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Some aspects of monsoon rainfall in India

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ABSTRACT. In this note, the day-to-day rainfall during the monsoon season in four small areas of 50 miles radius round about Calcutta, Delhi, Tiruchirapalli and Bangalore has been studied with a view to finding out what percentage of the monsoon rainfall occurs on what percentage of the days with precipitation in each of these areas. It is observed that although these areas fall within different rainfall regimes, the percentages of days with rain that account for a particular fraction of the total rainfall in these areas are nearly equal. A study has also been made of the rainfall over these areas during the monsoon season, associated with synoptic disturbances. It is found that the percentages of the disturbances which cause the same fraction of the total rainfall derived from such disturbances do not also differ appreciably from one area to another.

1. Introduction

Olascoaga (1950) has studied the rainfall distribution in widely separated climatic provinces of Argentina, and observed that the percentage of precipitation days which accounts for most of the rainfall in the various areas is very nearly constant in space and time. He has further observed that the same percentage of "rainstorms" accounts for the same major fraction of the total rainfall derived from such disturbances, regardless of season or geographical effects.

A study on the above lines has been made of the rainfall of the monsoon season for four selected areas in India, which are different from each other in their rainfall regimes, with a view to determine the characteristics, similar to the one observed by Olascoaga. The areas selected for the study are areas within 50 miles around Delhi, Calcutta, Tiruchirapalli (plain stations) and Bangalore which is at a height of about 3000 ft.

Rai Sircar and Hariharan (1954) made a study of the day-to-day distribution of rainfall in the same four areas and found that the record of one station is not sufficient to correctly represent the true character of raininess of these areas. There are 50 raingauge stations in the Tiruchirapalli area, 27 in the Bangalore area and 40 in each of the areas around Calcutta and Delhi. In this study, the rainfall records of all these raingauge stations in the four areas have been analysed for the five year period 1941-45. A day with precipitation has been defined as a day on which at least one station in the area recorded precipitation of one cent or more.

2. Analysis of daily rainfall data

The following procedure has been followed for analysing the rainfall data in the various areas. At first, the average precipitation was determined for each area for each day of the monsoon months during the five year period under study. On a few occasions when data were not available from all the stations in any of these areas, the daily averages were based on the records of stations for which data were available. These daily values were then arranged in a column in an ascending order of magnitude on a monthly basis (*i.e.* for 5 Junes, 5 Julies etc, separately). The cumulative sums of these values and of the number of days with rain were worked out and all the cumulative sub-totals were expressed as a percentage of the totals. To illustrate how the computation was carried out, the data for the Delhi area for 5 Julies are shown in Table 1. The cumulative percentage values of rainfall (column 5 of Table 1) were then plotted against the corresponding

TABLE 1

Delhi area (for 5 Julies)

Cumulative sums of days with precipitation	Cumulative percentage values of days with precipitation	Precipitation amounts arranged in ascending order	Cumulative sums of precipitation amounts	Cumulative percentage values of precipitation amounts
(1)	(2)	(3)	(4)	(5)
1	0·9	·01	·01	·03
2	1·8	·01	·02	·07
3	2·7	·01	·03	·10
4	3·6	·01	·04	·14
5	4·5	·01	·05	·17
6	5·4	·01	·06	·21
7	6·3	·01	·07	·24
8	7·2	·01	·08	·27
9	8·1	·01	·09	·31
10	9·0	·01	·10	·34
11	9·9	·01	·11	·38
12	10·8	·01	·12	·41
13	11·7	·01	·13	·44
14	12·6	·02	·15	·51
15	13·5	·02	·17	·58
16	14·4	·02	·19	·65
17	15·3	·02	·21	·72
18	16·2	·02	·23	·79
19	17·1	·03	·26	·89
20	18·0	·03	·29	·99
21	18·9	·03	·32	1·10
22	19·8	·03	·35	1·20
23	20·7	·03	·38	1·30
24	21·6	·03	·41	1·40
25	22·5	·04	·45	1·54
26	23·4	·04	·49	1·68
27	24·3	·04	·53	1·81
28	25·2	·04	·57	1·95
29	26·1	·05	·62	2·12
30	27·0	·05	·67	2·29
31	27·9	·06	·73	2·50
32	28·8	·06	·79	2·70
33	29·7	·06	·85	2·91
34	30·6	·06	·91	3·11
35	31·5	·07	·98	3·35
36	32·4	·07	1·05	3·59
37	33·3	·07	1·12	3·83
38	34·2	·08	1·20	4·11
39	35·1	·08	1·28	4·38
40	36·0	·08	1·36	4·65
41	36·9	·09	1·45	4·96
42	37·8	·09	1·54	5·27
43	38·7	·10	1·64	5·61
44	39·6	·10	1·74	5·95
45	40·5	·10	1·84	6·30
46	41·4	·10	1·94	6·64
47	42·3	·10	2·04	6·98
48	43·2	·11	2·15	7·36
49	44·1	·13	2·28	7·80
50	45·0	·13	2·41	8·25

