

Heavy rainfall during monsoon season: Point and spatial distribution

P. R. Rakhecha and P. R. Pisharoty

The daily rainfall records of about 5000 stations in India, during the monsoon periods of several decades, have been examined for occurrence of heavy rainfall. The point values of (i) the highest annual rainfalls, (ii) the highest rainfalls of one, two, and three day durations, and (iii) the highest hourly values, are presented in the form of tables and charts. The highest depth-area-duration values for twelve storm-centres are also given.

AN important feature during the Southwest and Northeast monsoon seasons of India is the occurrence of heavy rainfall associated with certain meteorological situations all over the country. Persistent copious rains throughout a season are associated with orographic lifting of moisture-laden winds, heavy rains for periods of days with cyclonic storms and the short period heavy falls with intense thunderstorms. The Western Ghats is an excellent example of an area where heavy rainfall occurs due to orographic effects. Rainfall caused by a depression is as high as 40–80 cm per day. Many stations have recorded their mean annual rainfall in a single day.

A great proportion of variability of rainfall in India is related to the occurrence and intensity of extremely heavy rainfall events and as such there is a need to know the magnitudes of heavy rainfall events over different parts of the country. Discussions on heavy rainfalls are also of great importance in the designing of water projects. The spatial distribution of point and areal values of highest rainfalls over the Indian region on the basis of historical rainfall data of a large number of stations, are summarized in this paper.

Rainfall stations in India

Rainfall measurement in India was started towards the end of the 18th century. The first recorded data were obtained at Calcutta in 1784 followed by observations at Madras from 1792, Bombay from 1823 and Simla from 1840. However, the recording of rainfall at a large number of stations was started from the middle of the 19th century. The need for increasing the networks of rainfall sites for hydroclimatic purposes was felt after 1947 and, as a result, extensive networks of rainfall

measurement sites were established throughout the country. At present there are about 5480 rainfall stations spread all over the country. The daily rainfall data of these stations are available in digital form at the National Data Centre of the India Meteorological Department, at Pune.

Causes of heavy rainfall

Heavy rainfalls occur over different parts of the country and are associated with:

- Formation and subsequent movement of cyclonic disturbances across the country
- Orographic lifting of moisture air as it rises along the slope of a mountain barrier across the air stream
- Breaks in the monsoon, when the rainfalls are confined to the Himalayas and the Indian regions close to it.

The cyclonic disturbances are low pressure systems in which the associated wind circulates in a counter clockwise direction in the Northern Hemisphere. The

Table 1. Highest annual rainfalls

Station	State	Amount (cm)
Amboli	Maharashtra	748
Agumbe	Karnataka	828
Bhagamandala	Karnataka	603
Buxa	West Bengal	532
Cherrapunji	Meghalaya	1087
Denning	Tripura	532
Gaganbavada	Maharashtra	621
Mahabaleshwar	Maharashtra	623
Matheran	Maharashtra	517
Mawsynram	Meghalaya	1141
Makut	Karnataka	506
Neriamangalam	Kerala	588
Peermade	Kerala	517
Pulingoth	Karnataka	594

The authors are in the Indian Institute of Tropical Meteorology, Pune 411 008, India.

criteria for describing the cyclonic disturbances over the Indian sea areas are as follows:

System	Wind speed in circulation
Low pressure	< 20 knots
Depression	20–33 knots
Cyclonic storm	34–47 knots
Severe cyclonic storm	> 48 knots

When the maximum wind in the circulation reaches 64 knots or more, the system is called a severe cyclonic storm with a core of hurricane winds.

During the SW monsoon period the cyclonic disturbances (mainly depressions with associated winds of 20–33 knots) form over the north of the Bay of Bengal to the north of 18°N and move in a northwesterly direction across the country. Depending upon the tracks

