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Droughts over Peninsular India during 1861-1980 and associated circulation features

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सार — 31 वर्षामापी स्टेशनों के भली भांति वंटित वर्षा के आंकड़ों से 1861 से 1980 की अवधि में प्रायद्वीपीय भारत को प्रभावित करने वाले सूखों का अध्ययन किया गया है। सूखे की पहचान के लिए उपयोग में लाया गया मानदंड वर्षा का विशिष्ट देहलवी मान है, जिसे मानक इकाई t_i में व्यक्त किया गया है। जहां $t_i = (R_i - \bar{R})/\sigma$ यदि किसी वर्ष में t_i का मान -1.28 से कम होता है तो उस स्टेशन को सूखे से प्रभावित समझा जाता है। प्रायद्वीपीय भारत में 25 प्रतिशत से अधिक स्टेशनों को सूखे से प्रभावित करने वाला वर्ष बड़े पैमान पर सूखे का वर्ष माना गया है। उपरोक्त अवधि में बड़े पैमाने पर सूखे के 10 वर्ष रहे हैं: 1876, 1877, 1891, 1899, 1905, 1913, 1918, 1920, 1952 एवं 1977। सांख्यिकीय परीक्षण यह दर्शाते हैं कि दो क्रमानुगत सूखे के वर्षों का अंतराल, काल के कन्टीन्यूयम में या दुच्छित: बंटित है। 1899 और 1918 के वर्ष भीषण सूखे के वर्ष रहे, जब इन वर्षों में 50 प्रतिशत से अधिक स्टेशनों पर सूखे की स्थितियां देखी गई।

भीषण सूखे वाले वर्षों में मानसूनी द्रोणी, अवदाब एवं झंझाओं की स्थिति, जैसे परिसंचलनी लक्षणों का, वर्षा की विसंगतियों को समझाने के लिए परीक्षण किया गया है। प्राप्त परिणामों को प्रस्तुत किया गया है।

ABSTRACT. Droughts which affected the Peninsular India during the period 1861-1980 have been studied with well distributed rainfall data of 31 raingauge stations. The criterion used for identification of drought is the specific threshold value of rainfall expressed as standard unit, t_i (where $t_i=(R_i-\bar{R})/\sigma$). If, in any year the t_i value is less than—1.28 then the station is considered to be affected by drought. A year with 25 per cent of the stations considered suffered from drought is taken as large scale drought year over Peninsular India. There are 10 large-scale drought years during the period, 1876, 1877, 1891, 1899, 1905, 1913, 1918, 1920, 1952 & 1972. Statistical test shows that the time interval between two successive drought years is randomly distributed in time continuum. The worst drought occurred in the years 1899 & 1918 when more than 50% of the stations showed drought conditions.

The circulation features like position of monsoon trough and the depressions & storms were examined with a view to understand the anomalies in rainfall during the large-scale drought years and the results presented.

1. Introduction

The Indian Peninsula which covers about one-third of the total Indian area has occasionally suffered from droughts resulting in acute misery to the people. The reports of the Famine Commission (1880, 1898 and 1901) give an account of the droughts experienced in the different parts of India and their impact on the people for the period 1769 to 1877 and for the years 1896 and 1899. It is seen from these accounts that the Peninsula suffered some severe droughts resulting in intense suffering to the people.

In this paper it is proposed to bring out the occurrence of well-marked drought over the Peninsula in the summer monsoon season (June-September) during the period 1861-1980 by using objective criteria, and to examine if the associated circulation features like monsoon trough, monsoon depressions and storms, show any distinguishing characteristics.

