REPORT

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CHARACTERISTICS OF INDIAN RAINFALL

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PREFACE

The methods of water management described in texbooks written by foreign scientists are generally based on the characteristics of rainfall experienced by countries in the middle latitudes. However, the rainfall of India has different characteristics. These have been highlighted in this pamphlet.

The writing has been largely in the style adopted by Blanford in his classical book "Climates and Weather of India," published in 1889. The data presented, however, are far more recent. They have been obtained from the publications of the India Meteorological Department, the research papers of Dr. R. Ananthakrishnan and his colleagues, as well as those of Dr. O. N. Dhar and his co-workers. I am indebted to all of them.

It is hoped that this pamphlet would be of some use to the public.

—P. R. PISHAROTY

CHARACTERISTICS OF INDIAN RAINFALL

Sahasra gunam utsrashtum ādatte rasam ravih. (Raghuvamsa)

The Sun abstracts water (from the oceans) to precipitate it as rain, a thousand fold.

Introduction

Water is essential for man's life. 65% of the human body is water, 5% of it is replaced every-day. Variations in this replacement are possible within a narrow limit of two or three per cent; large deficiencies of the order of 15% can be fatal. Apart from the direct consumption of water, fresh water is needed in large quantities for the agricultural production of food and industrial production of consumer goods. To amplify, the agricultural production of a kilogram of wheat needs about 500 kilograms of water; the industrial production of a kilogram of steel needs about 250 kilograms of water, and that of a kilogram of synthetic fibre, almost 20,000 kilograms of water.

All this fresh water has to be obtained by direct rainfall, or as run-off water in rivers and lakes, or from the past rainfall stored as ground-water. It is estimated that the annual withdrawal use of water in 1990, in India, would be around 2600 billion litres a day (bld) or about 95 million hectare-meters.

Mean Annual Rainfall

The average annual amount of total rainfall over India is adequate to provide this amount of fresh water, if all the falling rainwater is wisely managed. The annual rainfall over India, based on the daily data from 2800 stations, distributed over the country, is computed at 117 cm.* – (data for 1901–1970). Such a normal rainfall is the largest anywhere in the world for a country of the size of India – 3.2 million square kilometres.

The great problem of India's rainfall is its great diversity both by geographical divisions (in space) and by different months of the year (in time). Added to these is the large variations in the total rainfall in each geographical division from one year to another, causing floods or droughts. In fact no other political unit in the world furnishes such contrasts as Northern India.

In the east we have Cherrapunji in the Khasi hills with an annual rainfall of 1140 cm., and occasionally as mush as 100 cm. in a day. In the west, at Jaisalmer in West Rajasthan the annual rainfall is 21 cm. Between these extremes we have every possible variation; the contrasts afforded by large regions are only less striking than that of these extreme examples of single stations.

In Southern India also the diversity is large, but here the positions of the dry and wet tracts are reversed. It is the west coast of Peninsular India which receives the copious rainfall of the summer monsoon, while it is withheld from the plains of the east coast, and still more from certain parts of the high plains of the interior. The transition from the zone of the heaviest rainfall to that where it is least and lightest is extremely rapid in the Peninsular India. Thus on the crest of the western Ghats, there are serveral stations like Mahabaleswar, Agumbe, etc. with an average annual rainfall of 600 cm. or more; less than 80 km. to the leeward side, there is a broad zone extending all down the Peninsula in which the rainfall averages 40 cm. to 60 cm. in a year.

On the east coast of India, the annual rainfall is highest, nearly 150 cm., and it decreases inland. There is the Eastern Ghats near and parallel to the coast for some parts; the ralnfall increases along these hill regions.

As mentioned earlier, in the northern plains of the Indo-Gangetic valley, the annual rainfall decreases from 150 cm. over West Bengal to about 15 cm. in West Rajasthan.

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* The essential parts of a rain gauge are: a funnel into which the rain falls, the area of the aperture of which regulates the quantity received; a receiver in which the water is collected, and a graduated glass to measure the quantity, and adapted to the area of the funnel. A centimetre of rainfall means that if collected on an imperious level surface it would form a sheet of water one centimetre deep.