TABLE 1 *(contd)*

(1)	(2)	(3)	(4)	(5)
51	45·9	·14	2·55	8·73
52	46·8	·15	2·70	9·24
53	47·7	.15	2·85	9·75
54	48·6	.15	3·00	10·27
55	49·5	·15	3·15	10·78
56	50·4	.15	3·30	11·29
57	51·3	·15	3·45	11·81
58	52·2	·17	3·62	12·39
59	53·1	·18	3·80	13·00
60	54·0	·19	3·99	13·66
61	54·9	·19	4·18	14·31
62	55·8	·21	4·39	15·02
63	56·7	·21	4·60	15·74
64	57·6	·21	4·81	16·46
65	58·5	·21	5·02	17·18
66	59·4	·21	5·23	17·90
67	60·3	·22	5·45	18·65
68	61·2	·22	5·67	19·40
69	62·1	·23	5·90	20·19
70	63·0	·25	6·15	21·05
71	63·9	·25	6·40	21·90
72	64·8	.26	6·66	22·79
73	65·7	.27	6·93	23·72
74	66·6	.27	7·20	24·64
75	67·5	·27	7·47	25·56
76	68·4	·28	7·75	26·52
77	69·3	.29	8·04	27·52
78	70·2	·30	8·34	28·54
79	71·1	·30	8·64	29·57
80	72·0	·31	8·95	30·63
81	72·9	·33	9·28	31·76
82	73·8	·34	9·62	32·92
83	74·7	·35	9·97	34·12
84	75·6	·36	10·33	35·35
85	76·5	·36	10·69	36·58
86	77·4	·37	11·06	37·85
87	78·3	·37	11·43	39·12
88	79·2	·37	11·80	40·38
89	80·1	·38	12·18	41·68
90	81·0	·40	12·58	43·05
91	81·9	·40	12·98	44·42
92	82·8	·41	13·39	45·82
93	83·7	·44	13·83	47·33
94	84·6	·47	14·30	48·94
95	85·5	·49	14·79	50·62
96	86·4	·51	15·30	52·36
97	87·3	·53	15·83	54·18
98	88·2	·55	16·38	56·06
99	89·1	·56	16·94	57·97
100	90·0	·65	17·59	60·20
101	90·9	·66	18·25	62·46
102	91·8	·68	18·93	64·78
103	92·7	·72	19·65	67·25
104	93·6	·78	20·43	69·92
105	94·5	·94	21·37	73·13
106	95·5	1·03	22·40	76·66
107	96·4	1·10	23·50	80·42
108	97·3	1·22	24·72	84·60
109	98·2	1·26	25·98	88·91
110	99·1	1·43	27·41	93·81
111	100·0	1·81	29·22	100·00