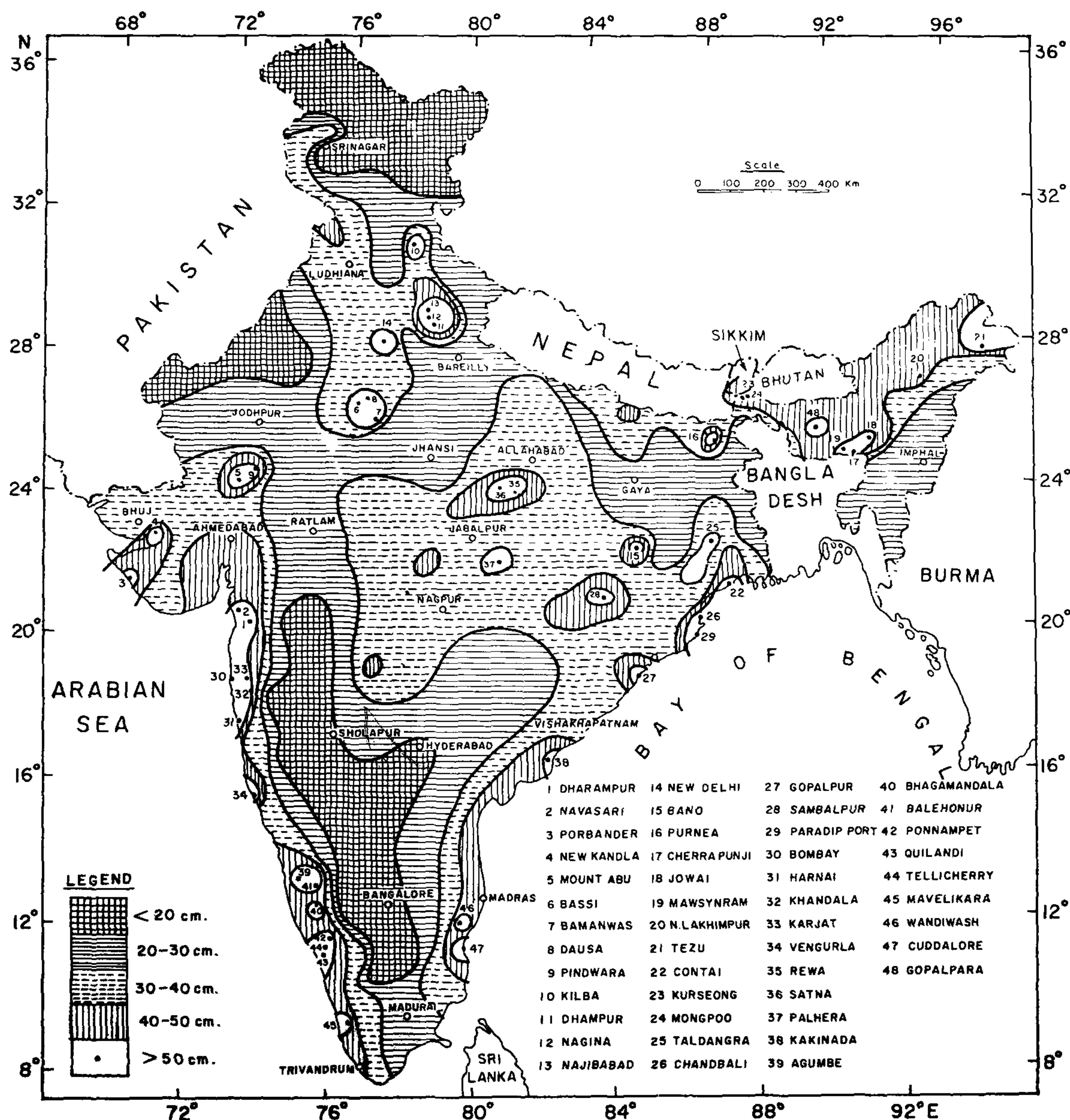


Figure 1. Highest rainfall for 1-day duration (period 1875–1982).

of these disturbances, heavy rainfall occurs in the regions which are exposed to these disturbances. Rainfall caused by such depressions can range from 40–80 cm per day. The maximum rainfall recorded in the plains during these disturbances are 90 cm in one day at Purnea in Bihar and 99 cm in one day at Dharampur in Surat district of Gujarat. The average annual frequency of monsoon depressions are 7, of which about 1 occurs

in June and two each in July, August and September. During the active monsoon the strengthening of the Arabian Sea current results in heavy rainfall along the west coast of the peninsula and on the Western Ghats. When a depression forms in the Bay of Bengal often the Arabian Sea monsoon current is strengthened; it causes heavy rainfall over the Western Ghats; due to orographic lifting of the moisture-laden winds.