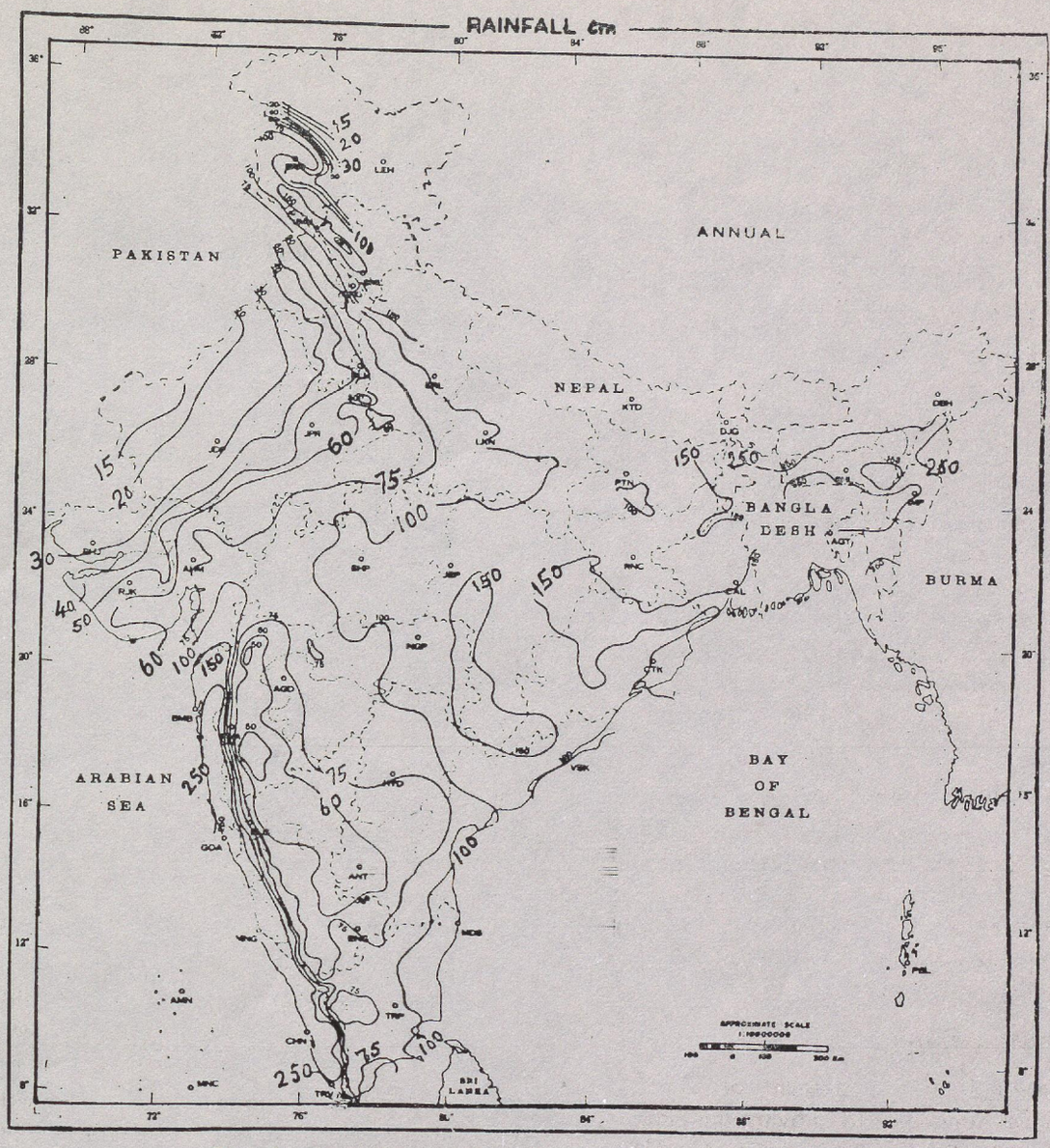


Fig. 1 gives the mean annual rainfall over India.

In the Himalays, rainfall over the eastern parts is more than that on the western parts; it is about 500 cm. on the eastern side and about 250 cm. on the western side. Rainfall increases with elevation upto about 3 kilometres, and decreases thereafter.

Heavy Rainfall

A remarkable feature of the Indian rainfall (perhaps of all rainfalls in Tropical regions) is the occasional heaviness of the falls, even at places where the average rainfall is not by any means, excessive. It need not be surprising if Cherrapunji gets a rainfall of 100 cms. in a day, more than the annual rainfall of many places in the world; but falls nearly as heavy, 60–80 cm. in a day, have occurred over several plain stations of India, where the average annual rainfall is of the order of only 100 to 150 cm. — that is half the annual rainfall can occur in a single day. In the very arid province of West Rajasthan, where the mean annual rainfall is only 20 cm., some stations have on rare occasions received as much as 30 or 35 cms. of rain in a single day.

Seasonal Distribution

By far the greater part of the rainfall is brought about by the Summer Monsoon, which holds sway during June to September or early October. Over a great part of India it is only during this season that there are rains of any importance. And this includes Maharashtra, Gujarat, Rajasthan, the greater part of Punjab, Madhya Pradesh, Orissa, Bengal, Assam, most of Andhra Pradesh and practically the whole of the West coast of the Peninsula. However, the south-east of the Peninsula, including Tamil Nadu and the southern parts of the eastern Ghats, and parts of Mysore receive only an occasional shower when the summer monsoon is active and mainly directed towards the rest of the country. Their season of significant rains comes later—October to December. In these months the rainfall belt moves continuously southwards, and finally is confined to a zone a few degrees North of the equator, where it rains throughout the year.

In the Punjab and Rajasthan, the summer rainfall is much interrupted. It seldom penetrates into the Indus region, nor does it penetrate across the Himalayas into the Kashmir Valley beyond the first snowy range. In the interior of this range, as well as over the western Himalayas, the latter part of the winter and the early part of the spring months are the season during which significant amounts of rain or snow occur. During this season parts of Punjab and the hills of U. P. also receive significant amounts of rain. These winter rains, occasionally penetrate into Rajasthan, the plains of Uttar Pradesh and sometimes into Bihar, Bengal and Assam.

In the spring, moist winds penetrate into Bengal and Assam and frequent thunder showers occur there. The showers become more frequent as the season advances, and the rainfall in Assam during the month of May is so frequent that it merges with the monsoon rainfall which commences in June.

During the months of April and May southern India also get occasional thunder showers–some of the thunderstorm-showers being accompanied by hail. The chance of hail storms is larger in northern India, particularly the hills, than in South India.

Thus, while some part or other of India gets some rain during the different months, the rainfall distribution is far more seasonal than in the mid-latitude countries. Figures 2 and 3 illustrate this point. It will be seen that at stations like Bombay, Ahmedabad or Indore, all the rain is confined to the southwest monsoon period June to September. The people have to collect and store the water for use during the rest of the period. Stations like, Madras, Nagapattanam or Pamban, receive all their rain during the period October to December. Stations like Ambala, Delhi or Allahabad, receive some rain during winter also. However, a station like Srinagar is almost like a mid-latitude station like London, which receives rainfall almost uniformly distributed during all the months of the year.

This is an aspect of Indian rainfall not adequately appreciated by our planners. A large amount of water is to be stored as water for use during the dry eight months of the year. (Our precipitation is not in the form of snow which can be stored as such over the gorund). It is this aspect which creates the problem of even drinking water in the

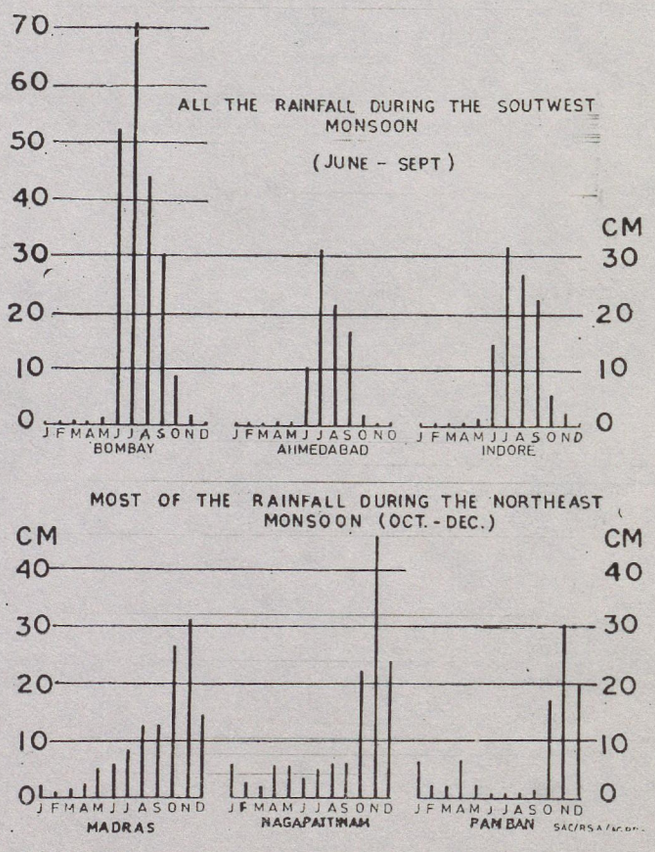
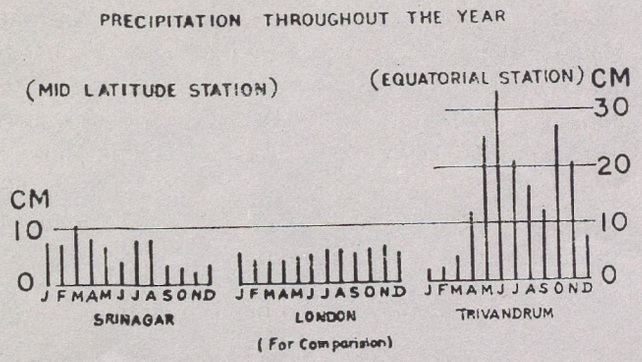


