

Some features of hourly rainfall during southwest monsoon season at Delhi

S. R. PURI, Y. M. DUGGAL, BHUKAN LAL and RAJNI KANT

Meteorological Office, New Delhi

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सार—1976-1985 की दस वर्ष अवधि के, सफदरजंग के हाइडोग्रामों में घंटेवार तथा कालांतर श्रृंखलाओं की संरचना करके नई दिल्ली के दक्षिण-पश्चिमी मानसून (जून से सितम्बर) के लक्षणों की दैनिक, संचयी तथा अवधिवार विविधता का अध्ययन किया गया है। इस केन्द्र पर भारी वर्षा की कुछ घटनाओं के अनिश्चित हल्की से मध्यम वर्षा होती है। प्रस्तुत शोध पत्र में मौसमी तथा घंटेवार औसत वर्षा की तीव्रता में परिवर्तित क्रमानुसार घंटेवार वर्षा वर्षा, की औसत प्रायिकता तथा औसत अवधि के विषय पर चर्चा की गई है। वर्षा की मात्रा, अवधि तथा वर्षा की बढ़ती हुई मात्रा, भारी वर्षा की घटनाओं के लिए अधिकतम सम्भावित तीव्रता तथा वर्षा की अवधि का परिकलन भी किया गया है।

ABSTRACT. Characteristic features of southwest monsoon (June to September) rainfall of New Delhi with its diurnal, cumulative and rangewise variation have been studied by constructing hourly and range-interval series from hyetograms of Safdarjung for the ten years' period, 1976-1985. Station exhibits light to moderate rainfall pattern with a few events of rather heavy rainfall. The pattern of variation of average seasonal and hourly rainfall intensity, rainfall per chronological hour, mean probability of occurrence and its average rain-duration have been discussed. Cumulative curves between rain amount, rain duration and rainfall of increasing amounts have been brought out. For heavy rainfall events, the highest probable intensity and its duration have been worked out.

Key words—Southwest monsoon, Diurnal variation, Cumulative rainfall, Probability of rain occurrence, Hourly rainfall intensity.

1. Introduction

For issue of meaningful local forecasts for professional or users in public, the knowledge about characteristics of the pattern of rainfall, its variations in space, time or intensity are very important. A number of studies exists with quite a few dealing with the diurnal variations of rainfall at Indian stations notably by Iyer (1946), Iyer and Das (1946), Mulky (1947), Rao and Raman (1958), Prasad (1970) and Ananthakrishnan *et al.* (1986). There are substantial differences in their characteristics depending upon the geographical locations of the station. With the above in view, the present study has been taken up for detailed examination of different features of southwest monsoon rainfall in the interior landmass over northern parts of the country. The following deals with these characteristics emphasising on diurnal, cumulative and range-interval behaviour of rainfall over Delhi during the southwest monsoon period.

Delhi has a normal annual rainfall of 692.1 mm of which 585.5 mm (85%) is received during the southwest monsoon period (1 June to 30 September, *i.e.*, 122 days). Graphical distribution of normal rainfall of month-wise and pentadwise are shown in Fig. 1. An attempt has been made in this study to understand :

- (a) Diurnal variation of rain amount and rain duration for different rainfall categories and its probability of occurrence,

- (b) Relation between cumulative percentage rain amount and cumulative percentage rain duration,
- (c) Association between rainfall of increasing amount and the cumulative percentage of :
 - (i) rain amount,
 - (ii) rain duration, and
 - (iii) rain hours.

2. Data

Hyetograms of Safdarjung (New Delhi, for the 10 years period from 1976 to 1985 have been utilised for preparation of rainfall series and form the basis for the study presented in this paper.