2. Rainfall data

The Peninsular India consists of the States of Maharashtra, Andhra Pradesh, Karnataka, Kerala and Tamilnadu and covers about 30 per cent of the total Indian area. The crops over most of this area are rainfed. Monsoon season contributes to 70-90 per cent of the annual rainfall over a large portion of the Peninsula. A network of 31 uniformly distributed raingauge stations over the Peninsula has been selected. This network is shown in Fig. 1. The names of these stations along with their abbreviations are given in Table 1. The rainfall data of each of these 31 stations are available for the period 1871-1980. Rainfall data prior to 1871 were carefully examined. It is found that the number of these stations for which rainfall data are available is 26 to 28 for the period 1864-1870, and 24, 18 and 16 for the years 1863, 1862 and 1861 respectively. The number of stations during the period 1853-60 varied from 9 to 15, and that during the period 1841-52 varied from 5 to 9. Since the number of stations available prior to 1861 is very small, the period prior to 1861 has not been considered.

Monthly rainfall data for these stations for the period 1861-1900 were obtained from Eliot (1902), the publications by the Governments of Mysore, Madras and Bombay, and from *"Daily Rainfall of India"* published by the India Meteorological Department since 1892, for the periods 1901-70 and 1971-80 these were respectively obtained from the punched cards and the records of the office of the Deputy Director General of Meteorology (Climatology & Geophysics), Pune.

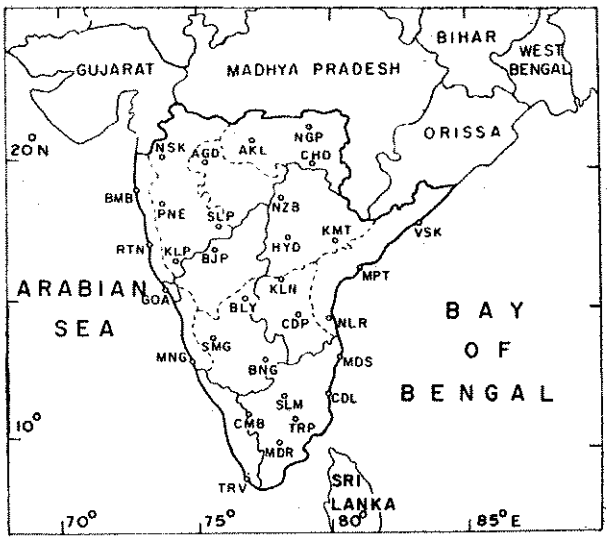

Fig. 1. Network of raingauge station over Peninsular India

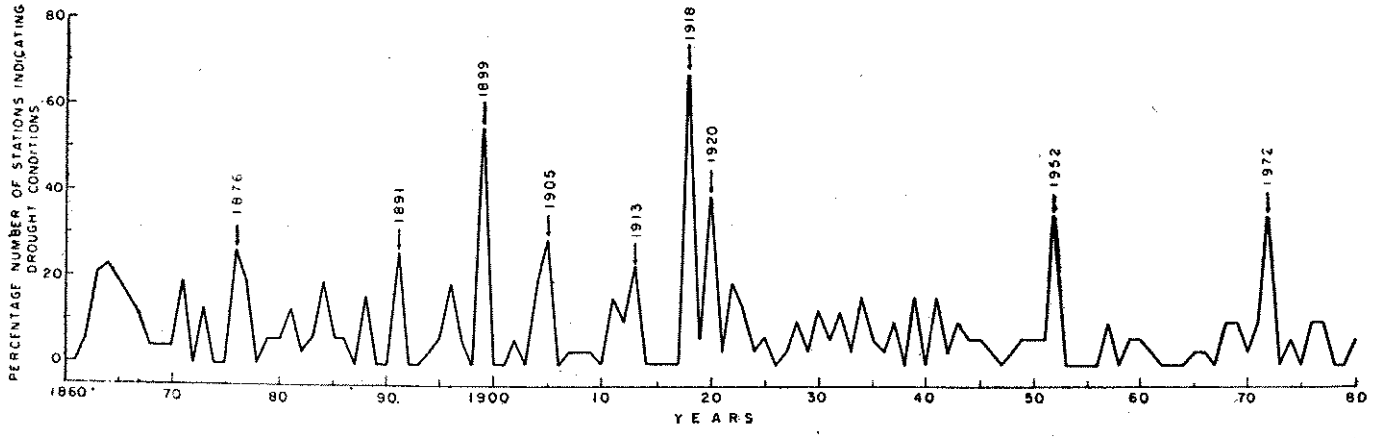

Fig. 2. Percentage of station showing drought conditions during monsoon season (Jun-Sep) for the period 1861-1980 over Peninsular India