Fig. 2. Examples where most of the rain occurs either during the SW monsoon or during the NE monsoon.

numerous villages, away from dam-sites, canals, and metropolitan cities. Even regions which receive adequate rainfall during the monsoon suffer during the spring and the premonsoon months due to lack of adequate storage facilities.



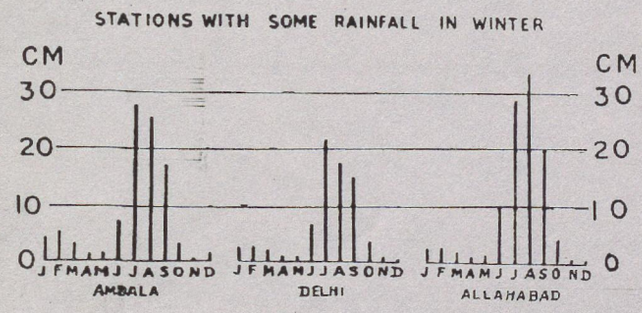


Fig. 3. Examples where rains occur throughout the year.

Since most of the rainfall over India occurs during the summer monsoon, a few words about it may be of interest to the general reader.

The word monsoon is of Arabic origin. The Arab sailors used it for denoting the seasonal winds over the Arabian Sea, which blows mostly from the south-west during the summer months June to September, and mostly from the north-east during the winter months November to March. Thus for the sailors and other sea-faring people the *summer monsoon* means moderate to strong south-west winds, rough seas and occasional rain squalls. However, for those on land, particularly the farmer, the word monsoon represents the rainy season associated with high humidity, cloudy skies, and abundant rainfall. This rainfall occurs in spells of heavy to moderate showers, each spell lasting for a couple of days at a time.

Meterologically, the summer monsoon is an atmospheric situation in which the dry hot air prevailing over the country in April and May has been completely replaced by very moist, equatorial, oceanic air, upto an altitude of three to five kilometres. Dynamic and thermo-dynamic processes occurring within this moist air causes the rainfall. The replacement of the pre-monsoon dry hot air prevailing over the whole country by the deep moist equatorial oceanic air is a gradual process and is usually accomplished in about thirty days, commencing around the first of June, starting from the extreme South (Kerala) and from the extreme East (Assam). The replacement over the entire country is usually completed by the end of June. For the next two months this deep moist oceanic air prevails throughout the country from Kerala to Kashmir and Assam to Rajasthan.

The replacement of the dry air by the very most air over any part of the country is called the *onset of the monsoon.* It is a case of the moist air (extending to great altitudes) pushing out the dry air ahead of it. The zone of the atmosphere where this pushing out is taking place becomes violent generating lightning, thunder, strong up-and-down-currents of air and moderate to heavy rain. Over Kerala and Assam this replacement is accomplished over a period of several days; elsewhere over India, it takes place rather abruptly, i.e., within 24 hours. Fig. 4 gives the normal dates of the replacement of dry hot air by moist equatorial oceanic air– the so-called dates of onset of the monsoon.

By the first week of September, the dry air from the northern latitudes begins to take the upper hand and push back the moist equatorial maritime air. This is the commencement of the so-called *withdrawal of the monsoon.* This withdrawal (or pushing back) is spread out over a somewhat longer period, about two months, at the end of which, dry air prevails over most of the country outside Tamil Nadu and Kerala. The monsoon retreats from these parts also by the end of December. Fig. 5 gives the normal dates of withdrawal of the monsoon.