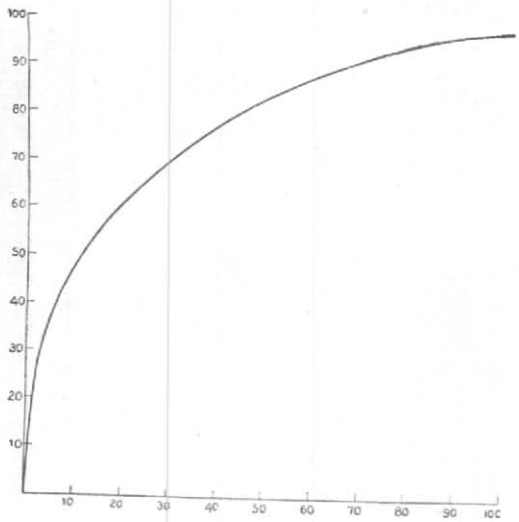

Fig. 1. Cumulative percentage values of precipitation (abscissa) against cumulative percentage values of days with precipitation (ordinate) for Delhi area for 5 Julies

cumulative percentage values of precipitation days (column 2 of Table 1) and shown in Fig. 1. The graphs for the other areas for the different monsoon months were also drawn in the same way. From these curves one can get both the maximum (measured upward from 0 per cent) and the minimum (measured downward from 100 per cent) percentage of precipitation days which account for a certain given percentage of total rainfall during a month. As one would ordinarily be interested more in the minimum number of such days, rather than the maximum, the various percentage number of occasions with precipitation discussed in this paper relate to those as have been determined from the graphs by going downwards from 100 per cent.

Graphs representing the percentages of days with precipitation that account for 25 per cent, 50 per cent and 75 per cent of the rainfall in the four areas during the various monsoon months are shown in Fig. 2. It will be seen that the percentage number of occasions with precipitation accounting for 75 per cent of the rainfall in the Calcutta area increases by about 10 per cent from June to July. Otherwise, in the four areas under consideration there are only small monthly variations

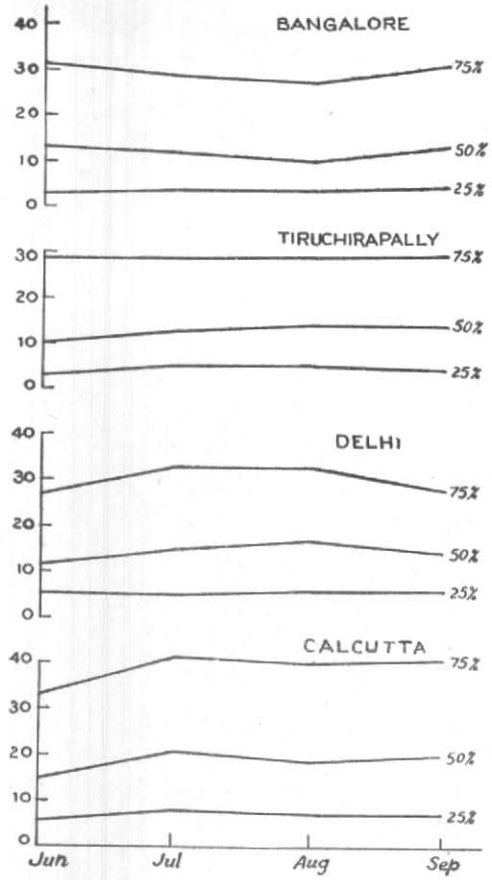

Fig. 2. The seasonal distribution of percentages of days with precipitation (ordinate) that could account for 25%, 50% and 75% of the monthly precipitation in the four zones

in the percentage number of rainy days yielding a given percentage of rainfall in the four areas. It is noticed that during the monsoon months 25 per cent of month's rainfall may be expected to occur on less than 8 per cent, 50 per cent on less than 20 per cent and 75 per cent on less than 42 per cent of days with precipitation in all the four areas under study.