TABLE 1

List of raingauge stations along with their abbreviations

Abbreviation	Name of stn.	Abbreviation	Name of stn.	Abbreviation	Name of stn.
GOA	Goa	AKL	Akola	MDS	Madras
RTN	Ratnagiri	NLR	Nellore	SLM	Salem
BMB	Bombay	MPT	Masulipatnam	CMB	Coimbatore
KLP	Kolhapur	VSK	Vishakhapatnam	MDR	Madurai
SLP	Sholapur	KMT	Khammam	TRP	Tiruchirapalli
PNE	Pune	NZB	Nizamabad	MNG	Mangalore
NSK	Nasik	HYD	Hyderabad	BJP	Bijapur
AGD	Aurangabad	CDP	Cuddapah	BNG	Bangalore
CHD	Chanda	KLN	Kurnool	BLY	Bellary
NGP	Nagpur	CDL	Cuddalore	SMG	Shimoga
				TRV	Trivandrum

TABLE 2

Mean and standard deviation of rainfall at stations in Peninsular India (1871-1980)

Station	Mean (mm)	Std. dev. (mm)	Station	Mean (mm)	Std. dev. (mm)	Station	Mean (mm)	Std. dev. (mm)
GOA	2420	524	AKL	690	203	MDS	389	124
RTN	2518	576	NLR	295	117	SLM	490	127
BMB	1813	477	MPT	605	188	CMB	152	81
KLP	803	216	VSK	528	167	MDR	316	118
SLP	536	203	KMT	722	203	TRP	304	115
PNE	520	153	NZB	877	241	MNG	2919	590
NSK	588	202	HYD	593	174	BJP	377	139
AGD	621	184	CDP	469	177	BNG	491	142
CHD	1141	258	KLN	471	161	BLY	272	110
NGP	1044	223	CDL	378	121	SMG	563	162
						TRV	840	251

3. Identification of well marked drought over Peninsula

From the monthly rainfall data, monsoon (June-Sep) rainfall series was obtained for each of the stations for the period 1861-1980. The monsoon rainfall series for each station was converted into standard units *i.e.*, in deviation from the long-period mean expressed in terms of the standard deviation. Table 2 gives the mean and standard deviation of the monsoon rainfall series of these stations for the period 1871-1980.

The water-dependent activities over any area get geared to the rainfall normally available and the variability of rainfall over the area.

In view of this basic fact, the criteria adopted are linked with the value of the rainfall expressed in standard units. If in any year, the monsoon rainfall at a station is equal to or less than —1.28 standard units, the station is considered to have suffered from drought in the monsoon season. The number of stations over the Peninsula which suffer from drought has been obtained for each of the years. Fig. 2 shows this number expressed as percentage of the total number of stations. If in an year 25 per cent or more of the stations over the Peninsula suffer from drought, then that year is considered as one in which the Peninsula suffered from well-marked drought. With these objective criteria, the years of well-marked drought in the Peninsula have been identified. These as shown in Fig. 2, are 1876, 1891, 1899, 1905, 1913, 1918, 1920, 1952 and 1972. Of these, 1876, 1891 and 1913 are the years which just satisfy the criterion of 25 per cent of the stations suffering from drought. In the remaining years the number of stations which suffered from drought varied from 9 to 21; Table 3 gives the names of these stations. The drought of 1918 is the most extensive over the Peninsula. The one next below this drought is the drought of 1899. In the period of record, Peninsula has not suffered from well-marked drought in two successive years. During the long periods from 1921 to 1951 and 1953 to 1971, the Peninsula did not experience any well-marked drought.