3. Methodology

3.1. For the rainfall analysis, the day is divided into 24 chronological hourly intervals (0000-0100, 0100-0200, 2300-2400 IST) which are designated as H_1, H_2, \dots, H_{24} . The rain amount r (mm) and the rain duration t (min) are estimated for each hour from the records corrected to 0.1 mm and 1 min respectively. Rain occurring within any chronological hour is called rain event. The maximum limit of t is 60 min when rainfall extends throughout hour. No such limit exists

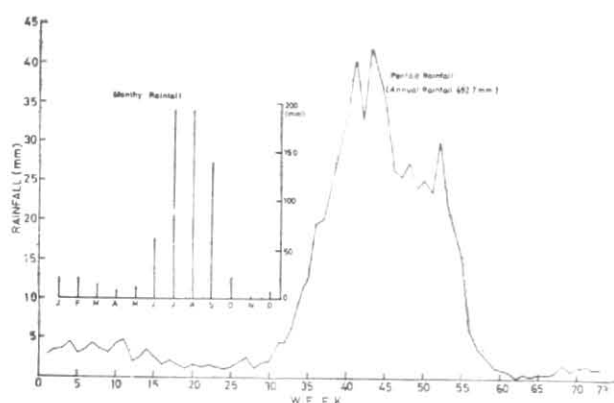


Fig. 1. Monthly and pentad normal rainfall of Safdarjung (New Delhi)

for r . When rainfall extends into the subsequent hour without break, it is regarded as a separate event. The chronological hour pertaining to rain event is called rain hour.

3.2. For the southwest monsoon period of 122 days, the number (n_k) of rain events or for any chronological hour H_k is ≤ 122 days (where, k varies from 1 to 24). The value of n_k shall vary depending upon the numbers of years of data taken into consideration and the actual number of rain events in the concerned chronological hour H_k (for the 10 years period considered in the present study $n \leq 1220$). Let $r_1, r_2, r_3, \dots, r_n$ be the rain amounts and $t_1, t_2, t_3, \dots, t_n$ be the corresponding rain duration associated with n events. For constructing the orderly series, the rain amounts $r_1, r_2, r_3, \dots, r_n$ are arranged in the ascending order. The corresponding rain duration, i.e., $t_1, t_2, t_3, \dots, t_n$ can not have such an order since the value of t associated with the corresponding value of r can vary from 1 to 60 min for the chronological hour H_k under consideration, we then have :

$$\sum_{i=1}^{n_k} r_i = A_k \quad \text{the total rain amount for the hour } H_k,$$

$$\sum_{i=1}^{n_k} t_i = D_k \quad \text{the total rain duration for the hour } H_k,$$

$$A_k/D_k = I_k \quad \text{the average rain intensity for the hour } H_k,$$

$$A_k/n_k \quad \text{—} \quad \text{the average rain amount during the hour } H_k,$$

$$D_k/n_k \quad \text{—} \quad \text{the average rain duration during the hour } H_k,$$

$$(n_k/122) \cdot 100 = P_k \quad \text{the average probability of occurrence of rain during the hour } H_k.$$

3.3. Similarly for the seasonal total, the following seven set of values can be arranged as follows :

$$\sum_{k=1}^{24} A_k = A \quad \text{the total seasonal rain amount,}$$

$$\sum_{k=1}^{24} D_k = D \quad \text{the total seasonal rain duration,}$$

$$\sum_{k=1}^{24} n_k = N \quad \text{the total number of rain events in the season or rain hours,}$$

$$A/D = I \quad \text{the average seasonal rain intensity,}$$

$$A/N \quad \text{seasonal rain amount per rain hour or per rain event,}$$

$$D/N \quad \text{seasonal rain duration per rain hour or per rain event.}$$

$$100N/(122 \times 24) = P \quad \text{seasonal mean probability of rain occurrence per chronological hour}$$