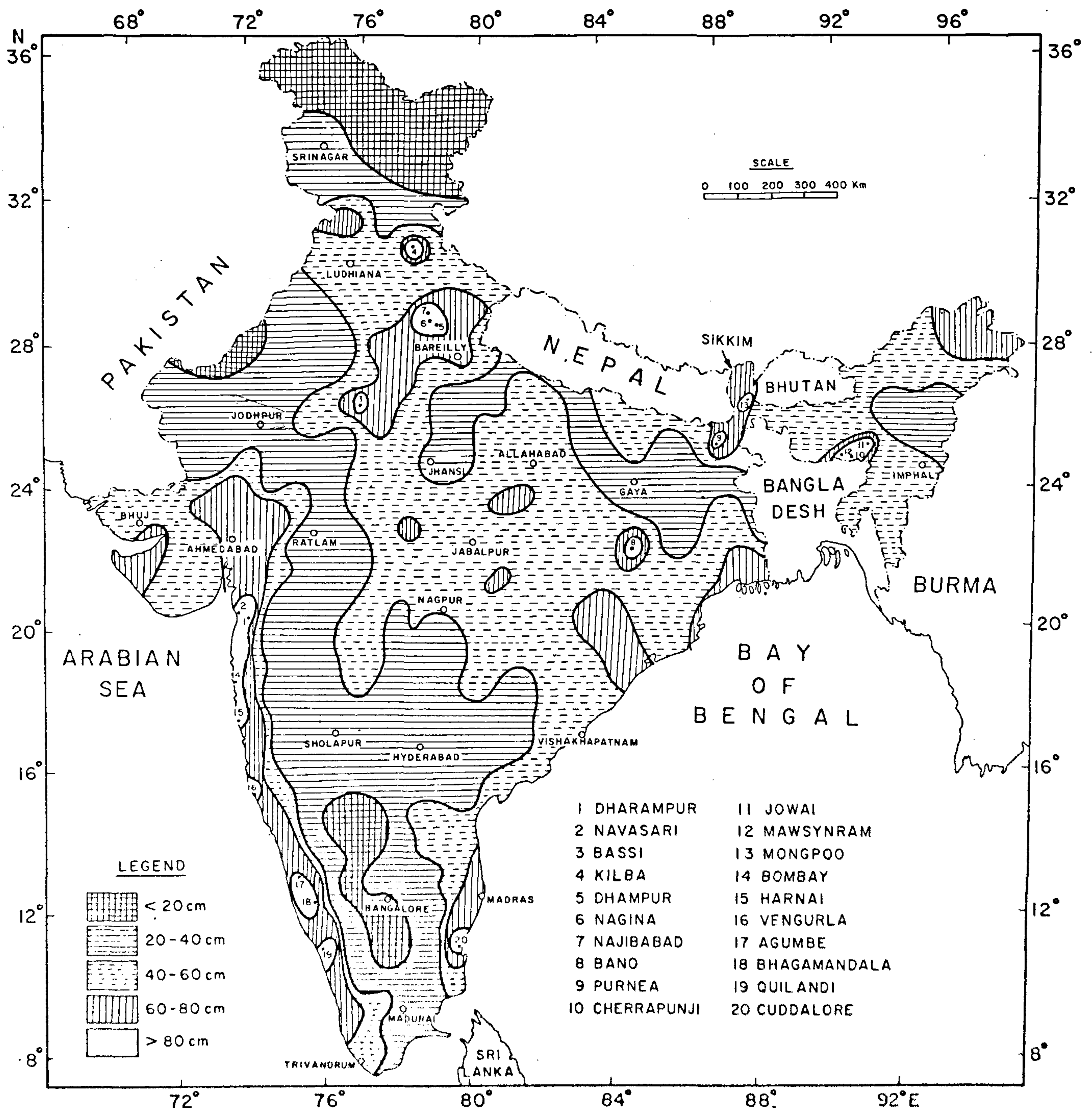


Figure 2. Highest rainfall for 2-day duration (period 1875-1982).

Rainfall during the monsoon season is not continuous but alternates with active and break monsoon conditions. During a 'break' the seasonal monsoon trough of low pressure shifts northwards from its normal position to the foothills of Himalayas where heavy rainfalls occur.

During the pre-monsoon and post-monsoon months, tropical storms form in south Bay of Bengal and Arabian Sea. Many of these storms move inland and cause heavy to very heavy rainfall along and near their tracks over the southern parts of India.

The magnitude and frequencies of the heavy rainfalls, however, differ widely because of variations of physiography and atmospheric features.

Highest annual rainfalls

The data on annual rainfall, from about 4000 stations, show that there are about 14 stations in the country where mean annual rainfall is 500 cm or more (Table 1). Of these 14 stations, 4 stations (Buxa, Cherrapunji,