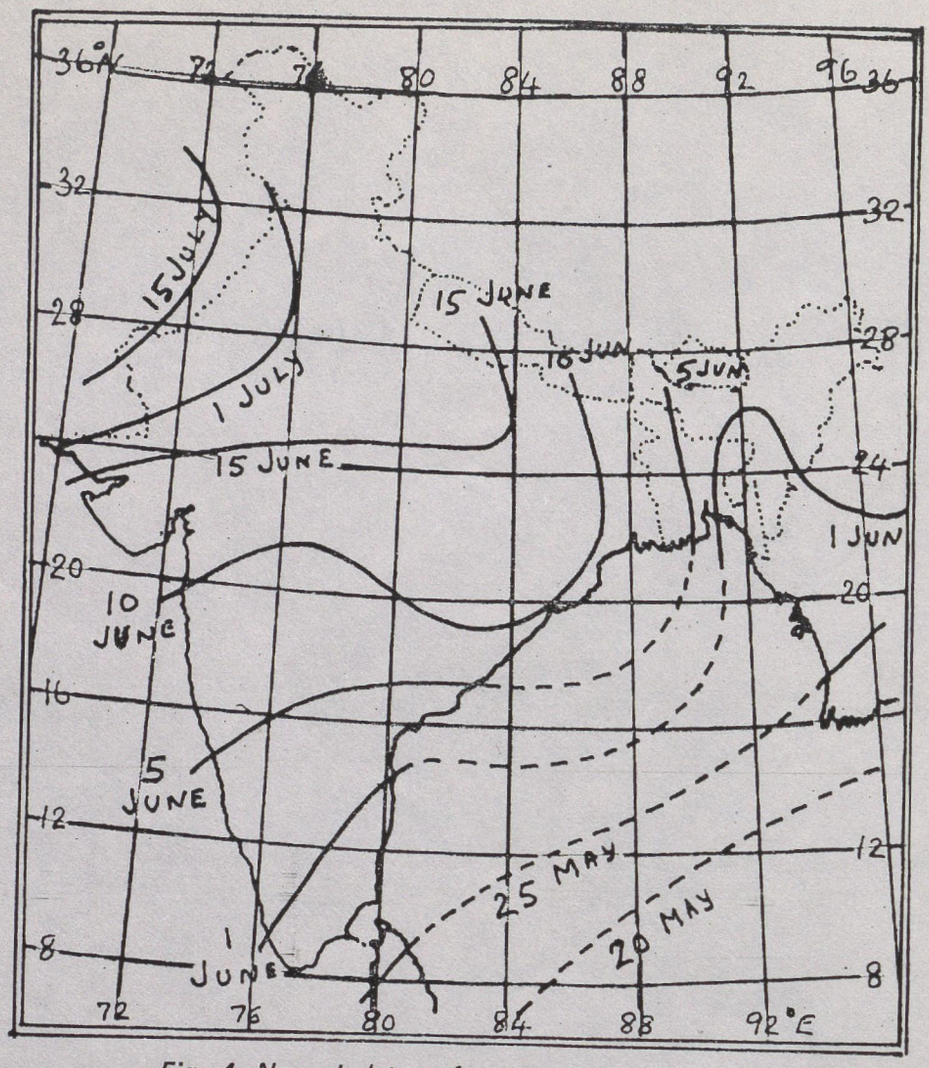


Fig. 4. Normal dates of onset of the monsoon. (standard deviation – one week).

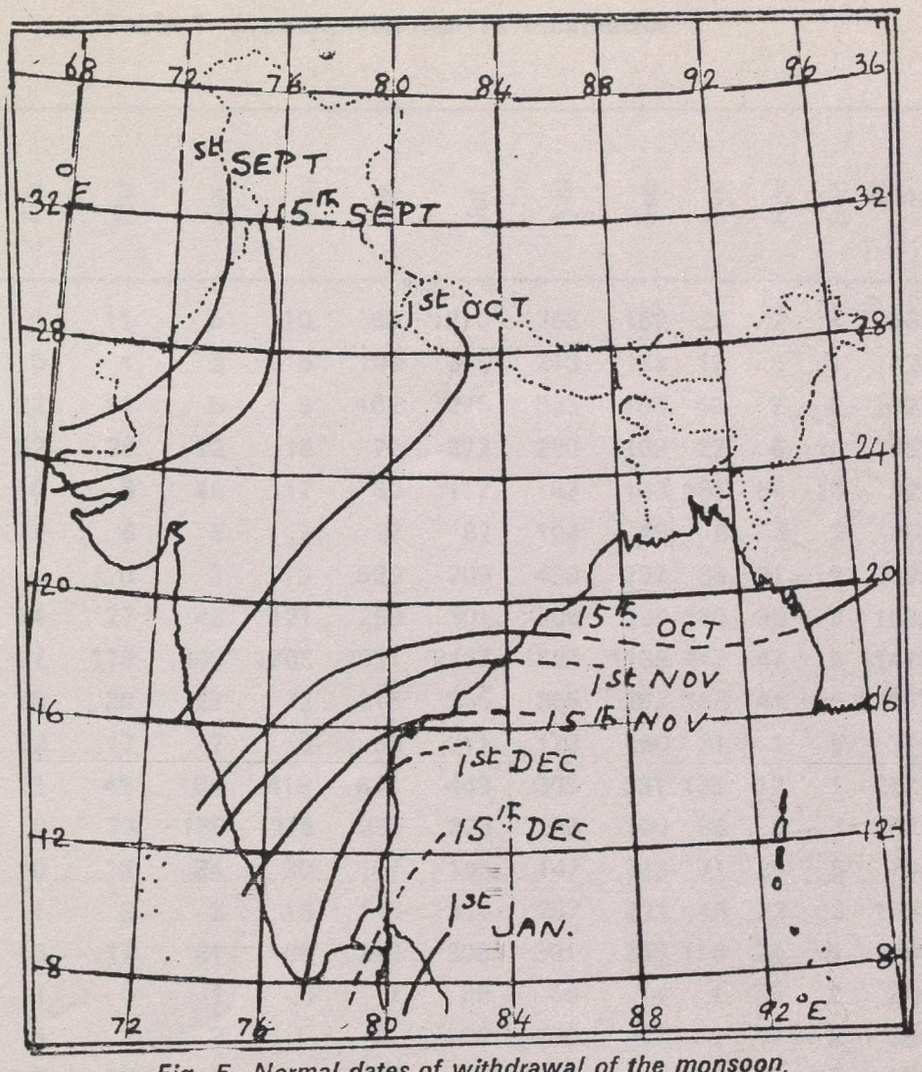


Fig. 5. Normal dates of withdrawal of the monsoon.

Table 1 Monthly Rainfall in millimetres

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Recorded heaviest fall in 24 hrs
Agra	16	9	11	5	10	60	210	263	152	23	2	4	765	286
Ahmedabad	4	0	1	2	5	100	316	213	163	13	5	1	823	415
Allahabad	20	22	14	5	8	102	275	333	195	40	7	6	1027	335
Ambala	42	52	28	12	15	72	272	250	168	27	6	15	959	229
Bangalore	3	10	6	46	117	80	117	147	143	185	54	16	924	169
Bikaner	6	7	6	5	7	27	87	104	45	6	3	2	305	166
Bombay	2	1	0	3	16	520	709	439	297	88	21	2	2099	548
Calcutta	14	24	27	43	121	259	301	306	290	160	35	3	1582	369
Cherrapunji	20	37	179	605	1705	2921	2457	1827	1168	447	47	5	11419	974
Cuttack	10	28	20	27	72	215	355	365	252	168	41	5	1557	321
Delhi	25	22	17	7	8	65	211	173	150	31	1	5	714	267
Dhubri	11	19	45	154	418	644	448	305	331	135	12	1	2525	368
Gauhati	17	9	73	136	276	350	373	294	190	86	8	7	1821	233
Hyderabad	2	10	13	24	30	107	165	147	163	71	25	5	764	190
Indore	8	1	3	3	13	145	316	267	221	48	22	3	1053	293
Jagdalpore	5	15	17	51	66	212	398	381	246	116	24	4	1534	203
Jaisalmer	2	1	3	1	5	7	89	86	14	1	5	2	216	104
Jodhpur	7	5	2	2	6	31	122	146	47	7	3	2	380	216
Leh	12	9	12	7	7	4	16	20	12	7	3	8	115	51
Madras	24	7	15	25	52	53	84	124	118	267	309	139	1217	262
Mangalore	5	2	9	40	233	982	1059	577	267	206	71	18	3467	361
Masulipatam	1	11	9	18	36	106	199	152	156	259	111	16	1075	502
Nagapattanam	57	25	22	55	56	29	48	62	62	224	458	239	1337	396
Nagpur	15	2	25	20	10	174	351	277	180	62	9	2	1127	315
Pamban	66	19	24	68	24	5	9	12	16	175	308	196	923	219
Poona	2	0	3	18	35	103	187	106	127	92	37	5	715	150
Silchar	15	45	97	313	493	605	547	475	378	207	44	7	3225	290
Srinagar	73	72	104	78	63	36	61	63	32	29	18	36	664	~~51~~ 148
Trivandrum	20	20	44	122	249	331	215	164	123	271	207	73	1839	278
London (for comparision)	53	40	37	38	46	46	56	59	50	57	64	48	594	—