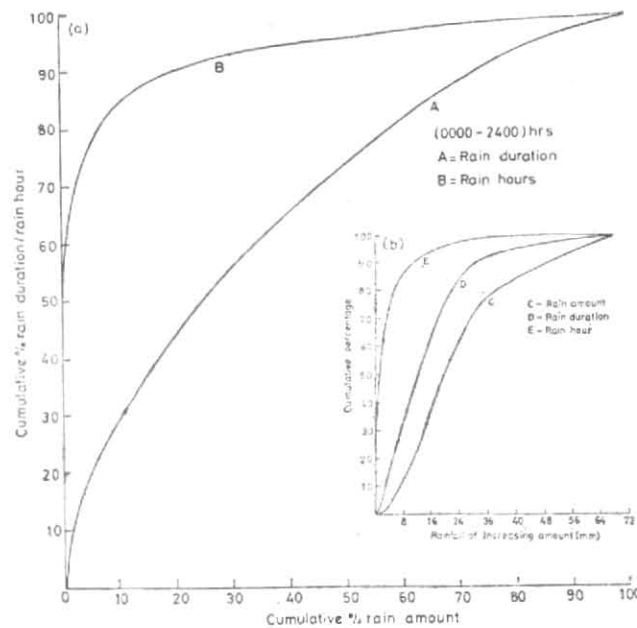
3.4. In order to study the variation in the rainfall pattern with the increasing rainfall amounts, the rain events during different chronological hours for each of the following range interval categories are also analysed as per analysis similar to that indicated in the previous sub-section :

(i) rain events with $r < 5$ mm.

(ii) rain events with $r \geq 5$ mm, 10 mm, 15 mm, 20 mm, 25 mm, and 30 mm.

The above throws light on the diurnal variation of rain events with progressively increasing rain amounts.

3.5. To understand the fine structure of rainfall pattern as regards its amount, duration, number of events and the variations in the pattern of rainfall with increasing rainfall amounts, it is considered useful to study inter-association between various cumulative parameters. For this association between cumulative percentage rain amount and (i) cumulative percentage rain duration, and (ii) cumulative percentage rain hours have been studied graphically. For the above seasonal rainfall with rain amounts $r_1, r_2, r_3, \dots, r_n$ corresponding to rain duration $t_1, t_2, t_3, \dots, t_n$ is arranged in ascending order. Cumulative percentage values of rain amount, rain duration and rain events are calculated starting from lowest to the highest. By plotting the cumulative values of rain amount along x-axis against corresponding cumulative values of rain duration and rain events along y-axis, graphical association is obtained as shown in Fig. 2 (a).



Figs. 2 (a & b). (a) Variation of cumulative % rain amount versus cumulative % rain duration/rain hour and (b) variation of % cumulative parameters versus rainfall of increasing amount

An attempt has also been made to study the graphical association between rain events of increasing amounts with cumulative percentage of rain amounts, rain duration and rain hours. This is done by plotting the cumulative percentage values of rainfall of increasing amounts along x-axis against corresponding cumulative values of rain amount, rain duration and rain events along y-axis as shown in Fig. 2(b). These graphs show interesting fine structure of rainfall pattern as described below :

4. Results and discussion

4.1. Diurnal variation — The various statistical parameters classified as per para 3.2 from 10 years hourly series for different hours of the day are presented in Table 1.

4.1.1. It is observed that the hourly average rain intensity in general is maximum in the afternoons and early mornings/morning hours. It is about 10 mm/hr (9.9 mm/hr) at H_{14} that is between 1300 and 1400 IST. It shows another maxima at H_{03} - H_{04} hrs, i.e., between 0200 & 0400 IST where it is about 8.5 mm/hrs. The minimum intensity is observed at H_{01} , i.e., between 0000 & 0100 IST when it is 4.0 mm/hr.

