm occurrences such as the occurrence period and total number of storms occurred. The long duration of storm occurrence period increase average storm longevity, while increasing number of storms decreases it because it acts in denominator in storm-longevity fraction. Monsoon period of about 186 days (i.e., six months period from May to October) is main storm occurrence period at Cherrapunjee. It was recorded longer (239 days duration started from 31 March to 24 November) with moderate number of rainstorms in the year 1998 and, on the other hand, shorter (as 124 days started from 23 May to 23 September) with lesser number of total storms (i.e., 15) in 1997. The average storm longevity was recorded the longest (307 hrs per storm) in the year 1987 and the shortest (160.0 hrs per storm) in 1990 because of higher fluctuation in the

Table 2: Temporal Variation in Storm Occurrences Period (1986-1998)

Years	Storm Occurrence Period Total Days (Period)	Total No of Storms	Average Storm longevity (hrs per storm)
1986	181 (11 April-9 Oct)	17	255.5
1987	205 (8 March-28 Sept)	16	307.5
1988	207 (9 May-1 Dec)	17	292.2
1989	201 (2 April-19 Oct)	26	185.5
1990	180 (14 April-10 Oct)	27	160.0
1991	167 (2 May-15 Oct)	17	235.7
1992	209 (21 March-15 Oct)	18	278.7
1993	229 (18 Feb-4 Oct)	19	289.2
1994	205 (21 March-11 Oct)	17	289.4
1995	195 (1 May-11 Nov)	20	234.0
1996	231 (14 March-30 Oct)	23	241.0
1997	124 (23 May-23 Sept)	15	198.4
1998	239 (31 March-24 Nov)	19	301.9
Mean	197.69	19.31	251.46
S. D.	29.14	3.62	45.71
C.V. (in %)	14.74	18.77	18.18

Abbreviations: S. D. = Standard Deviation, and C. V. = Coefficient of Variation based on 13 years (observations) data.

Table 3: Total Number (n), Total Stormy Rainfall (Pn) and Average Precipitation Depth per Storm (Pd) in Different Duration during 13 years (1986-1998) in Cherrapunjee

Duration of Rainstorms	No of Storms occurred		Stormy Rainfall (mm)		Average Rainfall Depth per storm (mm)
	Total	%	Total	%	
One-day	116	46.01	18642	15.53	160.7
Two-days	57	22.64	19537	16.28	342.7
Three-days	30	11.90	18088	15.07	602.9
Four-days	18	7.14	18361	15.30	1020.0
Five-days	14	5.55	17691	14.74	1263.6
Six-days	5	1.98	6143	5.13	1228.7
Seven-days	5	1.98	7432	6.19	1486.5
Eight-days	4	1.59	6008	5.00	1502.0
Nine-days	1	0.40	3039	2.52	3038.9
Ten-days	1	0.40	2828	2.35	2827.9
Eleven-days	-	-	-	-	-
Twelve-days	1	0.40	2259	1.88	2259.0
Total for 13 yrs.	252	99.99	120028	99.99	476.3

temporal variation of total number of storms (CV= 18.77%, i.e., higher than the CV of storm occurrence period as well as of average storm longevity) (Table 2).

The duration-wise number of rainstorm varies from year to year. Out of a total of 252 rainstorms, which occurred

in Cherrapunjee during the last 13 years as many as 173 storms (that are more than two-third number of its total rainstorms) were of one to two-days duration accounting for nearly one-third of total stormy rain. However, it is intensity that the share of total rainfall precipitated during

Table 4: The Magnitude and Intensity of Rainfall for Six Major Storms in Cherrapunjee

	Period of Storm		Duration (in days)	Total Precipitation (in mm)	Average Intensity (mm/hr)
1.	21-29 August	1988	9	3038.9	14.07
2.	14-17 June	1995	4	3017.1	31.43
3.	2-11 July	1988	10	2827.9	11.78
4.	5-11 June	1998	7	2278.6	13.56
5.	21 July-1 August	1987	12	2259.0	7.84
6.	29 June-6 July	1993	8	2074.4	10.81
	Total		50	15495.9	12.91

N.B. The 16th June 1995, that is the day of 4-day duration rainstorm receives the highest rain of 1563.0 mm. It increases the average intensity of that storm.