Table 2. Number of RAINY DAYS (⩾ 2.5 mm a day) and Mean INTENSITY in millimetres per day

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Mean intensity (mm/day)
Agra	2	1	1	1	1	3	11	12	7	1	0.2	0.6	41	19
Ahmedabad	0.4	0	0.2	0.2	0.3	4	13	11	6	1	1	0.1	37	22
Allahabad	2	2	1	0.5	1	5	14	15	10	3	0.4	0.5	54	19
Ambala	3	3	2	1	2	4	11	10	6	1	0.2	1	44	22
Bangalore	0.4	0.5	1	3	7	6	9	10	8	9	4	1	59	16
Bikaner	1	1	1	0.3	1	2	5	5	2	0.3	0.1	0.3	18	17
Bombay	0.3	0.1	0	0.3	1	15	24	19	13	4	1	0.3	78	27
Calcutta	1	2	2	3	6	12	18	18	13	7	1	0.2	83	19
Cherrapunji	2	3	7	15	24	25	28	24	18	10	2	0.5	158	72
Cuttack	1	2	1	2	4	11	16	17	13	8	2	0.4	77	20
(New) Delhi	2	2	1	1	1	3	10	9	6	1	0.1	0.5	37	19
Dhubri	1	2	3	8	16	18	16	14	11	5	1	0.1	95	25
Gauhati	1	2	4	8	15	15	14	11	9	5	1	0.5	86	21
Hyderabad	0.2	1	1	2	3	7	12	10	10	5	2	0.4	53	14
Indore	1	0.1	0.4	0.4	1	7	15	12	10	2	1	0.4	50	21
Jagadalpur	0.4	1	1	4	5	12	20	19	14	6	2	0.3	86	18
Jaisalmer	0.4	0.2	0.3	0.1	1	1	4	4	1	0.2	0.2	0.4	13	17
Jodhpur	0.5	0.4	0.3	0.3	1	2	6	7	3	0.5	0.3	0.1	21	18
Leh	1	1	2	1	1	0.5	2	2	1	0.5	0.4	1	13	—
Madras	1	1	1	1	1	4	7	8	7	10	10	5	56	22
Mangalore	0.3	0.1	0.5	2	9	25	29	24	16	11	5	1	123	28
Masulipatam	0.2	0.4	1	1	2	7	12	10	10	9	4	1	57	19
Nagapattonam	3	1	1	2	2	2	3	4	4	10	13	8	53	25
Nagpur	1	0.4	2	2	0.6	8	17	14	11	4	0.4	0.1	60	19
Pamban	4	1	2	4	2	0.4	1	1	1	8	13	8	145	20
Poona	0.2	0	0.3	1	2	7	14	9	8	6	2	0.4	50	14
Silchar	1	3	7	12	18	21	24	21	16	8	2	0.5	134	24
Srinagar	7	6	8	7	6	3	5	5	3	2	2	3	57	—
Trivandrum	2	1	3	7	11	19	16	12	9	11	11	4	106	17

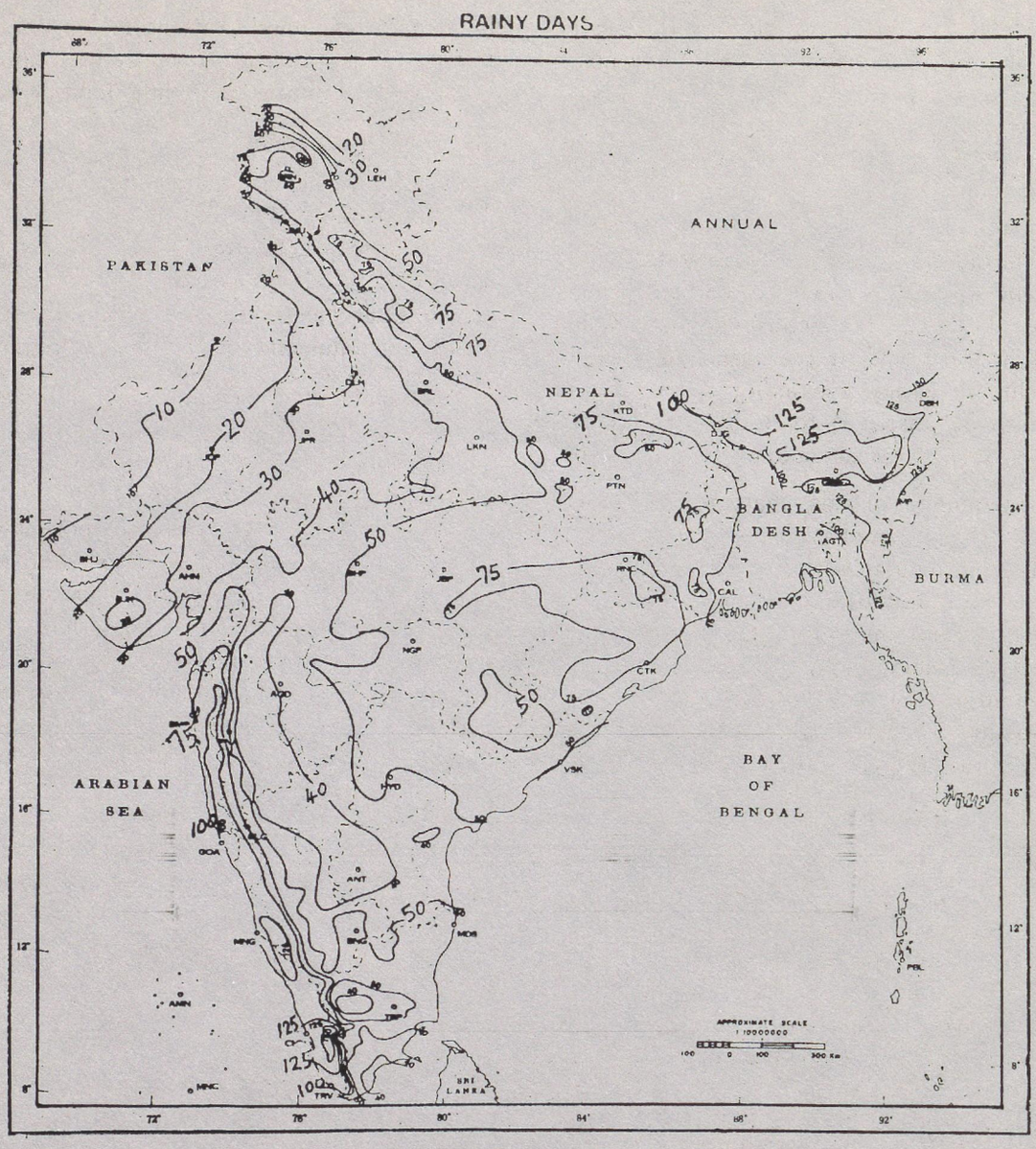


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Fig. 6 Annual number of Rainy Days (≥ 2.5mm in a day)

Table 1 gives the monthly rainfall at a few stations in India.