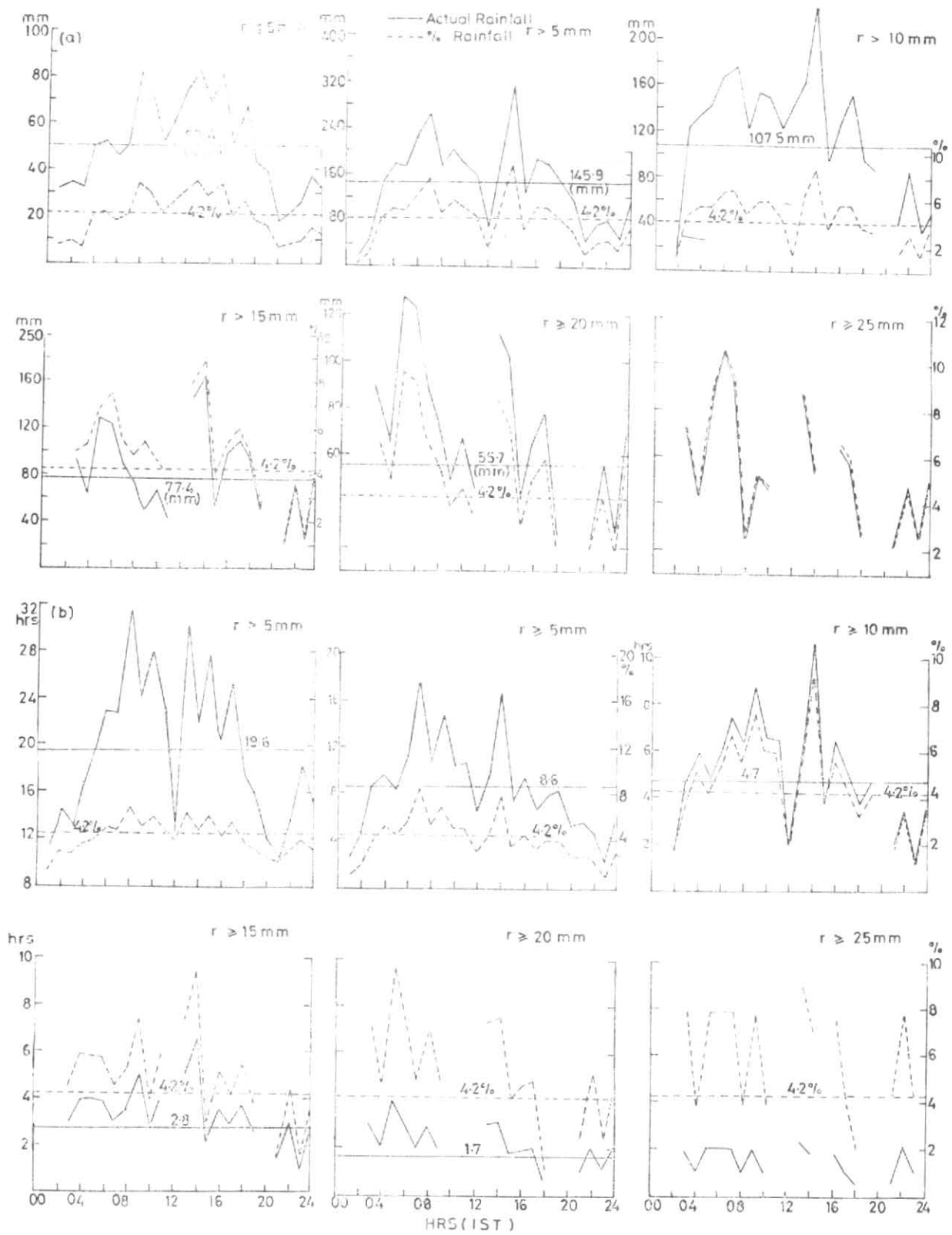
4.1.2. The average rain amount during the chronological hour is maximum in the afternoon at H_{14} i.e., between 1300 and 1400 IST where it is 4.9 mm. The lowest value is at H_{01} (0000-0100 IST) where it is 1.9 mm.

4.1.3. The average rain duration during any chronological hour is of the order of about 30 min except at H_{12} (1100-1200 IST) where it is lowest of the order of about 17 min. The highest values are at H_{10} and H_{22} , i.e., between 0900 and 1000 IST and between 2100 & 2200 IST when they are 42 min and 39 min respectively.

4.1.4. The probability of occurrence of rain during any chronological hour is maximum at H_{14} (1300-1400 IST) when it is 64%. It is minimum at H_{22} (2100-2200 IST) and H_{01} (0000-0100 IST) when its values are 23% and 24% respectively.