The seasonal means of percentages of precipitation days in the four areas for three precipitation levels (25 per cent, 50 per cent and 75 per cent of total rainfall), together with the mean values of deviations of monthly values from the seasonal mean for each area are shown in Table 2. It will be seen that the

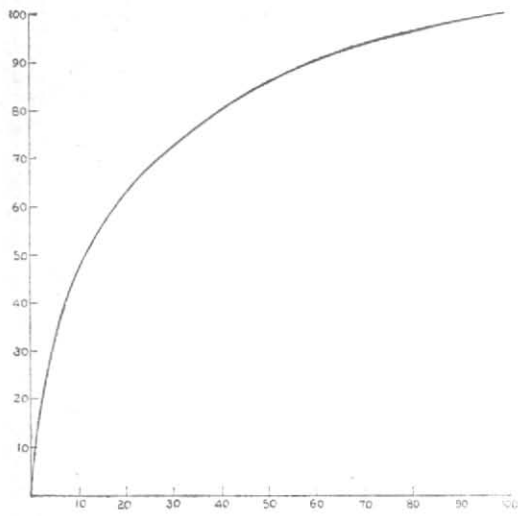

Fig. 3. Cumulative percentage values of precipitation (abscissa) against cumulative percentage values of days with precipitation (ordinate) for the monsoon season for all the zones combined

mean deviation are small in each case, and as such the mean curve for each area may for all practical purposes be considered as representative for each month. It is further noticed that the mean values of the percentage number of rainy days corresponding to the various precipitation levels in the three areas, namely, Delhi, Tiruchirapalli and Bangalore are nearly equal. The Calcutta values differ slightly but their departures from the values of the other three areas are not large. In view of the general uniformity both in regard to space and time, it is possible to combine all the groups and construct one single curve representing all the four areas. Such a composite curve is shown in Fig. 3. This curve is approximately represented (the error being within ± 3 per cent), by the equation

$$x = aye^{by}$$

where x is the rainfall expressed as cumulative percentage of the total, and y the number of days with precipitation expressed as cumulative percentage of the total number of such days. The values of the constants a and b are $2{\cdot}87 \times 10^{-2}$ and $3{\cdot}55 \times 10^{-2}$ respectively. It has not been possible to make similar study for all the different climatic zones in India in view of the large computational work involved in it. The above curve may, however, be considered to hold good at least approximately for the other parts of India also. Olascoaga, who got a similar curve for Argentina with $a = 2{\cdot}30 \times 10^{-2}$ and $b = 3{\cdot}78 \times 10^{-2}$ is of the view that this equation probably represents a general statistical law valid for most regions of the globe. Comparisons of the values of the constants for India and Argentina would seem to confirm his expectations.

3. Analysis of rainfall associated with rainstorms

The spatial distribution of rainfall in an area depends on the general meteorological situations over the area, and during the passage of a well defined synoptic disturbance one can reasonably expect more than half the stations in the zone reporting some precipitation. Following Riehl (1949), the term "rainstorm" is used to denote occasions on which more than 50 per cent of the stations in the area record rainfall on a day.

TABLE 2

Mean percentages during the season as a whole, of precipitation days that account for 25%, 50% and 75% rainfall, and mean deviations of their monthly values from the seasonal means for the four areas

Area	Percentage of the total precipitation					
	25%		50%		75%	
	Mean	Mean deviation	Mean	Mean deviation	Mean	Mean deviation
Calcutta	7	1	19	2	39	4
Delhi	5	1	14	2	30	3
Tiruchirapalli	4	1	13	2	29	0
Bangalore	4	1	12	2	28	3

On the basis of the above definition, a study has been made of the rainfall associated with rainstorm in each of the four areas during the different months of the monsoon season. The difference between this amount and the total rainfall gives the amount that is derived from precipitation in the nature of scattered showers. The average number of days with precipitation and the average number of rainstorm days for the four areas in different months are shown in Table 3. It will be seen that the majority of the precipitation days in the Calcutta area during the months of July and August are rainstorm days. In the other three areas, the percentage of rainstorm days is not so high. It is minimum in June and gradually increases to a maximum value of about 30 per cent in September. The mean monthly total rainfall and the mean monthly rainfall due to rainstorms alone are shown in Table 4. It will be seen that in the Calcutta area as much as 82 per cent of the total monsoon rainfall occurs in association with rainstorms. The corresponding figures for Delhi, Bangalore and Tiruchirapalli area are 68 per cent, 63 per cent and 56 per cent respectively. It is thus seen that although the incidence of scattered showers is more frequent (except in Calcutta in July and August), the amount of rainfall derived from such showers is not relatively so high.