storms in 13 years is recorded almost same upto 6 days duration storms. The distribution shows that the rainstorms of one-day to two-days duration account for nearly 31.0% to total stormy rain. Likewise, the storms of 3 to 4 days duration also account for a share of 30.0%, while 5 to 6 days duration storms claim 20.0% share of total stormy rain. The percentage share of stormy rain tends to decline fast after 6-days duration storms by increasing its duration. On the other hand, the average precipitation depth per storm increases from 160.7 mm for one-day duration to a maximum of 3039.0 mm for 9-days duration in the distribution (Table 3). It means that the average precipitation depth of the storms and its percentage share to total stormy rain are inversely related to storm-duration

in Cherrapunjee. It may be either due to less frequency of storms of large-duration or because of increasing magnitude of rainstorms with increasing duration. For example, the five storms of long duration (more than 6-days) and one storm of 4-days duration which occurred during pre-monsoon period (June to August) have very high magnitudes of more than 2000 mm of rainfall with extremely high rainfall intensity. They account for a total amount of 15,496.0 mm of rain, which is nearly 13.0% to total stormy rain of 13 years. The storm of 4-days duration occurred during 14-17 June 1995 which received more than 3,000 mm of rain with an average rainfall intensity of about 31.4 mm/hr. It is surprising to note that the highest rain of the day (i.e., 1563.0 mm) was recorded in Cherrapunjee on 16th June during this 4-days duration rainstorm (Table 4).

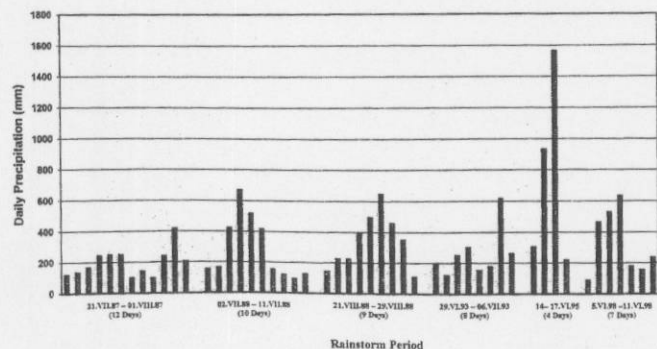


Fig. 2 : Rainstorm pattern (Six Major Events)

More details about rainstorm pattern of these six major events have been highlighted graphically by showing their daily rainfall pattern. It is obvious from the graph that there appears to be the 'bell-shaped pattern' with its peak of about 615 to 668 mm of rain in a day, which represent their central points. The rainstorm of 4-days duration, which occurred in June 1995, also has the same pattern with its 'leptokurtic' nature, while the long-duration storm of July 1987 has different pattern of its 'dual shape' (Fig. 2). It means advancement and recession rates of rain storms

Table 5: Temporal Fluctuation in the Number (n), Total Stormy Rain (Pn in mm) and Average Precipitation Depth per Storm (Pd in mm) by Different Duration of Rainstorms.