Rainy Days

Table 2 gives (for a few stations) the monthly average of the number of rainy days - days in which 2.5 mm or more rain fall in 24 hrs. ending at 8 a. m. Fig. 6 gives the annual distribution of rainy days. The pattern of rainy days, follows roughly the pattern of annual rainfall, suggesting that occurence of more rain is mainly because of a correspondingly large number of rainy days. In the heavy rainfall areas, there are about 120 rain-days–at Alleppy it is as much as 137 days. In the arid tracts the mean annual number of rainy days is fifteen or even ten. In the areas of moderate rain the number varies between forty and sixty.

Average Heavyness of the Rainfall

Taking the tables 1 and 2 together, it will be seen that the average rainfall during each rainy

day is about 15 mm to 20 mm practically all over the plains of India, whether it be in a rainy place like Calcutta or in an an arid place like Jaisalmer. (It is somewhat higher in those regions where the annual rainfall is about 200 cm. or more). This means that regions of more rainfall have more rainy days, and of less rainfall less rainy days; on days of rain the intensity is practically the same whether it be at Madras, Bombay, Calcutta, Delhi, Bikaner or Jodhpur. The corresponding average rainfall for a rainy day, in the plains of Western Europe including England is about 2 mm a day, about a tenth of what it is for India—(or for that matter any other tropical country).

In consequence of this character of Indian rainfall, it is less penetrating in proportion to quantity than in countries where much of it falls in a state of fine division, allowing time for its absorption by the ground. Instead of feeding perennial springs and nourishing an absorbent cushion of green vegetation, the greater part flows off the surface and fills the dry beds of drains and water courses with temporary torrents. In uncultivated lands with bare soil, the rain drops which are on the average bigger, produce greater impact on the soil and loosen it, thereby producing greater erosion than in middle latitude countries. We in India thus have greater erosion, and greater run off. Some recent experiments have shown that the percolation into the ground can be as small as 7% to 10% of the rainfall. Thus when the falling rain is not conserved by bunding or small reservoirs, a large fraction of it runs off the surface carrying with it valuable top soil, which fills the reservoirs with sediments, at rates much faster than in the reservoirs of middle latitudes. Thus an abundant rainfall which, if husbanded by nature and art, would suffice for agriculture and domestic requirements of large population, is thrown into nullahs and rivers along with much top soil, and not only is wasted and lost for any useful purpose, but by producing floods, becomes an agent for destruction. With continued removal of forests and use of herbiage covered lands for housing and townships, the flood hazards along the river courses increase year by year.

It is to be emphasised that the character of our rainfall is such that it requires considerable resourcefulness and expenditure, more than in temperate latitutdes, to conserve the provident arrangements nature has made for our welfare.

Rainfall Intensities

We have already stated that the average rainfall, on a rainy day anywhere in India, is about 18 mm or more. But this is not all. This amount of rainfall of a rainy day, occurs during short spells which total much less than 24 hours; in other words the intensities of rainfall in India are high.

A study of the rainfall data of observatories with selfrecording rainguages shows that the actual duration of the rainfall during the summer monsoon is hardly ten per cent of the total monsoon season. In other words in those areas where all the rain falls during the monsoon, it rains for only about 300 hours during the whole year. And even of these 300 hours, about 50% of the total rain is received in heavy spells lasting only ten per cent of the total duration of the rain. Stated differently, fifty per cent of the annual rain at even Cochin or Bombay, occurs in a total duration of about 30 hours spread over the monsoon period of a hundred days. It is these intensities which contribute to the high erosion of our top soil and the high run offs of our annual rainfall. Nature has ordained that unless we are careful, India with all its abundant rainfall will experience lack of water for agricultural, industrial and even domestic uses.

Excessive Rainfalls

Rainfalls of 30 cms to 60 cms in one day occur at one or two places each year somewhere or other in the plains of India. Such days of excessive falls are preceeded or followed by another day or two of heavy rainfall although somewhat less in magnitude. Consequently a three day total of 60 to 100 cm. is not un-common at some one station, if not every year, at least once in three or four years. Although in their extreme intensity such falls are generally local, they are only part of a less copious but still heavy fall often extending over thousands of square kilometers.

Table 3 gives the area-depth-durations of a rainspell which occured over northwest U. P. in September 1880 and Table 4 for a similar heavy

spell which occured over Gujarat in July 1927. Figs. 7 and 8 give the isohyetal maps to illustrate the magnitudes of heavy rainfall over large areas on the above two occasions.

There is also a risk of a similar, but less excessive spell occuring over the same area or its neighbourhood within a month or so before or after, in the same year.

These excessive rains are always the result of long lived tropical cyclones which move towards these regions after exhausting their wind fury over the coastal belts.

Table 3. Maximum observed Area-depth-duration associated with a rainspell over North-west Uttar Pradesh in September 1880.