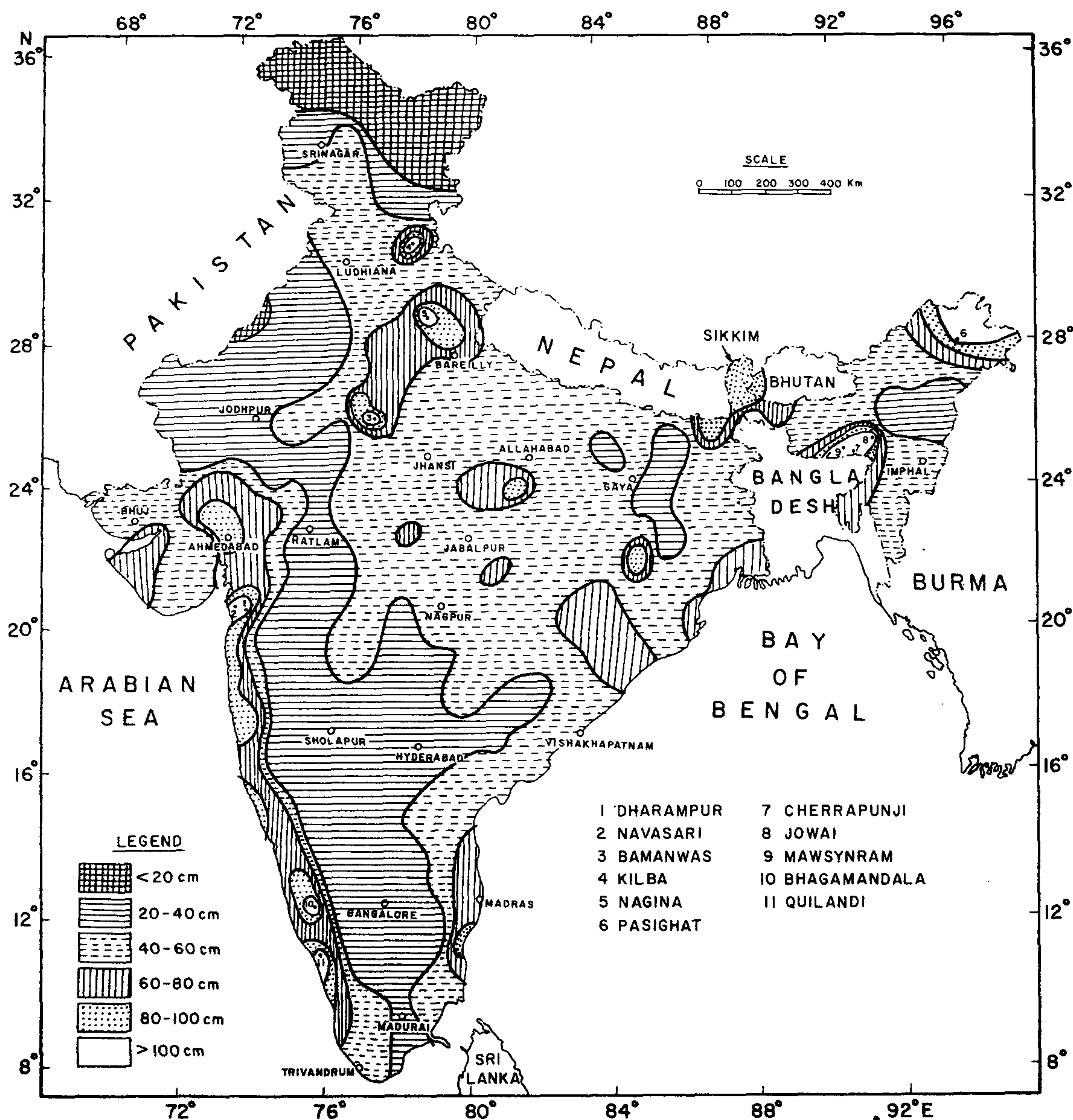


Figure 3. Highest rainfall for 3-day duration (period 1875-1982).

Table 2. Highest recorded point rainfalls (cm) for 1, 2 and 3-day durations (1875 to 1982)

Station	State	Height (m)	1-Day	2-Day	3-Day	Date
Mawsynram	Meghalaya	1401	99	143	201	July 1952
Cherrapunji	Meghalaya	1313	104	165	224	June 1876
Bhagamandala	Karnataka	876	84	136	136	July 1924
Ponnampet	Karnataka	857	52	61	67	July 1965
Agumbe	Karnataka	659	62	93	95	July 1963
Satna	Madhya Pradesh	549	54	58	61	June 1882
Khandala	Maharashtra	539	52	67	73	July 1958
Bassi	Rajasthan	351	56	84	85	July 1981
Rewa	Madhya Pradesh	286	77	77	82	June 1882
Dhampur	Uttar Pradesh	258	77	99	99	Sept. 1880
Bamanwas	Rajasthan	252	51	76	103	July 1981
Nagina	Uttar Pradesh	250	82	104	104	Sept. 1880
Najibabad	Uttar Pradesh	240	72	98	98	Sept. 1880
Karjat	Maharashtra	107	61	67	73	July 1958
Dharampur	Gujarat	38	99	126	145	July 1941
Gopalpur	Orissa	17	51	65	70	Oct. 1954
Porbandar	Gujarat	12	51	62	66	Sept. 1977
Cuddalore	Tamil Nadu	12	57	82	95	May 1943
Bombay	Maharashtra	11	57	80	88	July 1974
Vengurla	Maharashtra	9	53	82	88	June 1958
Kakinada	Andhra Pradesh	8	50	53	57	June 1941
Quilandi	Kerala	8	91	109	113	May 1961