Storm Duration		Years													
		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(13)	(14)	(15)
One-day	n	8	5	4	12	16	7	9	9	5	10	12	11	8	
	Pn	1221.6	474.0	970.8	1774.8	3224.0	1143.1	1421.1	1098.0	599.0	1284.0	2268.0	2214.3	949.6	
	Pd	152.7	94.8	242.7	147.9	201.5	163.3	157.9	122.0	119.8	128.4	189.0	201.3	118.7	
Two-days	n	4	5	2	9	6	4	6	3	6	4	6	-	2	
	Pn	1074.8	1275.0	728.0	2763.9	1671.6	1694.4	1845.6	1295.4	2140.2	1198.0	2646.6	-	1203.4	
	Pd	268.7	255.0	364.0	307.1	278.6	423.6	307.6	431.8	356.7	299.5	441.1	-	601.7	
Three-days	n	3	2	5	2	5	3	2	2	2	1	-	1		
	Pn	1242.6	1203.0	3005.0	1994.4	2745.0	2054.0	1062.8	1029.0	1309.4	1445.6	406.2	-	591.0	
	Pd	414.2	601.5	601.0	997.2	549.0	684.6	531.4	514.4	654.7	722.8	406.2	-	591.0	
Four-days	n	2	1	1	1	-	-	1	1	2	1	1	3	4	
	Pn	1562.0	1842.1	635.8	1181.4	-	-	994.9	1330.4	1406.6	3017.1	1327.2	1969.2	3094.0	
	Pd	781.0	1842.1	635.8	1181.4	-	-	994.9	1330.4	703.3	3017.1	1327.2	656.4	773.5	
Five-days	n	-	2	3	1	-	-	-	1	2	3	-	1	1	
	Pn	-	2422.8	4089.0	999.5	-	-	-	707.4	2401.6	4754.4	-	1479.8	835.9	
	Pd	-	1211.4	1363.6	999.5	-	-	-	707.4	1200.8	1584.8	-	1479.8	835.9	
Six-days	n	-	-	-	1	-	-	-	-	-	-	2	-	2	
	Pn	-	-	-	1515.7	-	-	-	-	-	-	2166.4	-	2461.4	
	Pd	-	-	-	1515.7	-	-	-	-	-	-	1083.2	-	1230.7	
Seven-days	n	-	-	-	-	-	2	-	2	-	-	-	-	1	
	Pn	-	-	-	-	-	2717.8	-	2436.0	-	-	-	-	2278.6	
	Pd	-	-	-	-	-	1358.9	-	1218.0	-	-	-	-	2278.6	
Eight-days	n	-	-	-	-	-	2	-	1	-	-	1	-	-	
	Pn	-	-	-	-	-	2658.0	-	2074.4	-	-	1275.7	-	-	
	Pd	-	-	-	-	-	1329.2	-	2074.4	-	-	1275.7	-	-	
Nine-days	n	-	-	1	-	-	-	-	-	-	-	-	-	-	
	Pn	-	-	3038.9	-	-	-	-	-	-	-	-	-	-	
	Pd	-	-	3038.9	-	-	-	-	-	-	-	-	-	-	
Ten-days	n	-	-	1	-	-	-	-	-	-	-	-	-	-	
	Pn	-	-	2827.9	-	-	-	-	-	-	-	-	-	-	
	Pd	-	-	2829.9	-	-	-	-	-	-	-	-	-	-	

Contd.....

Table 5 Contd.....

Storm Duration	Years													
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(13)	(14)	(15)
Eleven-days	n	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pn	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pd	-	-	-	-	-	-	-	-	-	-	-	-	-
Twelve-days	n	-	1	-	-	-	-	-	-	-	-	-	-	-
	Pn	-	2259.0	-	-	-	-	-	-	-	-	-	-	-
	Pd	-	2259.0	-	-	-	-	-	-	-	-	-	-	-
Total	n	17	16	17	26	27	18	18	19	17	20	23	15	19
	Pn	5101	9476	15293	10294	7716	10271	5324	9970	7857	11474	10091	5664	11345
	Pd	300.0	592.2	900.0	396.0	285.8	570.6	295.8	524.7	462.2	573.7	438.7	377.6	597.1

NB: Bold figures indicate the rainstorms receiving more than 2, 000 mm of rain.

Table 6: Average Intensity of Rainstorm (mm/hr) over time

Duration	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Average
One-day	6.4	4.0	10.1	6.7	8.4	6.8	6.6	5.1	5.0	5.3	7.9	8.4	4.9	6.5
Two-days	5.6	5.3	7.6	6.4	5.8	8.8	6.4	9.0	7.4	6.2	9.2	-	12.5	7.5
Three-days	5.8	8.4	8.3	13.8	7.6	9.5	7.4	7.1	9.1	10.0	5.6	-	8.2	8.4
Four-days	8.1	19.2	6.6	12.3	-	-	10.4	13.8	7.3	31.4	13.8	6.8	8.1	12.5
Five-days	-	10.1	11.4	8.3	-	-	-	5.9	10.0	13.2	-	12.3	7.0	9.8
Six-days	-	-	-	10.5	-	-	-	-	-	-	7.5	-	8.5	8.8
Seven-days	-	-	-	-	-	8.1	-	7.3	-	-	-	-	13.6	9.7
Eight-days	-	-	-	-	-	6.9	-	10.8	-	-	6.6	-	-	7.8
Nine-days	-	-	14.1	-	-	-	-	-	-	-	-	-	-	14.1
Ten-days	-	-	11.8	-	-	-	-	-	-	-	-	-	-	11.8
Eleven-days	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Twelve-days	-	7.8	-	-	-	-	-	-	-	-	-	-	-	7.8
Total for 13 yrs.	6.5	9.4	10.0	9.7	7.3	8.0	7.7	8.4	7.7	13.2	8.4	9.2	9.0	8.8

- N.B.: 1. Rainstorm Intensity is calculated dividing storm magnitude by its hourly duration.
 2. Bold type-face figures are above average, i. e, 8.8 mm/hr in present case.

are more or less same of those major storms. The hourly pattern of some specific rainstorms would be interpreted separately in next part of the discussion.

