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Rainfall distribution over India during the monsoon months in the absence of depressions and cyclonic storms

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सार — यह सर्वविदित है कि भारत में वर्षा वंटन में मानसूनी अवदाब और चक्रवाती तूफान महत्वपूर्ण भूमिका अदा करते हैं। स्वाभाविक है, मानसून ऋतु के किसी भी महीने में भारतीय क्षेत्र में इनकी अनुपस्थिति सामान्य से कम वर्षा और सूखे की स्थिति का कारण बनती है।

इसलिये यह जानना लाभकारी होगा कि इन सिनॉप्टिक प्रणालियों की किस सीमा तक अनुपस्थिति, मानसून ऋतु के अलग-अलग महीनों में सामान्य से कम वर्षा के लिये जिम्मेदार है। चक्रवाती तूफानों और अवदाबों की अनुपस्थिति वाले मानसूनी महीनों में 15 अक्षांश उ० के उत्तरी भाग में स्थित भारतीय मैदानों के विभिन्न मौसम विज्ञानी उप-मण्डलों की औसत वर्षा की गणना करके इस बारे में जांच की गई है।

1891 से 1980 की अवधि में जून, जुलाई, अगस्त और सितम्बर महीनों में अलग-अलग 25, 13, 7 और 4 ऐसे अवसर आए हैं जब भारतीय भू-क्षेत्र से चक्रवाती तूफानों का कोई भी अवदाब नहीं गुजरा। इस अध्ययन से पता चलता है कि (1) मानसून के चार महीनों में सितम्बर मास इन प्रतिकूलताओं से सबसे अधिक प्रभावित हुआ तथा (2) अन्य मानसून महीनों जून, जुलाई और अगस्त में निम्नलिखित स्थितियों में से एक भी मौजूद होने पर वर्षा की मात्रा में असामान्य रूप से कमी आई :

(क) देश में मानसून का विलम्ब से आना और अनुगामी कमजोर मानसूनी स्थितियां,

(ख) मानसूनी द्रोणी का अक्ष अपनी सामान्य स्थिति से उत्तर में होने पर, तथा

(ग) देशभर में कम दबाव वाले क्षेत्र बिल्कुल न होने पर।

देखा गया है कि उपरोक्त मौसमी स्थितियों में से कोई भी स्थिति न हो, तो पूर्वोक्त प्रतिकूलताओं के बावजूद भी देश में सामान्य या सामान्य से अधिक वर्षा हो जाती है।

अत: इस अध्ययन से पता चलता है कि इस देश में सामान्य से कम वर्षा और उसके परिणाम स्वरूप सूखे की स्थिति के लिये मानसूनी अवदाबों और चक्रवाती तूफानों की अनुपस्थिति ही मुख्य कारण नहीं है।

ABSTRACT. It is well known that monsoon depressions and cyclonic storms play an important role in the distribution of rainfall over India. Naturally, their absence from the Indian area during any month of the monsoon season is considered to be responsible for causing deficient rainfall and consequent drought conditions. It is, therefore, of interest to know as to what extent the absence of these synoptic systems cause deficient rainfall during the individual monsoon months. This aspect has been examined by computing the average rainfall of the different meteorological sub-divisions of the Indian plains north of Lat. 15°N for those monsoon months which were free from depressions and cyclonic storms.

There have been in all 25, 13, 7 and 4 occasions of June, July, August and September respectively, when no depressions or cyclonic storms moved through the Indian land area during the period 1891-1980. This study has shown that (i) of the 4 monsoon months, the September month is worst affected by the absence of these disturbances and (ii) in the case of other monsoon months of June, July and August, rainfall can be abnormally deficient depending upon the presence of any of the following meteorological situations :

(a) Late arrival and subsequent weak monsoon conditions over the country,

(b) The axis of monsoon trough remains shifted to the north of its normal position, and

(c) Non-occurrence of low pressure areas (or land lows) across the country.

It has been seen that rainfall over the country can be normal or even above normal inspite of the absence of these disturbances if the meteorological situations like the above are not there.