4. Examination for trend in the occurrence of well-marked drought

Test as given by Cox (1970) has been applied to the series of occurrence and non-occurrence of well-marked drought over the Peninsula to find out if there is any trend in the occurrence of the well-marked drought. Suppose the period considered has N years, and in this period well-marked drought has occurred in n years. Arrange the years of the period in chronological order, *i.e.*, in the order of increasing time and assign ranks 1 to N to these years. The statistic $T_0 = \sum_{i=1}^{n} R_i$ where R_i is the rank of the i^{th} drought year. T_0 is thus the sum of the ranks of the years of well-marked drought. T_0 is normally distributed. $E(T_0)$, *i.e.*, expected value of T_0 and σ_{T0} the standard deviation of T_0, have been computed as indicated by Cox (1970). The test statistic, the standard deviate, $[T_0 - E(T_0)] / \sigma_{T0}$ has been obtained. The same is found to be —0.38 which is too low to be of any significance. The test does not suggest any trend. The occurrence of well-marked drought over the Peninsula can be taken to be random in time continuum.

Swed and Eisenhart's test (WMO, 1966a) and Mann-Kendall Rank statistic test (WMO, 1966 b) have also been applied to the time interval between the successive occurrences of well-marked drought for detection of trend, if any. The results of these tests confirm the randomness of the occurrence of well-marked drought over the Peninsula.

5. Associated circulation features

Drought is a complex phenomena resulting in severe hardship to the population of the affected area. It is often difficult to estimate the factors which contribute

TABLE 3

Stations which suffered from drought in some of the selected years of well-marked drought over the Peninsula and the corresponding rainfall expressed in standard units

S.No.	1899	1905	1918	1920	1952	1972
1	GOA —2.31	GOA —2.06	GOA —2.25	GOA —1.50	GOA —1.32	RTN —1.37
2	RTN —1.81	RTN —2.22	RTN —2.08	RTN —1.91	RTN —1.52	KLP —1.63
3	BMB —1.98	BMB —2.08	BMB —2.58	BMB —1.70	CHD —1.42	SLP —1.63
4	KLP —1.54	KLP —2.22	KLP —2.37	SLP —1.29	NGP —1.87	PNE —1.49
5	SLP —2.16	SLP —1.52	SLP —1.55	AGD —2.29	NZB —1.68	NSK —1.28
6	PNE —1.74	AGD —1.80	PNE —2.73	CHD —1.63	HYD —1.34	AGD —1.99
7	NSK —1.34	MDS —1.50	NSK —1.53	NGP —1.60	CDP —1.46	CHD —2.30
8	AGD —1.87	BJP —1.39	AGD —2.43	AKL —2.08	MDS —1.55	NZB —1.40
9	CHD —2.55	SMG —1.40	NGP —1.60	NLR —1.67	BLY —1.93	HYD —1.66
10	NGP —3.20		AKL —2.23	VSK —1.39	SMG —1.57	MDS —1.55
11	AKL —2.07		NLR —1.44	KLN —1.69	TRV —1.50	BJP —1.55
12	KMT —1.74		NZB —1.66	MDS —2.04		
13	NZB —2.14		CDL —1.32			
14	TRP —1.48		MDS —1.34			
15	MDR —1.94		SLM —2.08			
16	MNG —2.00		CMB —1.68			
17	TRV —1.42		MDR —1.35			
18			MNG —2.41			
19			BJP —1.81			
20			SMG —2.35			
21			TRV —1.92			

to the occurrence of well-marked drought and the relative importance of these factors. In this study, the circulation features associated with the rainfall over the area under consideration have been examined in years of drought and flood over the Peninsula to bring out distinguishing characteristics. The circulation systems examined are the frequency of the monsoon trough over foot-Himalayas, and the monsoon storms and depressions.