Further, a few salient features of the distribution of rainstorm duration are shown by comparing the temporal fluctuations of the average precipitation depth per storm (Pd). It is found that there is a significant temporal variation in storm depth of its various durations. For instance, the year 1988 when the average precipitation depth per storm is recorded highest in distribution as Pd=242.7 mm for in one-day duration storm, it may affect the intensity of storms of same duration. In the distribution of 2-days duration storms, the average precipitation depth is accounted for highest as 601.7 mm in 1998, that is nearly double to the 13 years average (342.7 mm). It is because of less storm frequency and higher magnitude of rainfall under this category of 2-days storm (Table 5).

The precipitation intensity of rainstorm is a true indicator for the estimation of its severity. Infact, it (intensity) is the function of two elements of rainstorm: the rain precipitated during storm and its duration. The higher amount of stormy rain increases the intensity and, inversely, the longer duration of storm has negative effects on intensity measurement. Average intensity (in mm/hr) has been calculated by storm-duration over time to interpret the intensity pattern of rainstorms. On account of variations in total annual stormy rain as well as in number of storms, there appears to be the significant temporal fluctuation in the average intensity of rainstorms. The year 1995 is considered to be the most wet year of the last 13 years, when an average intensity of 13.2 mm/hr has been recorded. While the year 1986 has the lowest intensity (6.5 mm/hr) in Cherrapunjee. The average intensity by its storm-duration follow the normal pattern of its increase from 6.5 mm/hr (one-day storm duration) to 12.5 mm/hr (4-days storm) and then it stabilizes at 9.7 mm/hr for larger-duration storms except very large-duration storms of their less frequencies (Table 6).

In the bi-variate frequency distribution of storm intensity, the intensity table contains a total 156 cells (12x13), out of which the storm occurrences can be seen only in 68 cells (i.e., 43.60 percent to its total). The cells above average intensity (i.e., 8.8 mm/hr) are enumerated only 25 in number (that are nearly 36.7 percent to total cells of rainstorm occurrences). It means that intensity pattern is concentrated on a few places in the distribution. It is visualised that 3 to 5-days duration classes especially in the years 1989, 1994 and 1995 have the higher intensity of rainstorms than its average one. The cell 4-days duration of 1995 when big storm was occurred has the highest

intensity of 31.4 mm/hr. It concentrates the whole distribution (Table-6). Now, the rainstorms characteristics may be analysed more elaborately by establishing the componential relationships to find out their general behaviour.

4. Storm trend and probability of its occurrences

The inter-storm rainfall difference is an indicator of storm trend. The higher the difference, the faster are the changes in the storm trends and vice-versa. In order to interpret the storm trend of Cherrapunjee, the magnitude of storm-rain (Pr) is arranged in descending order by their ranks (r) to observe the inter-storm rainfall differences. There is obviously negative relationship between rank and magnitude of stormy rain in the distribution which follows concavity to the origin in distribution (decreasing with declining rate) (Fig. 3). Plotting them on double-log graph, it is almost linear (Fig. 4), so the storm-trend is log-based rather than being an arithmetic distribution. The regression statistics show a normal decrease of stormy rain as the coefficient of trend equation is close to unity ($q = -0.9089$).¹ It confirms that the decrease in inter-storm rainfall difference appears to be normal as it should happen.

The rainfall frequency and probability of its occurrences are observed by plotting the magnitude of stormy rain, Pr, with its frequency (F) expressed as percentage of time of that particular magnitude of a storm of rank, r. It is mathematically expressed as $F = [100(r/n)]$, where n = total number of items (or observations) in the distribution. The semi-logarithmic graph of Pr (on simple scale) against F (on log-scale) will show the rainfall frequency and recurrence interval of rainstorm in Cherrapunjee. The regression analysis shows that magnitude of stormy rain decreases at 1254 mm per unit of the percentage of time frequency with a high determinant level ($R^2 = .9677$) and significant level of .01 of the distribution.