This study has, therefore, shown that the absence of monsoon depressions and cyclonic storms are not the main factors which cause deficient rainfall and consequent drought conditions in this country.

1. Introduction

Monsoon depressions and cyclonic storms are the most important synoptic scale disturbances and play a vital role in the space-time distribution of rainfall over India (Sikka 1977). Considering this influence

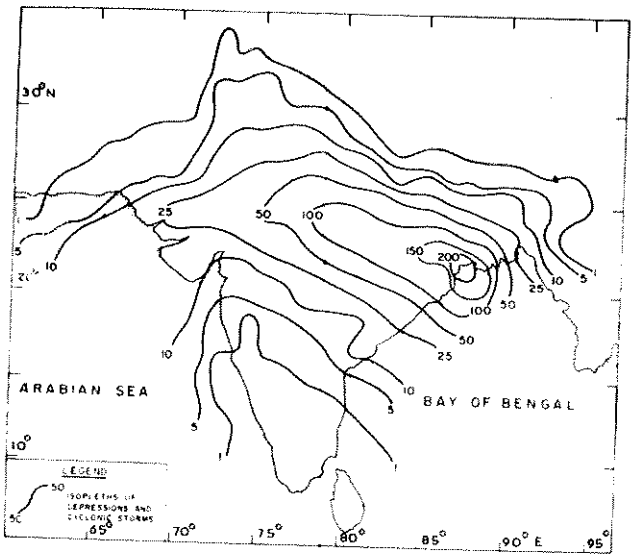

Fig. 1. Areal distribution of disturbances over India during monsoon season (1891-1980)

of these disturbances (*i.e.*, depressions and cyclonic storms) on the rainfall activity of India has been studied by several workers. Pisharoty and Asnani (1957) showed that on a particular day heavy rainfall associated with these disturbances extends to about 500 km ahead and 500 km in the rear of their respective pressure centres and this area has a width of about 400 km lying almost entirely to the south of their tracks. Raghavan (1967) computed the average rainfall for those days in July and August months which were free from these disturbances. He found that these disturbances were capable of distributing rainfall in such a way that in some areas rainfall was increased by about 10% while other areas were deprived by the same amount.

The average rainfall potential over the Indian plains north of Lat. 20 deg. N was estimated by Dhar and Rakhecha (1976) for those July and August months which did not at all experience these disturbances. They found that the average deficit of rainfall over north India in July and August months was of the order of 19% and 14% respectively in the absence of these disturbances. In recent years Dhar *et al.* (1978, 1980 and 1981) have found that there was no direct relationship between the frequency of these disturbances and the rainfall of the country when the monsoon season (*i.e.*, June to September) as a whole was considered. On the other hand, it was seen that if each of the monsoon months were considered separately, there was a significant relationship between the two.

In the present note an attempt has been made to study rainfall distribution over India during monsoon months of June to September which did not have any monsoon depression, using the 90-year data from 1891 to 1980.

2. Area of the country considered for analysis

Fig. 1 shows the areal distribution of these disturbances over the Indian land area during the monsoon seasons of the period 1891-1980. It is observed from this figure that after their formation in the neighbouring seas of the Bay of Bengal and the Arabian Sea, most of these disturbances traverse the Indian land area north of Lat. 15 deg. N after crossing the east and the west coasts of the country. Thus, in view of the fact that these disturbances affect the land area of the country mostly to the north of Lat. 15 deg. N during the monsoon season, the areal distribution of rainfall over the Indian land area has, therefore, been considered to the north of this latitude in this study. In order to eliminate the influence of orography on rainfall distribution due to mountaineous terrain, the hilly sub-divisions of the Himalayas as well as north-east India (*i.e.*, Assam and its adjoining sub-divisions) have not been considered while working out the areal rainfall of the country north of Lat. 15 deg. N.