4.2. Seasonal average — The seasonal averages for the southwest monsoon period June to September as worked out for the decade 1976-1985 are as follows :

- (a) Average seasonal rain duration 68 hrs
- (b) Average seasonal rain events 126
- (c) Average seasonal rain intensity 7mm/hr
- (d) Average seasonal rain for chronological hour 3.7 mm
- (e) Average seasonal rain duration 30 min
- (f) Average seasonal probability of occurrence per chronological hour 43%



Figs. 3 (a & b). Diurnal variation of (a) rain amount and (b) rain duration at Safdarjung

TABLE 1
Chronological variation of average rainfall parameters

Hour (IST)	Rainfall A_k (mm)	Rain duration D_k (hr)	Rain events n_k	Average rain intensity $I_k = A_k/D_k$ (mm/hr)	Average rain amount during the hour A_k/n_k (mm)	Average rain duration during the hour D_k/n_k (min)	Probability of occurrence of rain during the hour $F_k = (n_k / 22) 100 \%$
1	54.1	13.5	29	4.0	1.87	27.9	24
2	89.2	18.5	36	4.8	2.48	30.8	29
3	184.0	21.7	40	8.5	4.60	32.6	33
4	229.9	27.3	51	8.4	4.51	32.2	42
5	225.1	28.5	49	7.9	4.59	34.9	40
6	271.3	34.5	56	7.9	4.84	36.9	46
7	315.3	40.6	65	7.8	4.85	37.4	53
8	253.5	42.4	74	6.0	3.42	34.4	61
9	278.4	38.9	63	7.1	4.42	37.1	52
10	230.6	38.2	55	6.0	4.19	41.7	45
11	221.2	34.4	63	6.4	3.51	32.8	52
12	143.9	19.1	69	7.5	2.08	16.6	57
13	284.0	40.0	73	7.1	3.89	32.9	60
14	383.7	38.9	78	9.9	4.92	30.0	64
15	208.7	35.2	73	5.9	2.86	28.9	60
16	237.9	29.7	61	8.0	3.90	29.2	50
17	236.4	34.0	64	6.9	3.69	31.9	52
18	195.4	25.6	54	7.6	3.62	28.4	44
19	156.5	24.1	46	6.5	3.40	31.5	38
20	74.4	17.2	35	4.3	2.13	29.5	29
21	93.6	15.9	34	5.9	2.75	28.1	28
22	109.5	18.3	28	6.0	3.91	39.3	23
23	90.1	20.4	36	4.4	2.50	34.0	29
24	146.0	20.5	37	7.1	3.94	33.3	30

4.3. Range variation and amplitude of diurnal change—
The diurnal variation of rain events with progressively increasing rain amounts in different ranges as per para 3.4 has also been classified and the characteristic features are presented in Table 2 and also shown diagrammatically as per Figs. 3 (a&b).

4.3.1. It is observed from the above table that the amplitude of the diurnal variation of the rain events, i.e., the ratio of rainfall of maximum amount to the minimum amount during the day bring out progressive decrease in the amplitude for rain events of increasing amounts. This indicates that the events of high rainfall amounts are more uniform and equally probable in different chronological hours as compared to event of lower rainfall amount. Further, for most of the events

the maximum rainfall occurs around morning (0400-0800 IST) and afternoon (1300-1400 IST) and minimum around night(2000-2400 IST) and early hours of the day (0800-1000 IST). Both these results are contrary to the results arrived at for coastal stations of Cochin and Minicoy (Ananthkrishnan and Rajan 1987) in which the amplitude of the diurnal variation for rain events of observed to increase progressively with increasing rainfall amounts, indicating thereby that the events of low rainfall amount are more uniform and equally probable in different chronological hours as compared to events of higher rainfall amounts. Further the period of maximum rainfall activity was observed to be around early hrs (0300 IST) and minimum around later afternoon (1500 IST) showing thereby a changed pattern of rainfall for a coastal and deep inland station.