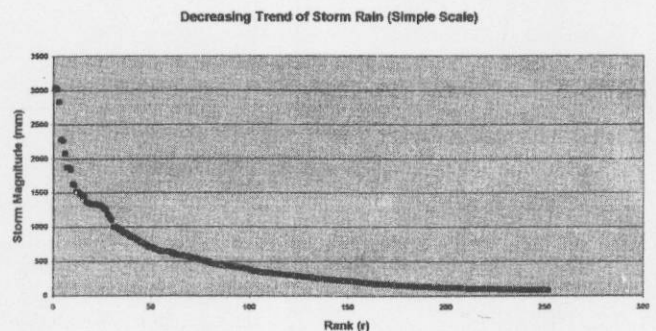


Fig. 3: Decreasing trend of storm rain (simple scale)

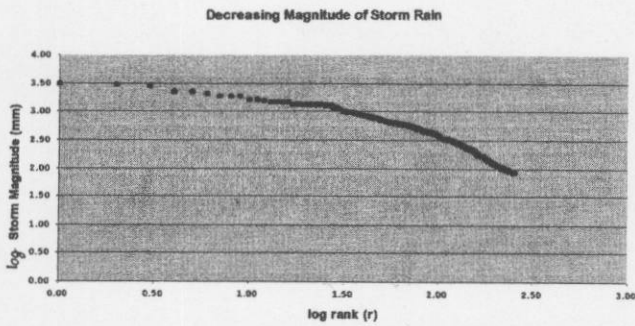


Fig. 4 : Decreasing magnitude of storm rain

The stormy rainfall curve shows that the storm of 2500 mm of rain of 5% probability of its occurrence occurred once in two years during the period of 13 years (1987-1998). The storm of 1900 mm of rain occurs twice in a year with 25% of its probability. Likewise, the storm of a moderate magnitude of 1250 mm occurs four times in a year, while the small magnitude storms (200 mm) occur frequently after 49 days in Cherrapunjee (Fig. 5).

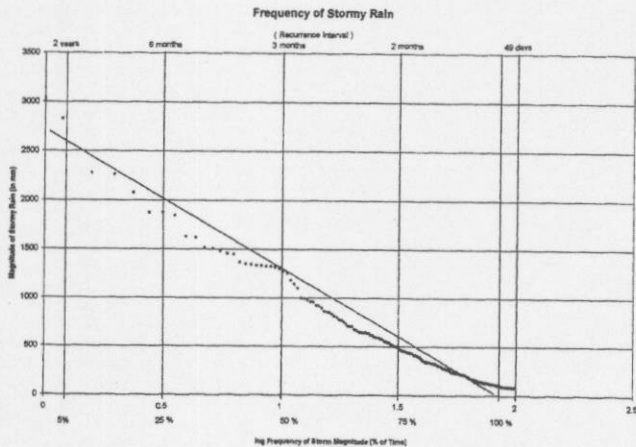


Fig. 5: Frequency of stormy rain

5. Intensity-duration relationship

Intensity and duration of rainstorms have the varieties of hydrological events on landscape because they influence the rate and volume of runoff, which may be the cause of floods and may damage the controlled structure in the area. The intensity-duration relationship is

3. Babu, *et al.* (1979) observed the following form of intensity-duration relationship for Indian rainstorm conditions as

$$I = K \frac{T^a}{(t + b)^n}$$

where, I = intensity of rain (cm/hr), T = return period desired (years), t = duration of rainfall (hrs) and K, a, b & n are constants which are calculated for different conditions. If T^a is considered constant as unity in the above equation, then $I = K (t + b)^n$

It follows the logarithmic form of decreasing nature.

generalised by many hydrologists and found that storm intensity is inversely related to its duration with its semi-logarithmic form; the linearity may be observed by plotting storm intensity on arithmetic (or simple) scale and storm-duration on logarithmic scale (Chow *et al.*¹⁴). The relationship was analysed by Babu, *et al.*¹⁵ by collecting the rainfall statistics for 42 rain gauge stations of India and concluded that the intensity-duration relationship is curvilinearly negative but follows its logarithmic form rather than semi-log³. We simplified the logarithmic form for magnitude-duration as well as intensity-duration relationships as:

$$Pd = K_1 (D)^b \text{ and}$$

$$Id = K_2 (D)^{-c}$$

Magnitude-Duration Relationship (log-log Scale)