The duration of a rainstorm is taken as the number of consecutive days with precipitation at the majority of the stations in a zone. The average number of rainstorms and their average duration have been found out for each area during the monsoon months, and are shown in Table 5. It is seen that in the Calcutta area rainstorms are fairly uniformly distributed during the various months, their frequency being 3–4 in each month. Their duration is longest in July and August, when monsoon fully establishes itself throughout the sub-continent and maximum number of Bay depressions move westwards across the country. The average frequency of rainstorms in the Delhi area is also highest during the above two months, but their duration is small compared to that in the neighbourhood of Calcutta. In both Bangalore and Tiruchirapalli areas, the maximum number of rainstorms occur in September when the monsoon begins to withdraw from the country. These two areas get widespread showers only on a few occasions during the onset of the monsoon although the weather remains very much disturbed along and near the western coast during that period. The average duration of rainstorms in these two areas is less than two days, and is shorter than that in the other two areas.

The rainfall features during periods of rainstorms were analysed in the same way as indicated earlier in relation to daily precipitation, and curves showing what percentage of rainfall attributed to rainstorms was caused by what percentage of the rainstorms were drawn for each area for each month. As an illustration, the data for Delhi area for five Julies and the corresponding graph are shown in Table 6 and Fig. 4 respectively. From these graphs the percentages of rainstorms accounting for 25 per cent, 50 per cent and 75 per cent of the total rainfall due to rainstorms have been determined for each area for each month and are shown in Fig. 5. It is seen that the monthly variations in the percentage number of rainstorms corresponding to a particular precipitation level are not large, especially in the areas around Calcutta and Delhi. In all the four areas, 75 per cent rainfall was caused by less than 58 per cent rainstorms, 50 per cent rainfall by less than 32 per cent rainstorms and 25 per cent rainfall by less than 15 per cent rainstorms.

The seasonal averages of the percentages of rainstorms for various precipitation levels and the mean deviations of the corresponding monthly values are shown in Table 7. It is seen that the mean deviations are small, although slightly larger than those in the case of daily rainfall discussed earlier. It is also noticed that the seasonal averages of the percentages of rainstorms for a particular precipitation level in the four areas do not differ from one another appreciably and hence all the curves can be combined, as in the first case,

TABLE 3

Mean number of days with precipitation and mean number of rainstorm days for the four areas during the different monsoon months

Area	June		July		August		September	
	Precipitation days	Rainstorm days	Precipitation days	Rainstorm days	Precipitation days	Rainstorm days	Precipitation days	Rainstorm days
Calcutta	28·2	10·6 *38*	31·0	21·0 *68*	31·0	19·4 *63*	29·0	12·8 *44*
Delhi	13·6	2·2 *16*	22·2	5·8 *26*	25·8	6·4 *25*	16·0	4·8 *30*
Tiruchirapalli	18·4	0·4 *2*	18·4	1·4 *8*	23·6	4·2 *18*	21·0	6·6 *31*
Bangalore	19·0	1·4 *7*	23·0	4·6 *20*	23·2	4·8 *21*	22·6	6·8 *30*

The figures in italics indicate the percentage

TABLE 4

Monthly mean rainfall and mean rainfall on rainstorm days in inches in the four areas during the monsoon season