TABLE 2
Rain events with progressively increasing rain amounts

Rain events (<i>N</i>)	Cumulative rain amounts (mm)				Cumulative rain duration (hr)				Intensity $I=A/D$ (mm/hr)	Average rain amount per hr (A/N)	Average rain duration per hr (D/N)
	Total (<i>A</i>)	Max (period)	Min (period)	Max/ Min	Total (<i>D</i>)	Max (period)	Min (period)	Max/ Min			
All (1259)	2408.0 (100%)	383.7	54.1	7.1	140.38 (100%)	42.38 (07-08)	13.50 (00-01)	3.1	17.15	11.18	0.11
<5 mm (790)	122.5 (5.09%)	83.5 (12-13) (07-08) (14-15)	18.5 (20-31)	4.5	29.43 (21.0%)	31.47 (07-08)	11.25 (20-21)	2.8	4.16	0.15	0.04
≥5 mm (469)	2275.5 (94.9%)	264.9 (13-14) (06-07)	22.2 (00-01) (15-16)	11.9	110.95 (79.0%)	16.70 (06-07)	2.17 (00-01)	7.7	20.51	4.85	0.24
≥10 mm (131)	1976.8 (82.09%)	232.8 (13-14) (06-07) (16-17)	22.5 (01-02) (11-12)	10.3	80.77 (57.5%)	10.60 (13-14)	1.50 (01-02)	7.0	24.47	15.09	0.62
≥15 mm (74)	1610.5 (66.88%)	165.3 (13-14) (05-06) (16-17)	26.2 (20-21)	6.3	56.68 (40.47%)	6.41 (13-14)	1.00 (22-23)	6.4	28.41	27.76	0.77
≥20 mm (42)	1200.5 (49.85%)	128.9 (04-05)	26.2 (20-21)	4.9	36.17 (25.76%)	4.0 (04-05) (13-14)	0.50 (17-18) (22-23)	8.0	33.19	28.58	0.86
≥25 mm (27)	912.5 (37.89%)	102.7 (05-06)	26.2 (20-21) (22-23) (07-08)	3.9	23.58 (16.8%)	2.25 (13-14)	0.50 (17-18) (20-21)	4.5	38.70	33.80	0.87
≥30mm (13)	593.7 (24.65%)	102.7	39.8	2.6	12.37 (8.81%)	2.0 (05-06)	0.71 (15-16)	2.3	47.99	48.47	0.95

The above gives an indication of distinct physical processes involved in generation of light and heavy rainfall at a coastal station and deep inland station. The development of rain drops from cooling of comparatively stratified clouds may be more probable at a coastal station and responsible for maximum activity in the early hrs of date, whereas convective phenomenon in the late morning and early afternoons can be considered to be more probable for maximum rainfall activity in the stated hours of the day.

4.3.2. For most of the events, the maximum duration of rainfall occurs around late morning (0400-0800 IST) and early afternoon (1200-1600 IST) and the minimum around late night (2000-2400 IST) and early hrs of the date (0000-0400 IST). The diurnal variation is presented in Fig. 4.

The amplitude of diurnal variation of rain duration, *i.e.*, the ratio of maximum to minimum of rainfall duration also show progressive decrease in the amplitude with increasing rain amounts, except between 20 & 25mm range where the amplitude is maximum. This indicate that for most of the events the rainfall duration tends to become uniform and even with increasing rainfall amounts in different chronological hours except for value between 20 & 25 mm range where the maximum variation in the duration of rainfall can be expected in different chronological hrs by the forecaster. These results are again contrary to the one arrived at coastal stations as stated in para 4.3.1 in which the amplitude has been shown to increase with the increasing rainfall amounts indicating thereby that there is maximum variation in the rain duration in different chronological hrs for events of high rainfall amounts at a coastal station.

4.3.3. Number of rain events in the season decrease rapidly with increase in rainfall amounts indicating thereby that low rainfall is more probable as compared to high rainfall event. It is observed from Table 2 that on an average out of about 126 rain events in a season they decrease from about 79 events for rainfall range < 5 mm to only about 1.3 events for rainfall range > 30 mm. Further, out of the total seasonal rainfall amount, roughly about 50% occur above 20 mm range and about 50% below it.