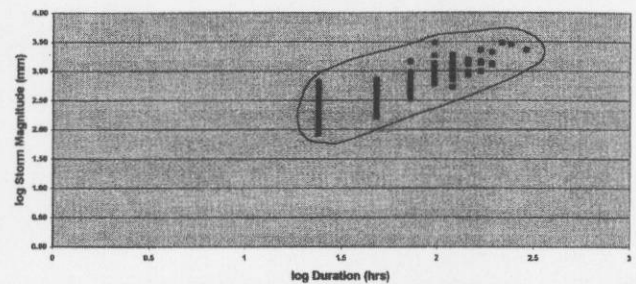


Fig. 6: Magnitude - duration relationship (Log-Log scale)

where Pd = magnitude of rainstorm of its duration (D), Id = rainfall intensity during D period of time and K_1, K_2, b & c are constants. After plotting the variables on double-log scale and conducting regression analysis test for the distribution, the following results may be forwarded for the rainstorm characteristics of Cherrapunjee area:

- (a) The magnitude-duration relationship is strongly positive with higher degree of determination level

1. The rank - magnitude relationship follows the following equation as

$$Pr = P_1 (r)^{-q}$$

where Pr = magnitude of rainstorm of rank (r), P_1 = the magnitude of rainstorm of rank 1 (i.e., its largest figure in distribution), and q = coefficient which shows the degree of concavity and has its three main conditions as :

- if $q < 1.0$, the inter-storm difference is lesser than normal.
- if $q = 1.0$ this difference of storm magnitude is normal,
- if $q > 1.0$, the degree of concavity is very high which shows the greater inter-storm differences in its magnitude.

In present case, the following are parameters of the functions as

$$Pr = 18875.5 (r)^{0.9089}$$

$$R^2 = 0.8884, SE = 0.t (q) = (q) \quad 44.706 \text{ and significant at } 1\% \text{ level with d.o.f.} = 250.$$

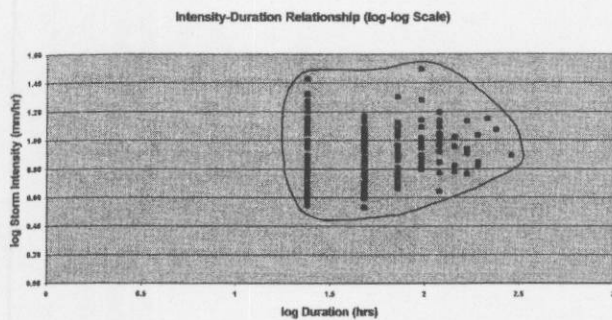


Fig. 7: Intensity - duration relationship (log-Log scale)

($R^2=0.7984$) and lesser degree of standard error ($SE=0.1810$). It means the rainstorm magnitude increases fast as its duration increases (Fig.6). This fact has already been highlighted in the earlier part of the discussion. However, the same fact has been confirmed here that the relationship is logarithmic and the rate of increase of the magnitude is observed faster (as $b=1.2564$) with respect to increase in the per unit of the time period of the storm duration. The established form of the relationship is realised as:

$$Pd = 2.598 (D)^{1.256}$$

$R^2 = 0.7984$, $SE=0.1810$, $t(b)= 31.466$ with 1% significant level at d.o.f. = 250.

It is interesting to note that the value of b is far higher for Cherrapunjee than observed by WMO¹⁶ for extreme rainfall areas of the world (i.e., 0.475).

(b) So far as intensity-duration relationship is concerned, the same form has been predicted by

Babu *et al.*¹⁵ as described above. While fitting the data of both these variables in the regression procedure, it appears from the results that the trend of distribution is positive with higher degree of its scatterness (Fig.7) rather than negative with compact scatterness as generalised by the hydrologists. The c value of the equation has an insignificant value of about 0.2564 with very low determination level ($R^2=0.1416$). Full form of the equation follows some constants as:

$$Id = 2.598 (D)^{0.2564}$$

$R^2=0.1416$, $SE=0.181$, $t(c)=6.42249$ with d.o.f = 250.

It means that intensity-duration relationship has a unique nature. The small duration storms have lesser degree of intensity and *vice-versa*. Intensity increases by duration, though its increasing rate is very low in Cherrapunjee. The long-duration rainstorms occur continuously in the pre-monsoon time in Cherrapunjee. Since their intensity increases by duration, the pre-monsoon period (May to August) has very high rate of run off and soil loss on the landscape of Cherrapunjee. This is typical characteristic of rainstorm in this area and the validity of this fact may be tested considering other humid areas of the country.