Area	June		July		August		September	
	Mean monthly rainfall	Mean monthly rainfall due to rainstorms	Mean monthly rainfall	Mean monthly rainfall due to rainstorms	Mean monthly rainfall	Mean monthly rainfall due to rainstorms	Mean monthly rainfall	Mean monthly rainfall due to rainstorms
Calcutta	9·41	7·12 *76*	13·30	11·53 *87*	15·70	13·89 *88*	8·77	6·37 *73*
Delhi	1·85	1·07 *58*	5·84	4·01 *69*	5·30	3·36 *63*	4·81	3·75 *78*
Tiruchirapalli	1·24	0·24 *19*	1·50	0·54 *36*	4·14	2·34 *57*	5·41	3·75 *69*
Bangalore	1·93	0·63 *33*	2·90	1·86 *64*	4·02	2·76 *69*	5·06	3·53 *70*

The figures in italics indicate the percentages

TABLE 5

Mean number and duration of rainstorms in the four areas during the different monsoon months

Areas	June		July		August		September	
	Mean No. of rainstorms	Mean period of rainstorms (days)	Mean No. of rainstorms	Mean period of rainstorms (days)	Mean No. of rainstorms	Mean period of rainstorms (days)	Mean No. of rainstorms	Mean period of rainstorms (days)
Calcutta	3·4	3·1	4·4	4·8	3·4	5·7	4·0	3·2
Delhi	1·4	1·6	3·2	1·8	3·0	2·1	1·6	3·0
Tiruchirapalli	0·4	1·0	1·2	1·2	3·0	1·4	4·2	1·6
Bangalore	1·0	1·4	3·2	1·4	2·6	1·8	4·0	1·7

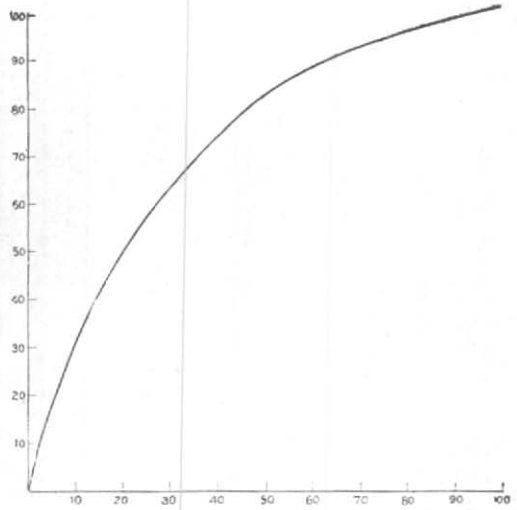

Fig. 4. Cumulative percentage values of precipitation due to rainstorms (abscissa) against cumulative percentage values of rainstorms (ordinate) for the Delhi area for 5 Julies

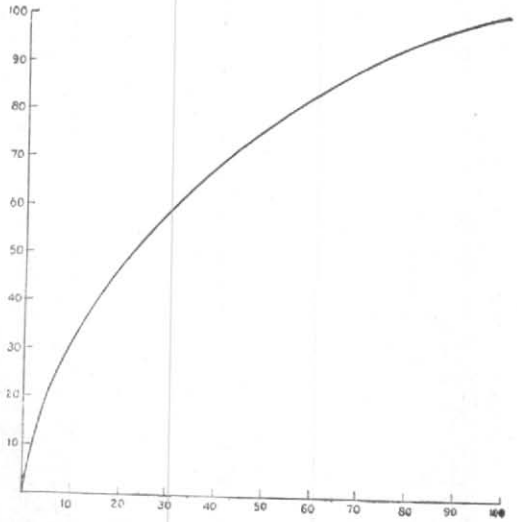

Fig. 6. Cumulative percentage values of precipitation due to rainstorms (abscissa) against cumulative percentage values of rainstorms (ordinate) for the monsoon season for all the zones combined