Table 3. Depth-area-duration values (cm) of extreme rainstorms in India

Rainstorm date	Storm centre	Area affected	Duration	Area in 100 km ²					
				0	1	10	50	100	200
17-18 Sept. 1880	Nagina	Uttar Pradesh	1	82	82	78	63	52	40
			2	104	103	99	87	77	62
20-22 Sept. 1900	Serampore	West Bengal	1	44	43	41	36	33	28
			2	73	72	67	58	52	44
			3	83	82	78	69	62	52
19-21 Sept. 1926	Bichhia	Madhya Pradesh	1	36	36	35	33	30	26
			2	65	65	63	57	53	47
			3	83	82	81	76	71	62
1-3 July 1930	Wani	Maharashtra	1	36	36	31	24	22	19
			2	71	70	58	40	33	28
			3	77	76	66	47	39	35
1-3 July 1941	Dharampur	Gujarat	1	99	97	85	65	54	43
			2	127	126	118	97	83	66
			3	145	143	134	117	105	86
17-19 May 1943	Vanur	Tamil Nadu	1	42	41	37	29	25	21
			2	72	72	69	55	46	37
			3	95	95	91	73	61	49
3-5 Oct. 1955	Batala	Punjab	1	50	47	45	40	35	29
			2	72	70	64	56	51	44
			3	72	71	67	59	53	47
1-3 Oct. 1961	Sheikhpura	Bihar	1	37	37	36	32	28	23
			2	55	54	53	49	44	35
			3	58	57	57	54	50	42
28-30 Sept. 1964	Atmakur	Karnataka	1	24	23	23	22	21	19
			2	44	43	32	27	25	22
			3	62	61	51	38	34	30
13-15 July 1965	Nizamsagar	Andhra Pradesh	1	51	49	39	25	20	16
			2	54	52	41	27	23	20
			3	60	57	45	30	27	23
18-20 July 1981	Bassi	Rajasthan	1	56	56	54	45	37	27
			2	84	83	76	62	52	40
			3	97	95	85	71	61	48
28-30 Aug. 1982	Bijapur	Orissa	1	52	52	51	45	38	30
			2	70	70	69	65	59	50
			3	88	88	84	74	66	55

Denning, Mawsynram) are located in northeast India and the other 10 stations are located in the Western Ghats of Peninsular India. Apparently, very high annual rainfalls occur in the hilly regions. Mawsynram in the Khasi hills and Agumbe in the Western Ghats of south India have received the highest annual mean orographic rainfall of about 1141 cm and 828 cm respectively.

Highest daily rainfalls

Heavy to very heavy rainfall for periods of days occurs associated with the movement of cyclonic disturbances from the Bay of Bengal and the Arabian Seas over India. The daily rainfall data for about 300 stations for the period 1875 to 1982 were used to determine the