3. Data used and technique employed

From a careful examination of the *Storm Track Atlas* (India Met. Dep., 1979) and the *Daily, Monthly and Annual Weather Summaries* published by the India Meteorological Department for the period 1891 to 1980, the individual monsoon months when no depressions and cyclonic storms affected the Indian land area, were sorted out. This examination revealed that during the 90-year period (1891 to 1980) there were in all 25 June, 13 July, 7 August and 4 September months when the Indian land area was completely free from these disturbances. Table 1 shows the individual monsoon months which were free from these disturbances during the above period. This table also shows that in the year 1901 the country was free from these disturbances for the first three consecutive monsoon months while in the years 1924, 1931 and 1957 these disturbances did not move through the country in the first two monsoon months of June and July.

Using the available rainfall data of all the observatory and State raingauge stations, average rainfall for

the Indian region, north of Lat. 15 deg. N, excluding the hilly sub-divisions of the Himalayas and north-east India, was computed for all those monsoon months which were free from these disturbances as shown in Table 1. Percentage departures of the rainfall from the normal of these months were then worked out. In this study following two types of rainfall normals were used due to non-availability of State raingauge data for different sub-divisions of the country during the decade 1971 to 1980 :

(*i*) Normals based upon monthly rainfall data of 80-year period of all the raingauge stations (*i.e.*, State raingauge as well as observatory stations) for the period 1891 to 1970, and

(*ii*) Normals based upon the rainfall data of observatory stations only for the 10-year period from 1971 to 1980.

Using the following drought classification based on rainfall given by Krishna Rao (1953) and recently used by Dhar and Rakhecha (1976), monthly percentage departures of rainfall for the individual monsoon months which were free from these disturbances were then worked out :

Drought classification based on rainfall	*Percentage departures from the normal*
(*i*) Excess rainfall	+ 11% or more,
(*ii*) Normal rainfall	+ 10% to —10%,
(*iii*) Slight drought	—11% to —25%,
(*iv*) Moderate drought	—26% to —40%, and
(*v*) Severe drought	—41% and less.

Table 2 shows the highest and the lowest percentage departures of rainfall from the normal for the different sub-divisions as well as the plain areas of the country north of Lat. 15 deg. N, for each of the monsoon months which did not experience these disturbances. Frequency of occurrence of drought conditions and other details are not included in Table 2.

TABLE 1

Monsoon months when the Indian land area did not experience depressions and cyclonic storms during the period 1891 to 1980

June		July	August	September
1891	1930	1901	1901	1913
1899	1931	1907	1905	1929
1901	1938	1908	1930	1952
1909	1942	1911	1932	1979
1910	1946	1915	1961	
1912	1957	1916	1962	
1913	1958	1924	1966	
1919	1960	1931		
1921	1965	1953		
1922	1972	1955		
1923	1973	1957		
1924	1977	1974		
1926		1980		

4. Discussion of results

4.1. *Month of June*

It was observed that during the 90-year period, the Indian land area was traversed by about 105 disturbances in this month. Out of these, 82 disturbances entered from the Bay of Bengal, 15 from the Arabian Sea and the remaining 8 were land depressions. Thus, it can be said that, on an average, the country was affected by about 1 disturbance in this month. However, there have been 7 instances in the past 90 years when 3 disturbances moved through the country in this month.

Percentage departures of rainfall from the normals for the different sub-divisions as well as the plain areas of the country north of Lat. 15 deg. N were worked out for each of the June months shown in Table 1. It was observed that in June 1926 the country experienced severe drought conditions (— 69%) while in June 1938 there was large excess (+ 77%) of rainfall over the country. Percentage departures of rainfall for other June months (*vide* Table 1) lay between these two extreme values, *i.e.*, + 77% to —69%.

The southwest monsoon, normally, strikes the southern tip of the west coast of India in early June, then advances northwards and gets fully established over the entire country by about 15 July. It is, however, seen that the onset of monsoon either gets delayed or sets in early by a few days to a couple of weeks from the normal date of onset. Even though monsoon may set in by the normal date in a particular year but the two branches of monsoon (*viz.*, the Bay of Bengal and the Arabian Sea) may fail to establish themselves over the different parts with the result that weak monsoon conditions prevail over the country in this month.