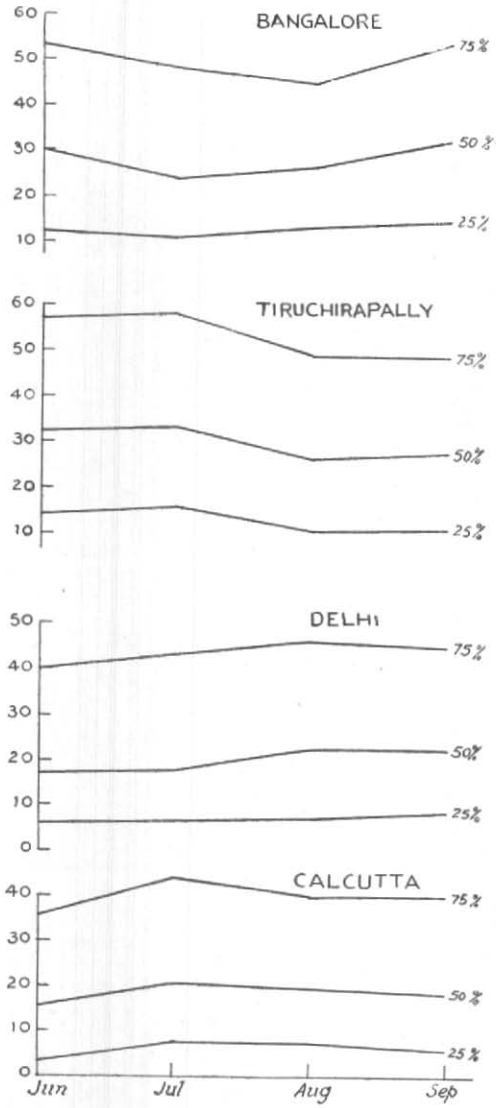

Fig. 5. The seasonal distribution of percentages of rainstorms (ordinate) that could account for 25%, 50% and 75% of the monthly precipitation derived from rainstorms in the four zones

TABLE 6

Delhi areas (For 5 Julies)

Cumulative sums of rainstorms	Cumulative percentage values of rainstorms	Precipitation amounts arranged in ascending order	Cumulative sums of precipitation amounts	Cumulative percentage values of precipitation amounts
1	6·2	·27	·27	1·35
2	12·5	·34	·61	3·04
3	18·7	·40	1·01	5·04
4	25·0	·53	1·54	7·68
5	31·2	·55	2·09	10·43
6	37·5	·58	2·67	13·32
7	43·7	·59	3·26	16·27
8	50·0	·68	3·94	19·66
9	56·2	·94	4·88	24·35
10	62·5	1·10	5·98	29·84
11	68·7	1·12	7·10	35·43
12	75·0	1·26	8·36	41·72
13	81·2	1·50	9·86	94·20
14	87·5	1·84	11·70	58·38
15	93·7	3·72	15·42	76·95
16	100·0	4·62	20·04	100·00

TABLE 7

Mean percentages during the season, as a whole, of rainstorms that account for 25%, 50% and 75% rainfall associated with such disturbances, and mean deviations of their monthly values from the seasonal means for the four areas

Area	Percentage of the total precipitation due to rainstorms					
	25%		50%		75%	
	Mean	Mean deviation	Mean	Mean deviation	Mean	Mean deviation
Calcutta	6	2	19	2	40	3
Delhi	7	1	20	3	44	3
Tiruchirapalli	12	2	30	4	54	5
Bangalore	11	2	27	4	48	4

to get a curve which is approximately representative of all the four areas. Such a curve is shown in Fig. 6, and this is given (the error is within $\pm$ 2 per cent) by the equation

$$x = aye^{by} \quad \text{where } a = 16{\cdot}20 \times 10^{-2}, \quad b = 1{\cdot}82 \times 10^{-2}$$

The values of the corresponding constants for Argentina are $17{\cdot}3 \times 10^{-2}$ and $1{\cdot}74 \times 10^{-2}$ respectively. The nearness of the values of the constants for the two countries would suggest that the above curve also may roughly be representative of a major part of the globe.

4. Acknowledgement

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