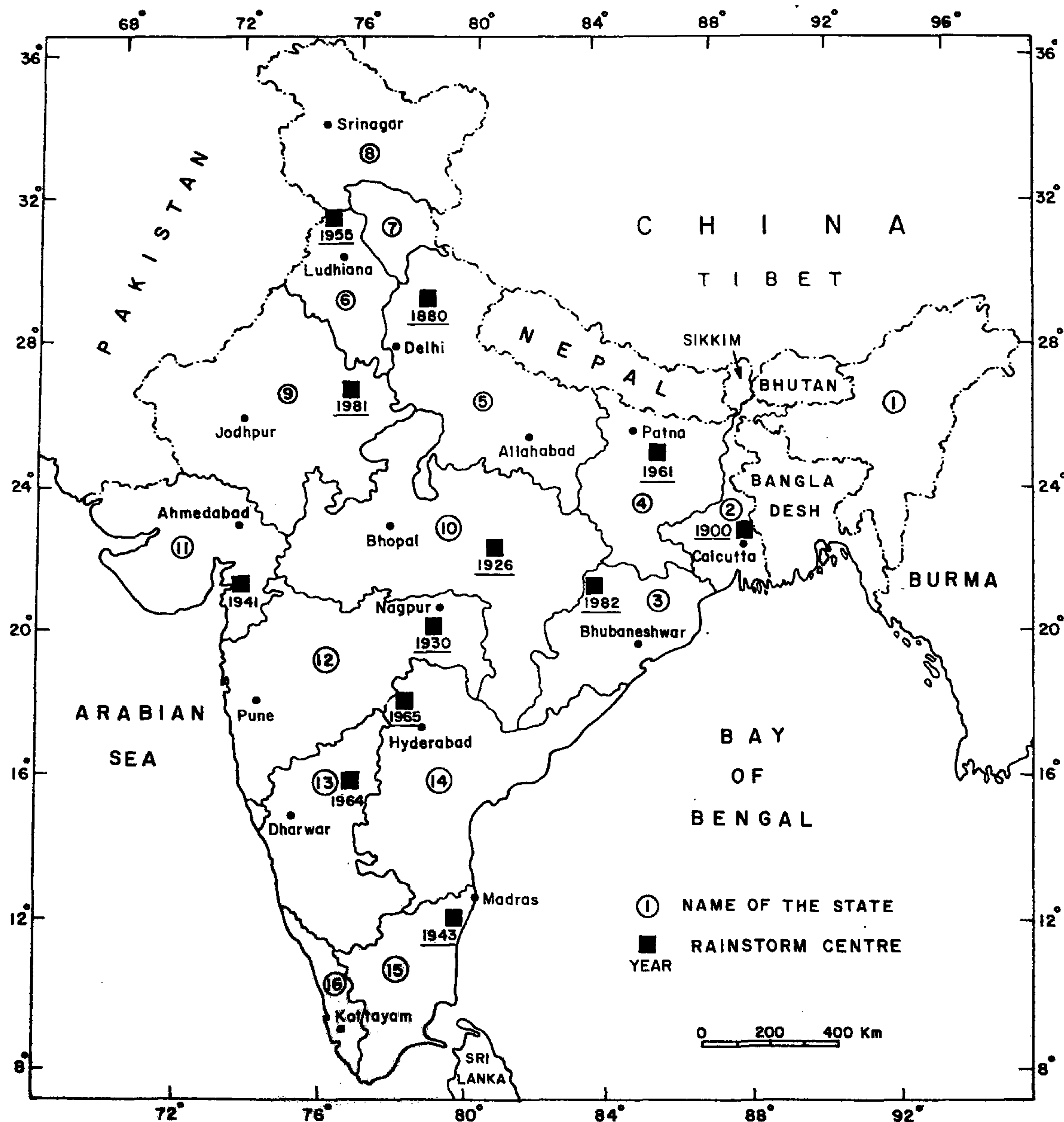


Figure 4. Locations of rainstorms centres.

highest rainfall values of one, two and three-day durations. It may be pointed out that there is an element of randomness in the magnitudes of the highest rainfall recorded even though observations are available for over 100 years. But when the data of all stations are examined together, some broad patterns emerge. The highest rainfalls for 1, 2 and 3-day durations were plotted separately on a large scale map of India and isolines drawn at suitable intervals. The resulting spatial patterns are shown in Figures 1 to 3.

Figure 1 shows the pattern of the highest 1-day rainfall across the Indian region. The isohyets of the highest 1-day rainfall range from less than 20 cm over large parts of the interior peninsula, the arid region of the west Rajasthan and northeast of Jammu and Kashmir to over 40 cm on and near the coastal strips including the Gujarat and Saurashtra coasts, the mountainous regions of the Western Ghats, the hills of Assam and the foothills of the Himalayas. Heavy rainfalls exceeding 30 cm in 1-day have also occurred over the central parts

of India lying between 19°N to 25°N and 70°E to 84°E. Some places on or near the coasts for example, Bombay, Harnai, Cuddalore, Wandiwash, Kakinada, Paradip, Gopalpur and Contai and some places in the hills such as Agumbe (Karnataka), Mount Abu (Rajasthan), Khandal (Maharashtra), Cherrapunji, Jowai and Mawsynram have recorded 60 to 100 cm rainfall in 1-day.

The spatial patterns of 2-day and 3-day highest rainfalls are shown in Figures 2 and 3 respectively. The highest recorded rainfall values of 1 to 3-day durations for some coastal as well as for high and low level stations are given in Table 2.

The highest rainfall values represent only small areas around the recording points. The table shows that Cherrapunji (mountainous area) recorded the highest rainfalls of 104 cm, 165 cm and 224 cm in 1, 2 and 3-day periods respectively. Dharampur (plain area) in south Gujarat recorded the highest rainfalls of 99 cm, 126 cm and 145 cm in 1, 2 and 3-day periods respectively. It was found that a cyclonic disturbance lasting for 6 days ravaged the area at that time and provided ideal conditions for spectacular falls.