6. Storm pattern and their nature of advancement

The nature of storm advancement is interpreted by generating hourly rainfall statistics of major rainstorms of 1999. During 83 days of pre-monsoon period (9th May to 30th July 1999), a total amount of about 6250.0 mm rainfall

Table 7: Storm Duration, Advancement Ratio and Rate of Four Major Events in Cherrapunjee during Pre-Monsoon 1999

Sl.No	Storm	Total rainfall (mm)	Duration (hrs)	Intensity (mm/hr)	Peak rainfall (mm/hr)	Storm Advancement Ratio	Storm Advancement Rate (mm/hr)
1	23-24 May 1999	223.6	36	6.20	36.5	.639	1.621
2	29-31 May 1999	672.1	57	11.79	55.2	.912	.942
3	7-10 July 1999	900.2	62	14.52	45.4	.855	.845
4	18-19 July 1999	350.3	46	7.61	30.6	.434	1.205

N.B.: (1) Storm Advancement Ratio is the difference of starting and peak time of specific storm with its total duration.

(2) Advancement Rate of storm (Ar) is the difference of starting and peak rainfall intensity per unit of time as $Ar(mm/hr) = [(I_p - I_s)/D_{sp}]$, where I_p = Intensity at peak (mm/hr), I_s = Intensity at starting time and D_{sp} = duration (hrs) between starting and peak of the storm.

with an average rainfall of 75.3 mm per day was recorded by oselometer (pluviograph). The total ten major events were identified by using DAER value (Fig. 8) Four events out of ten are analysed for the purpose: two from May and two from July 1999. The unique features of these rainstorm have been observed in Cherrapunjee. The storm of 23-24 May and 29-31 May 1999 have the dual pattern of 'two-segments'. Rainfall starts 3:00' clock after mid night and continues till noon (for about 12 hrs) and resumed after a gap of 10 hrs. The similar pattern may be seen for the storm occurred 29-31 May 1999. While during July 1999, there appears to be continuous rain of the peak of 46 mm/hr in the central part of distribution (Fig. 9). It is obvious from the Table 7 that rainfall intensity increases gradually as monsoon starts bursting in May with the fast advancement rate of about 1.6 mm/hr. It declines with increasing duration of monsoon storm.

7. Conclusion

The presently employed statistical analysis offers some insights into the characteristics of rainstorms for the extremely humid conditions. In general, Cherrapunjee area, which has an orographic effect on rainfall pattern, receives an amount of about 12,000 mm rainfall annually. In such humid conditions of S-W monsoon, the occurrence and severity of rainstorms are significantly high. Six months from May to October has been the occurrence period in which the high intensity is recorded in pre-monsoon time. The number of storms decreases by their longevity (storm-duration). However, average precipitation depth per storm increases subject to storm-duration. In particular, intensity of rainstorms fluctuates significantly over time. An average intensity of 13.2 mm/hr has been recorded in 1995, while it was only 6.5 mm/hr in 1986. However, the intensity pattern follows a normal increase from 6.5 mm/hr to 12.5 mm/hr as storm duration increases from one-day to 4-days in Cherrapunjee. In particular, there are five important characteristic features of rainstorms drawn from the present analysis.

- (i) The longer-duration storms of more than 8-days follow 'normal' pattern with their peak of 620 mm/day, if daily precipitation is considered for highlighting pattern of such rain storm.
- (ii) Decreasing magnitude of rainstorm follows concavity in its general trend. The regression on double log scale is 'best-fit' test which confirms that the declining trend of rainstorm is normal ($q = -.9089$) in Cherrapunjee. While the recurrence interval of large magnitude rainstorm is recorded two-years and small rainstorms occur frequently in 49 days.

- (iii) The magnitude-duration relationship is log-based and is positive because increasing duration of storm increases its rainfall magnitude ($b = 1.2564$).
- (iv) The intensity-duration relationship is expected to be negative as observed by many hydrologists. But it is observed positive even on log-based regression with the higher degree of its scatterness. It confirms that the rainstorm intensity increases marginally by their duration in the most extreme humid conditions. On account of such relationship, the area receives more rain.
- (v) The hourly hyetographs of pre-monsoon rainstorm follow the increasing trend of rainfall intensity with decreasing advancement ratio. It shows that the peak of rainstorm shifts as intensity increases specially during May to July period of time.

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