It has been observed that inspite of the absence of these disturbances the country experienced normal or even excess rainfall in the June months of the years 1899, 1909, 1910, 1913, 1919, 1921, 1922, 1930, 1938, 1942, 1946, 1960 and 1977. The meteorological factors responsible for causing normal or excess rainfall in June months of the above years were examined and it was found that due to early onset of monsoon and thereafter active monsoon conditions

TABLE 2

Highest and lowest percentage departures of rainfall for the different sub-divisions as well as the plain areas of the country during the different monsoon months which did not experience depressions and cyclonic storms during 1891-1980

Sub-Divisions	June				July				August				September			
	High-est	Yr	Low-est	Yr	High-est	Yr	Low-est	Yr	High-est	Yr	Low-est	Yr	High-est	Yr	Low-est	Yr
Gangetic West Bengal	123	1922	—61	1958	23	1974	—50	1916	—3	1930	—25	1966	—15	1913	—37	1979
Orissa	43	1919	—65	1891, 1926	30	1980	—53	1911	—7	1961	—40	1966	11	1952	—37	1913
Bihar plateau	88	1913	—60	1891	28	1953	—55	1911	9	1901	—15	1962, 1966	7	1952	—45	1929, 1979
Bihar plains	145	1909	—73	1926	75	1955	—39	1911	54	1905	—29	1966	18	1913	—51	1952
East Uttar Pradesh	152	1938	—83	1926, 1965	71	1924, 1955, 1980	—73	1911	32	1961	—11	1930	—33	1952	—83	1979
West Uttar Pradesh (plains)	168	1899	—93	1965	46	1953	—75	1911	51	1961	—50	1905	—73	1929	—85	1913
Haryana	171	1909	—98	1965	62	1953	—82	1911	123	1961	—79	1905	—61	1979	—99	1952
Punjab	145	1938	—100	1965	104	1980	—85	1911	27	1961	—70	1905	—27	1979	—99	1952
West Rajasthan	152	1910	—97	1891	142	1908	—96	1911	14	1932	—99	1905	—24	1913	—97	1952
East Rajasthan	160	1938	—91	1965	83	1908	—80	1911	14	1961	—83	1905	—71	1913, 1929	—95	1952
West Madhya Pradesh	155	1938	—88	1923	21	1908	—61	1911	43	1901	—58	1932	—46	1929	—77	1979
East Madhya Pradesh	80	1919	—81	1926	23	1980	—47	1911	43	1901	—33	1930, 1966	9	1952	—89	1979
Gujarat	221	1913	—97	1923	47	1908	—81	1911	—13	1901, 1961	—83	1905	—9	1913	—93	1952
Saurashtra & Kutch	220	1913	—99	1923	32	1980	—91	1911	9	1961	—92	1966	—12	1913	—89	1952
Konkan	79	1938	—65	1923	60	1931	—50	1911	23	1962	—63	1966	—30	1929	—91	1979
Madhaya Maharashtra	86	1913	—78	1923	15	1931	—49	1911	17	1932	—54	1905	—7	1929	—76	1979
Marathawada	102	1938	—86	1923	90	1916	—48	1974	48	1901	—60	1966	59	1979	—68	1913
Vidarbha	113	1938	—86	1923	13	1931	—47	1911	44	1901	—34	1932	47	1979	—29	1952
Coastal Andhra Pradesh	65	1930	—65	1923	67	1916	—31	1908	20	1905	—25	1930	36	1979	—37	1952
Telangana	72	1938	—72	1923	21	1916	—40	1974	38	1962	—36	1930	87	1979	—47	1913
Interior north Karnataka	41	1942	—59	1923	42	1916	—52	1974	64	1932	—56	1930	47	1979	—50	1952
Plain areas of India*	77	1938	—69	1926	14	1908	—56	1911	12	1901, 1961	—30	1905	—38	1929	—44	1979

*North of Lat. 15° N outside northeast India

prevailing over the country, there was excess or normal rainfall over the Indian land area. However, in some years, pre-monsoon thunderstorm activities over the northern and central parts of the country, was also responsible for causing excess rainfall in this month.