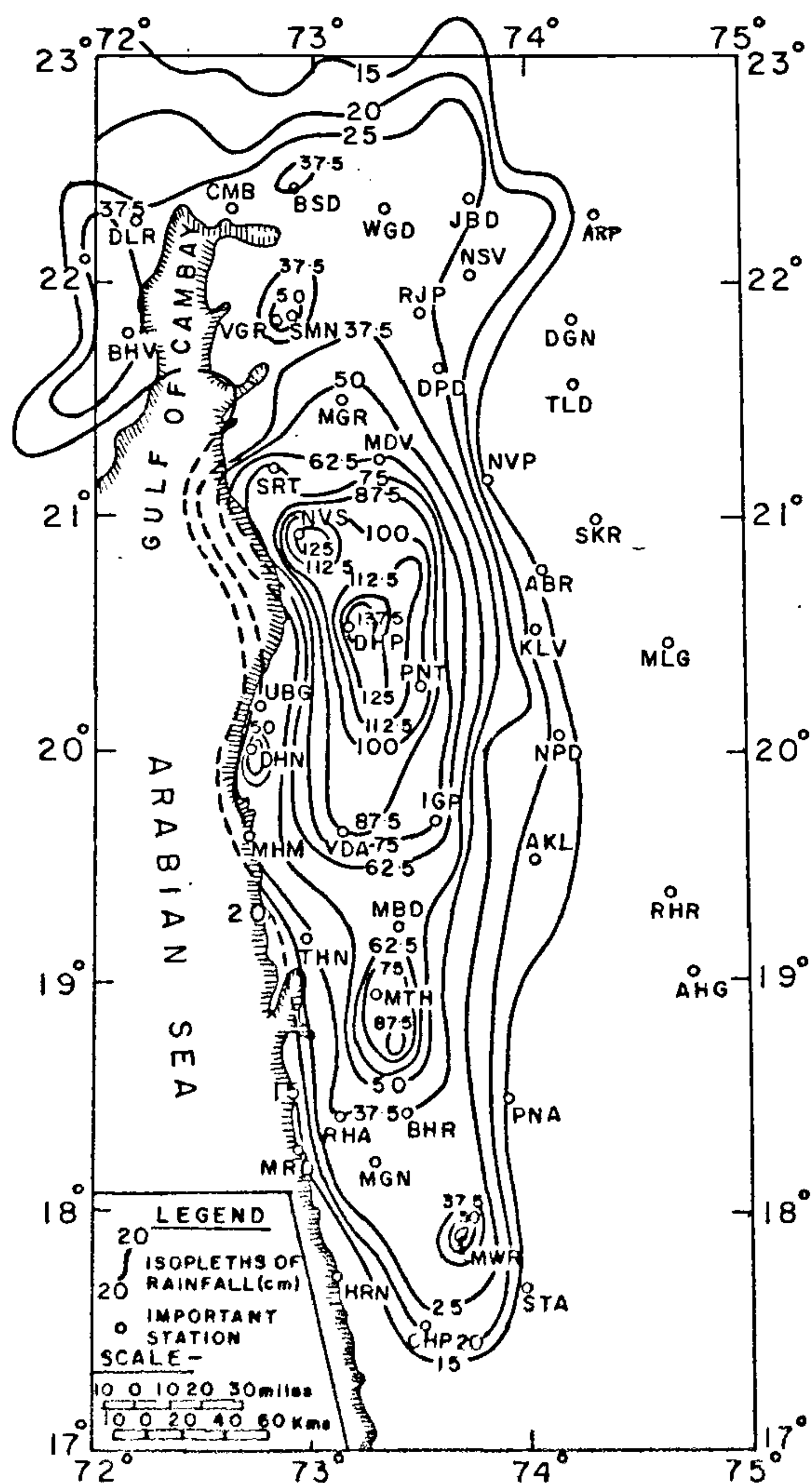


Figure 5. Rainstorm isohyetal pattern of 3 days (1-3 July 1941) over south Gujarat-North Konkan.

Table 4. Maximum 1-hour rainfall amounts

Station	Amount (cm)
Allahabad	7.5
Asansol	8.6
Amritsar	6.5
Aurangabad	6.1
Agartala	6.6
Ahmedabad	8.0
Baroda	6.7
Bombay	12.9
Bangalore	6.1
Bhopal	7.2
Cherrapunji	12.7
Calcutta	6.8
Dibrugarh	6.0
Gaya	7.0
Hyderabad	10.2
Hazaribagh	6.7
Hirakud	8.2
Jamshedpur	8.6
Jodhpur	5.1
Jaipur	5.7
Jabalpur	7.4
Jagdalpur	7.3
Kodaikanal	6.9
Lucknow	7.0
Madras	6.2
Mangalore	6.4
Mahabaleshwar	4.9
New Delhi	7.9
Nagpur	7.8
Pune	4.7
Trivandrum	7.1
Tiruchirapalli	7.8
Veraval	12.2
Vengurla	6.6
Visakhapatnam	6.3

Highest areal rainfalls

Heavy rainfalls are most important when the period extends to days and the area covered is extensive. Cyclonic disturbances (depressions/cyclonic storms) cause widespread and intense rainfall in areas over which they travel. During the SW monsoon season, the maximum number of cyclonic storms (mainly depressions) from over north Bay of Bengal which have usually a life period of 4 to 5 days. After formation they travel in a northwesterly direction across the country. Rainfall occurs in the region along and near the tracks of these moving storms. The total areal covered by the rainfall reaches about 400,000 km² and point rainfall ranges from 40 to 80 cm in 1-day. These monsoon depressions play a very critical role in the distribution of monsoon rains over the country.

The tracks of these disturbances in July and August are very significant. Their tracks in these two months are concentrated into a comparatively narrow band, indicating a certain amount of regularity in their movement during this period. During September, the spread of the storm tracks is noticeable and it increases further during the post-monsoon month of October. The larger spread of storm tracks indicates the possibility of heavy rainfall occurring not only in the northern river catchments, but also in the southern river catchments during September and October. Cyclones occur, some of them of severe intensity, during the premonsoon (March–May) and postmonsoon (October–December).