4.3.4. The range analysis show that the average rain amount per event (A/N) in the season increases steadily alongwith the average rain intensity (A/D) when the rainfall range increases from $r < 5$ mm to $r \leq 30$ mm. It is observed that the quantity A/N and A/D tend to be equal with increase of r . Further, it is interesting to note that with increasing value of r , the duration of an event progressively increases to about 0.95 hrs, i.e., it approaches one hour.

One can infer from above that, in general, the highest intensity of rainfall at Safdarjung can be of the order of 50 mm/hr and further that the rainfall of such an intensity may not last for more than one hour in its duration at a time.

4.4.1. *Cumulative association*—Cumulative association between cumulative percentage rain amount with cumulative percentage rain duration and cumulative percentage rain hours has been studied graphically as per Fig. 2 (a). Association between rain events of increasing amounts with cumulative percentage, rain amount, rain duration and rain hours have also been studied graphically by drawing curves as per Fig. 2(b).

The curves are useful for finding percentage cumulative rain amount, rain duration and rain hours for a given rain amount value. It is interesting to note that for rainfall amount of 20 mm, the corresponding percentage cumulative rain amount is 50%, the cumulative rain duration is 75% and the cumulative rain hours (events) are 95%. In other words up to 20mm of rainfall, accounts for half the cumulative rain which last the three fourth the cumulative rain duration and accounts for or covers about 95% of rain events. Only 5% of rain events covering remaining 25% of the rain duration are experienced in the remaining 50% of cumulative rain above 20 mm range. The associated cumulative values of these parameters for any value of rainfall can be determined from the curves.

Further inspection of rain events for rainfall values of $r=30, 40$ and 50 mm show the cumulative rain amount as 75%, 84% and 90%; the cumulative rain duration as 91%, 95% and 97% and cumulative rain events as 98%, 99% and 99.5% respectively. Thus majority of southwest monsoon rainfall at Safdarjung consists of light to moderate category with only a few events giving rather heavy rainfall.

5. Conclusions

(a) It is observed that late morning and early afternoons are the periods giving maximum rainfall activity.

Late night and early hours of date give minimum rainfall intensity, rain amounts per chronological hour, rain duration and the probability of occurrence also follow this pattern.

The diurnal variation pattern shows a distinct change from that of a coastal station like Cochin and Minicoy where the maximum is observed around early hours of date and minimum about late afternoon. Further the amplitude of the diurnal variation also shows a reversal of behaviour from that of a coastal station indicating distinct physical process which may be responsible for generation of rainfall at an inland and a coastal station.

(b) The highest average rain intensity (10 mm/hr), maximum average rain amount per chronological hour (4.9 mm) and highest probability of occurrence of rain (64%) observed between 1300 and 1400 IST. The minimum average rain intensity (4 mm/hr), the minimum average rain amount per chronological hour (1.9 mm) is observed at 0000-0100 IST with lowest probability of occurrence of rain (23-24%). However, the probability of occurrence is found to be greater than 50% between 0700 and 1700 IST.

The highest value of rain duration (42 min) is at 0900-1000 IST, and minimum (17 min) between 1100 and 1200 IST. Thus rain starting at 0900 IST can be expected to last 2.5 times longer than the one starting at 1100 IST under similar conditions.

(c) For rainfall range 20-25 mm, the maximum variation in the duration of rainfall (by a factor of 8) can be expected in its diurnal behaviour.

(d) The maximum probable intensity during southwest monsoon rainfall at Safdarjung can be expected to be 5 cm/hr and rainfall of such an intensity may not exceed one hour in each spell.

(e) About 50% cumulative rainfall during the season is experienced below 20 mm rainfall range with associated cumulative rain duration of 75% in about 95% rain events. Only 5% rain events give rainfall about 20 mm range with 25% cumulative rain duration.

(f) Considering overall southwest monsoon seasonal parameters at Safdarjung, it forms about 85% of its annual rainfall and is experienced in about 126 rain events with average seasonal rain intensity of 7 mm/hr, the average rain amount 3.7 mm per chronological hour, the mean probability of occurrence as 43% and average rain duration 30 min.

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