Area in sq. km.	One day rain depths in cm on 18 Sept. 1880	2 days rain depths in cm on 17+18 Sept. 1880
Point value	82.3	104.1
259 (100 sq. miles)	81.3	102.9
518 (200 ,,)	79.5	101.6
1295 (500 ,,)	76.5	98.3
2590 (1000 ,,)	71.1	93.5
12950 (5000 ,,)	47.8	72.6
25900 (10000 ,,)	36.6	56.4
51800 (20000 ,,)	25.9	40.9

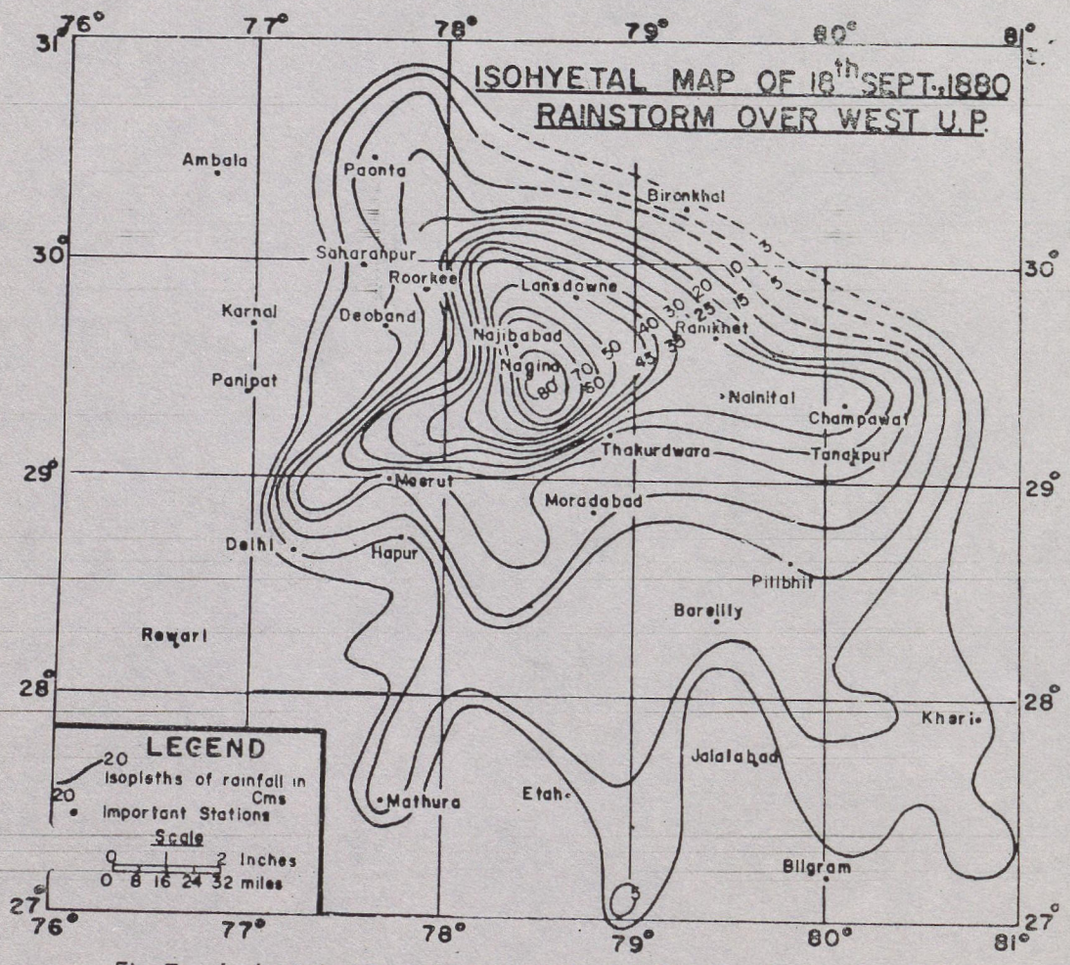

Fig. 7. Isohyetal map of one day rainfall on Sept. 18, 1880. Over nort-hwest Uttar Pradesh.

Table 4. Maximum observed Area-depth duration associated with a rainspeall over Gujarat in July 1927.

Area in sq. Km.	One day rain depth in cm on 28 July 1927	Two days rain depths in cm on 27+28 July 1927
Point value	54.1	99.8
259 (100 sq. miles)	52.3	91.4
518 (200 „)	50.8	85.8
1295 (500 „)	47.2	75.9
2590 (1000 „)	42.9	68.6
12950 (5000 „)	31.6	53.3
25900 (10000 „)	27.4	46.5
51800 (20000 „)	23.4	40.1

It is also noteworthy that such a heavy rainspell may occur over a region in a year of otherwise a partial drought there itself or in an adjacent region. It would look as if the entire energy of rain formation over that region for that year was used up in just one spell.

Annual Variability

It is well-known that the monsoon rainfall, and therefore the total annual rainfall, over the same region varies from one year to another. In any two years, the departures of rainfall from the long term mean, in the same region, often are not the same either in actual value or even percentagewise. A quantitative measure of this variability, generally used by statisticians, is the Coefficient of Variability. It is the *ratio* of the standard deviation of the