Recently, on the basis of rainfall data from the 15 highest storms that occurred in different parts of India, areal distribution maps of maximum 1-day, 2-day and 3-day rainfalls were prepared by IITM¹. Based on the

depth-area-duration (DAD) method, the largest average depth of rainfall that fell over various sizes of area during 1, 2 and 3-day durations are given in Table 3. For a 5000 km² area the maximum rainfall from these 12 storms varied from 22 to 65 cm for 1-day, from 27 to 97 cm for 2-day and from 38 to 117 cm for 3-day duration. The locations of the storms are shown in Figure 4.

The primary weather feature responsible for causing the above heavy rain spells were depressions/cyclonic storms from Bay of Bengal. The spatial pattern of rainfall for 3-day duration for the July 1941 storm is shown in Figure 5. The centre of the storm was located at the Dharampur station in the Gujarat region, which recorded 99 cm on the first day, 127 cm on the first and second day together, and 145 cm on the three days put together.

Highest hourly rainfalls

The highest 1-hour rainfall values for some stations are shown in Table 4. These figures represent intensities only over small areas around the recording points; for turbulence and exposure characteristics of the measuring gauge can vary even over a small distance of a few metres. Most of the very high 1-hour falls have occurred in the coastal and mountainous areas. The highest 1-hour fall, 12.9 cm occurred at Bombay.

1. Indian Institute of Tropical Meteorology, Severe Rainstorms of India Atlas, IITM Publ., 1994.

ACKNOWLEDGEMENT. We are grateful to Prof. R. N. Keshavmurthy, Director for constant encouragement.

Corrigendum

Advertisement published in Curr. Sci., 1996, 71, 96

Read 'Centre for Biochemical Technology' instead of 'Centre for Biotechnology' in lines 4 and 7.

Linking technology development with production – A methodology and case histories

S. C. Gupta

Significance and the process of linking technology development with production in the innovation chain are brought out. The individual and joint roles and responsibilities of the development and production agencies are identified. The methodology and attitude used for fruitful interaction between the development teams of VSSC and the different production agencies are illustrated by case histories of different items. A case of unsuccessful production is also presented to bring out the importance of market forces.

GLOBALIZATION of Indian economy has made pursuit of competitiveness by industry of the country an imperative. Generation and utilization of know-how for improved products and services contribute greatly to competitiveness. For this purpose, there has to be a strong team-work between the research and development teams – which generate the know-how, and the production teams – which utilize the know-how. Whether or not the two teams belong to the same corporate body, the team-work has to be meticulous. The data for India on expenditure on R&D by industry, utilization of know-how generated in India and import of know-how brings out unambiguously that there is little support for the generation of know-how in India and most of the need is met by import. India has a vast R&D infrastructure and substantial R&D manpower. India has also achieved impressive successes in developing and utilizing know-how in a number of important fields, such as space and agriculture. Thus, there is inherent capability. What is lacking is an effective harnessing of the inherent capability.

One of the most important functions of research and development is to generate know-how for transfer to industry for production of new and improved goods and services. Acceptance of the know-how by industry spurs R&D. However, acceptance depends on the techno-economic features of the know-how. The know-how has to be mature and comprehensive enough for smooth production. The respective responsibilities of the R&D and production teams during the transfer, production and marketing activities are to be identified clearly and discharged fully. Near certain prospects of attractive profits to the production agency strengthen acceptance. The R&D team can provide adequate information and

confidence on the first two features of the offered know-how. As the profit potential of the know-how also depends on factors such as market forces, beyond the control of laboratory and industry, the information generated by the R&D team has to be supplemented.

Lack of confidence in the dependability of the technical information provided by the R&D team is often a stumbling block. While critical analysis of the information by independent analysts and consultants may generate some confidence, naturally the clinching assurance comes from the earlier experience of working together successfully. An offer of systematic methodology of know-how transfer and team-work can also generate confidence, specially when past experience in know-how transfer from an R&D team is limited or non-existent. Since the production team is also intimately involved in the transfer of know-how, careful selection of the production team(s) is also critical for the success of the transfer process.

One of the motivations of technology development teams is to see the fruits of their labour being utilized by the needy users. Achieving higher performance and greater reliability at costs affordable to a large body of users is well worth the painstaking and innovative efforts to improve design, fabrication and testing processes. However, without ensuring production with specified quality and in needed quantities at required schedules and at competitive costs, the development process may not progress beyond the development laboratory and reach users. As a result, the developed product may eventually go to a museum rather than to the market place. Just as a development laboratory is the most likely place for innovation and technology development, a manufacturing facility is the most suitable place to do justice to the exacting demands of production. The development laboratory and manufacturing facility thus

S. C. Gupta is in the Vikram Sarabhai Space Centre, Thiruvananthapuram 695 022, India.