In the June months of the years 1891, 1901, 1912, 1923, 1924, 1926, 1931 and 1965 the country witnessed severe drought conditions. In 1958 and 1972 June months there were moderate drought conditions and in 1957 and 1973 slight drought conditions prevailed. On careful examination, the following unfavourable meteorological situations were found to be mainly responsible for causing slight to severe drought conditions over the country during the above years :

(*i*) Late arrival of monsoon,

(*ii*) Weak monsoon conditions prevailing over the country after the onset of monsoon, and

(*iii*) Absence of pre-monsoon thunderstorm activity over different parts of the country.

Thus, it can be said that in the June month drought conditions may prevail over the country in the absence of these disturbances if the unfavourable meteorological situations mentioned above also happen to be there at the same time.

4.2. *Month of July*

During the 90-year period there were in all 166 disturbances which affected the Indian land area during this month. This showed that on an average, about 2 disturbances moved through the country in this month. It has, however, been observed that there have been 7 instances in the past when 4 disturbances moved through the country in this month. Out of 166 disturbances, 133 had their origin in the Bay of Bengal, 6 in the Arabian Sea and the remaining 27 were land depressions.

It is well known that rainfall during the July month depends upon the position and strength of the monsoon trough as well as strength of the Bay and Arabian Sea branches of monsoon. It has also been observed that monsoon activity over the country is quite favourable for causing well distributed rainfall over most parts of the country, inspite of the absence of these disturbances, if the axis of the monsoon trough happens to lie in its normal or in a more southernly position (Das 1968 and Koteswaram 1974). Rainfall activity can also be increased considerably if a few low pressure areas from the head Bay or land lows move across the country. Rainfall activity over the country decreases considerably if monsoon currents are weak and the monsoon trough axis shifts northwards close to the foot of the Himalayas, thereby setting in 'break' monsoon conditions over the country.

Percentage departures of rainfall from the normals for the 13 months of July which were free from these disturbances (*vide* Table 1) were worked out for all the sub-divsions and the plain areas of the country north of Lat. 15 deg. N. It is seen from Table 2 that in July 1908 the country received excess rainfall (+ 14%) inspite of the absence of these disturbances while the July of 1911 was the worst affected month when the Indian land area experienced severe drought conditions (—56%). Moderate drought conditions prevailed over the country during the July months of the years 1907 and 1915 while in the July months of 1901, 1916, 1955 and 1974 slight drought conditions were experienced. The drought conditions which prevailed over the country in July months of the years mentioned above were found to be mainly due to the setting in of the prolonged 'break' monsoon conditions and/or due to weak monsoon conditions prevailing over the country. Excess rainfall over the country in July 1908 was found to be because of the passage of low pressure areas from the Bay of Bengal which gave fairly well distributed rainfall over the northern and central parts of the country. It was also observed that in July months of the years 1924, 1931, 1953, 1957 and 1980 the Indian land areas experienced normal rainfall in the absence of these disturbances.

It has been observed that in the absence of these disturbances in the month of July, sub-divisions of the country along the periphery of the Himalayas, *viz.*, Bihar plains, east and west Uttar Pradesh, Haryana and Punjab, experienced normal to excess rainfall caused by the setting in of 'break' monsoon conditions while the remaining sub-divisions of the country witnessed slight to severe drought conditions. The worst-hit sub-divisions of the country due to drought, conditions were west and east Rajasthan, Saurashtra and Kutch, Gujarat, west Madhya Pradesh, Vidarbha, Madhya Maharashtra, Telangana, coastal Andhra Pradesh and Orissa.

Thus, in the absence of these disturbances in the month of July, deficient rainfall causing slight to severe drought conditions can occur over most of the sub-divisions of the country outside the sub-divisions along the Himalayan periphery, provided : (*i*) no low pressure areas traverse the country, (*ii*) monsoon currents prevailing over the country are generally weak, and/or (*iii*) prolonged 'break' monsoon conditions occur by the shifting northwards of the monsoon trough axis.

4.3. *Month of August*

The total number of disturbances that affected the country during the 90-year period in the August month was found to be about 182. Majority of these disturbances (*i.e.*, about 148) entered the country through the east coast, 2 from the west coast and the remaining 32 were land depressions. Thus, like the July month in the August month also, on an average, the country experienced about 2 disturbances.