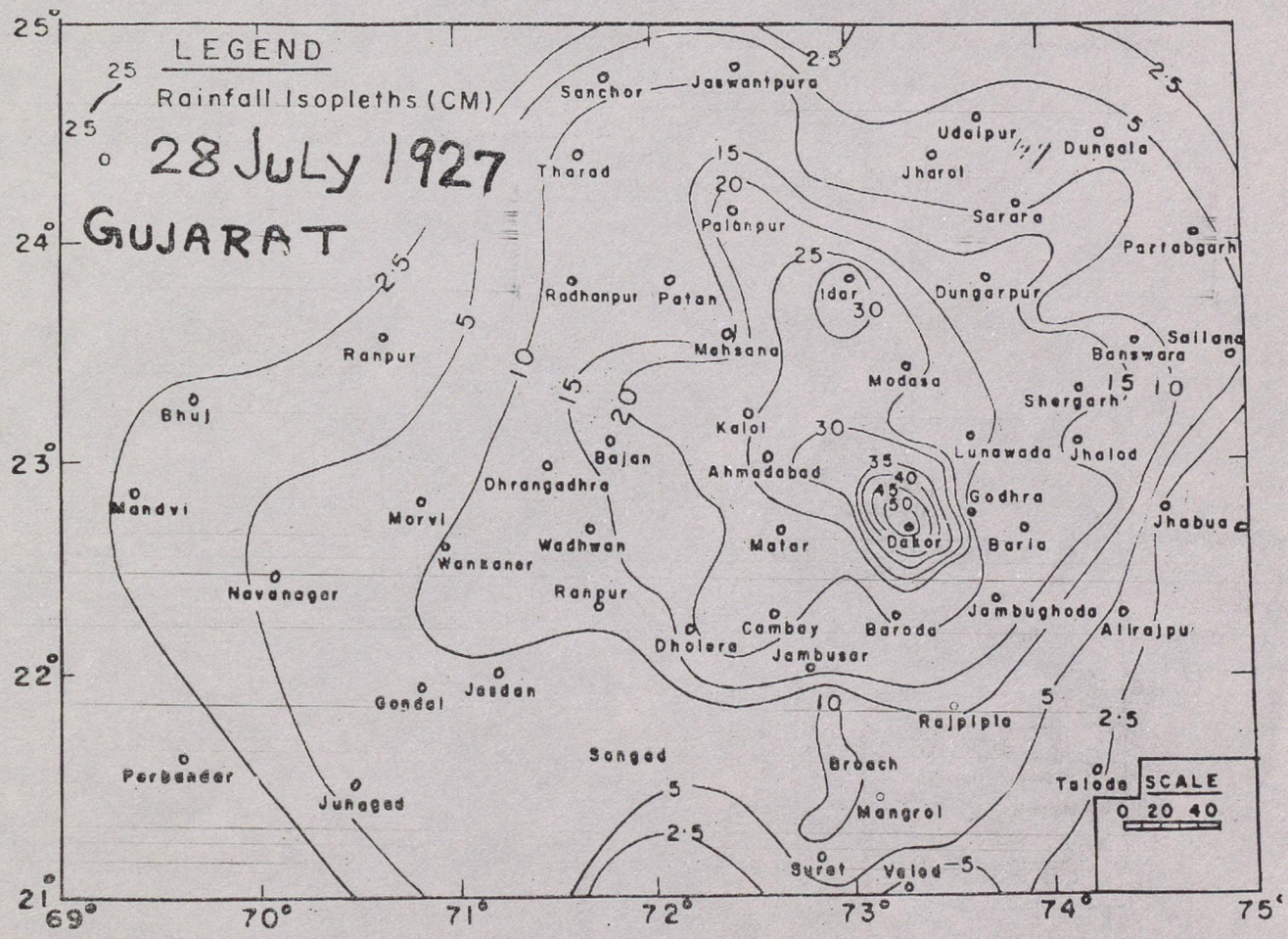

Fig. 8. Isohyetal map of one day rainfall on July 28, 1927. Over Central Gujarat.

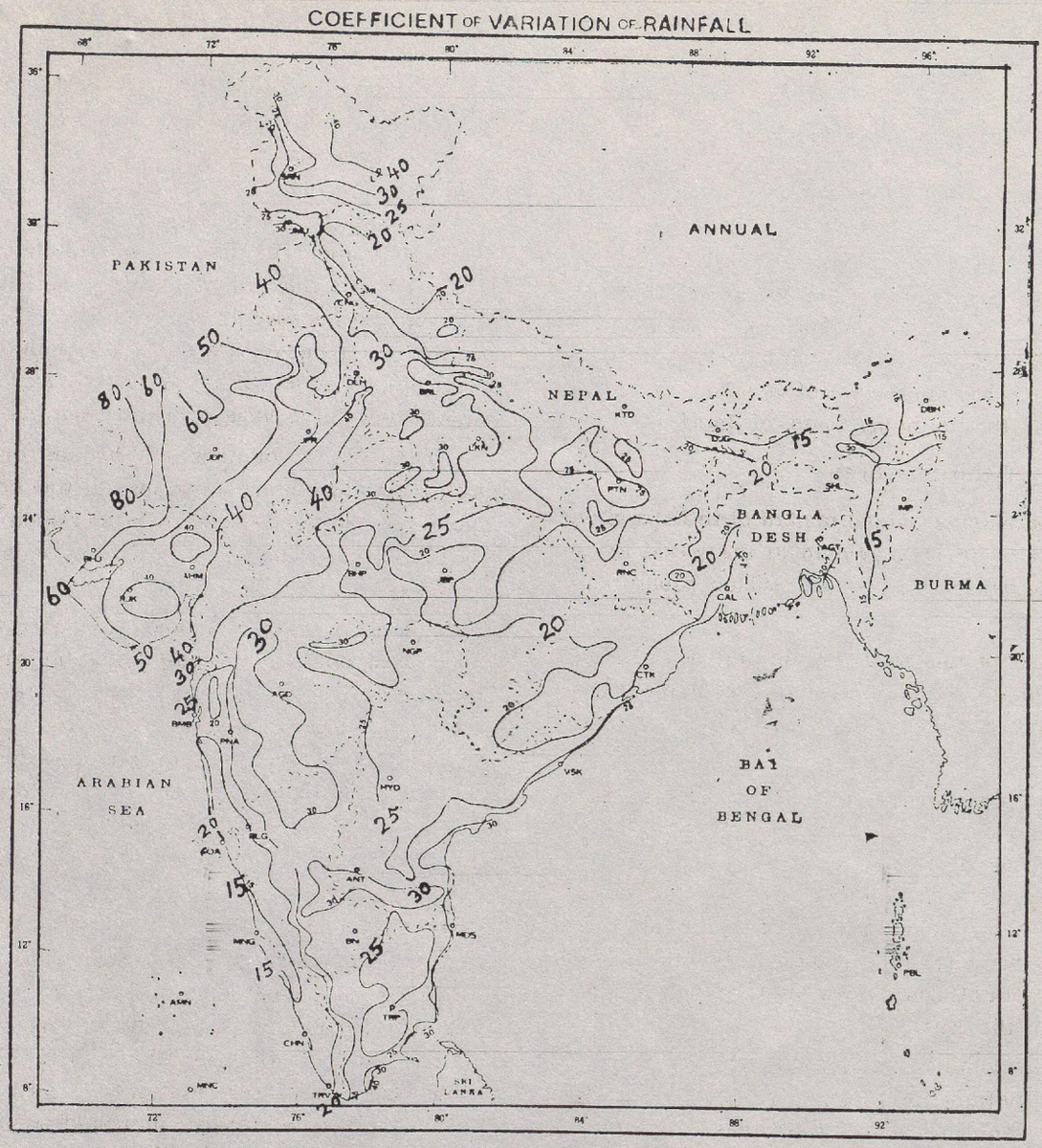

Fig. 9 Coefficient of Variation of annual rainfall (Percent)

annual (or monsoon) rainfall computed from the data for a large number of years, to the mean annual (or monsoon) rainfall over any given station. This ratio is often expressed as a percentage.

Thus a coefficient of variation of 50% implies that the standard deviation is half the annual (or monsoon) rainfall. It is equivalent to saying that only in about 30 years out of every hundred will the total rainfall be within $\pm$ 20% of the long term mean; in thirty-five years out of every hundred the rainfall will be deficient by more than 20%; and in about fifteen years our of a hundred, the rainfall will be deficient by 50% or more. Such a place is obviously a drought prone area. And it so happens, that the coefficient of variability is large precisely in those areas, where the average rainfall itself is small, 20-40 cms. or so. Rainfall in these regions is therefore precarious. Rajasthan and the adjoining idstricts of Gujarat and Punjab, and even parts of Maharashtra and of interior Andhra Pradesh, fall under this category.

On the other hand, if the coefficient of variability at a place is 15%, it is equivalent to saying that in about 80 years out of every hundred, the