There were 7 August months during the 90-year period (*vide* Table 1) when the country did not experience these disturbances. Percentage departures of rainfall from the normals in respect of these 7 cases were worked out for each of the sub-divisions and the plain areas of the country north of Lat. 15 deg. N outside the northeast India. Like July, rainfall of the August month also depends upon the position and strength of the monsoon trough over the Indo-Gangetic plains. Movement of a few low pressure areas and upper air cyclonic circulations across the country also causes strengthening of monsoon currents. On the other hand, deficit rainfall and consequent drought conditions may be caused if monsoon currents are weak and 'break' monsoon conditions prevail over the country for long intervals.

The country experienced excess rainfall in August 1901 and 1961 while moderate drought conditions prevailed in August months of 1905, 1930 and 1966 and slight drought conditions in 1932 and 1962. Excess rainfall in August 1901 and 1961 was found to be caused by the movement of low pressure areas and upper air cyclonic circulations along the trough axis which considerably strengthened the monsoon currents. Drought conditions in the above August months were found to be due to setting in of 'break' monsoon conditions or weak monsoon conditions prevailing over the country. The western and eastern sub-divisions of Rajasthan, Saurashtra and Kutch, Gujarat, east and west Madhya Pradesh, Madhya Maharashtra and Orissa were the worst affected regions which experienced slight to moderate drought conditions in the absence of these disturbances.

4.4. *Month of September*

In the month of September there were about 176 disturbances which traversed the country during the

90-year period. Thus, on an average, like the July and August months, about 2 disturbances moved across the country in this month. The maximum number of these disturbances that moved through the country was found to be 5 and this happened in September 1891. Out of 176 disturbances that entered the Indian land area, 147 had their origin in the Bay, 7 from the Arabian Sea and 22 were land depressions.

Normally, monsoon withdraws from half of the northern India by about the end of September. However, rainfall activity over the areas from which monsoon has already withdrawn can temporarily be revived by the passage of these disturbances over and near these regions.

It was found that during the 90-year period there were only 4 September months (*vide* Table 1) when the Indian land area did not experience these disturbances. Thus, the probability of non-occurrence of these disturbances is the lowest (*i.e.*, 4%) in this month compared to other three monsoon months of June, July and August. Percentage departures of rainfall from the normals for these 4 occasions were worked out. It was seen that in September 1929 the country experienced moderate drought conditions while in 1913, 1952 and 1979 severe drought conditions prevailed. It was also observed that in the absence of these disturbances, all the northwestern subdivisions of the country from Punjab in the north to Saurashtra and Kutch in the extreme west experienced very little rainfall. It can, therefore, be said that rainfall activity, especially, over the northwestern parts of the country to a large extent depends upon the passage of these disturbances in this month and their absence causes moderate to severe drought conditions in these parts.

5. Summary and conclusions

From the foregoing the following broad conclusions can be drawn :

(*i*) It is observed that in the absence of monsoon depressions and cyclonic storms in the individual monsoon months coupled with either of the following unfavourable meteorological situations, rainfall distribution over the country can be considerably deficient and consequently slight to severe drought conditions can prevail over the country :

- (*a*) *June* — Delayed onset of monsoon and weak monsoon conditions prevailing over the country,
- (*b*) *July and August* — Setting in of prolonged 'break' monsoon conditions and non-occurrence of low pressure areas/ upper air cyclonic circulations across the country, and
- (*c*) *September* — Early withdrawal of monmonsoon and/or weak monsoon conditions prevailing almost throughout this month.

(*ii*) It is also observed that of the 4 monsoon months, the month of September gets worst affected by the absence of these disturbances.

This study has thus shown that the absence of depressions and cyclonic storms from the Indian land area is not the main cause which can result in deficient rainfall and consequent drought conditions over the country. There have been a number of occasions in the past when the country received normal to excess rainfall, inspite of the absence of these disturbances, due to occurrence of other favourable meteorological situations. In monsoon months when these disturbances as well as the favourable meteorological situations are both absent, moderate to severe drought conditions can occur over the country.

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