The monsoon trough is the most important component of the summer monsoon system. In its normal position which is from Calcutta to Multan on sea level chart, and approximately along latitude 23 deg. N on 700 mb chart, monsoon is active over most parts of the country and fairly well-distributed rain occurs. When it shifts north to the foot-Himalayas under the influence of the westerly trough which moves across the extreme north of India and in the absence of the westward-moving low/depression from north Bay, rainfall over most parts of the country decreases substantially in an abrupt manner. This situation is referred to as a 'break' in the monsoon. During the period of 'break' sub-Himalayan area gets heavy rainfall and there is an increase in the thundershower activity over Tamilnadu. The number of such occasions, particularly in the active monsoon months July & August, is expected to affect adversely the rainfall in the Peninsula. Ramamurthy (1969) has tabulated the periods in July and August when the monsoon trough lay over the foot-Himalayas, during the period 1888-1967. Similar information for the period 1968-80 has been collected from the charts of Weather Central, Pune, and the *Indian Daily Weather Reports*. Table 4 gives the number of days during July and August when monsoon trough was over the foot-Himalayas in years of well-marked drought over the Peninsula. The table also gives similar information in respect of 9 flood years identified by the criterion of more than 25 per cent of the stations having seasonal rainfall greater than or equal to 1.28 standard units. It is seen that the number of such days during drought years is generally 12 or more and during flood years, generally 10 or less. The mean for drought years is about two and a half times of that for the flood years. Thus the more frequent trough position over the foot-Himalayas during drought years makes a contribution to the occurrence of well-marked drought over the Peninsula.

Depressions and storms form over the Bay of Bengal during the monsoon season and these generally move in a west/northwest direction across the central parts of the country and give rainfall over the central parts of the country and major portion of the Peninsula. In addition, these systems transport heat and moisture upwards and maintain the activity of the monsoon trough. Depressions and storms also form in the east Arabian Sea, mostly during June, and move either towards the coast or parallel to the coast for some time and later move westnorthwest or northwest; these give rain in the western part of the Peninsula. The information in respect of storms/depressions contained in the publication *"Tracks of storms and depressions in the Bay of Bengal and Arabian Sea"* by the India Meteorological Department (1979) for the period 1877-1970 has been utilised. Information for the period 1971-80 has been obtained from the accounts for the individual years published in the *Indian Journal of Meteorology and Geophysics* and in *Mausam*, and the accounts prepared by the Deputy Director General of Meteorology (Weather Forecasting), Pune. These systems have been examined in respect of their frequency of formation and their tracks to see if the behaviour of these systems in the

TABLE 4

Number of days during July and August in drought/flood years when monsoon trough axis lay over foot-Himalayas

S. No.	Drought years	No. of days when monsoon trough was over foot-Himalayas	Flood years	No. of days when monsoon trough was over foot-Himalayas
1	1876	—	1889	8
2	1891	7	1892	0
3	1899	23	1916	3
4	1905	13	1949	10
5	1913	16	1959	3
6	1918	23	1961	0
7	1920	12	1964	12
8	1952	4	1970	14
9	1972	22	1975	7
	Mean	15.0		6.3

TABLE 5

Mean frequency of storms/depressions forming in the Bay of Bengal and Arabian Sea in each of the monsoon months for years of well-marked drought/flood. Figures in parentheses show frequency of storms/depressions forming south of 20° N

	Jun	Jul	Aug	Sep	Season
Drought	0.6	2.1	2.0	1.8	6.5
	(0.2)	(0.2)	(0.7)	(1.2)	(2.5)
Flood	1.9	1.6	1.7	2.2	7.4
	(1.4)	(0.5)	(0.9)	(1.5)	(4.3)

TABLE 6

Mean frequency of depression days south of 25° N and west of 85° E in each of the monsoon months in years of drought/flood

	Jun	Jul	Aug	Sep	Season
Drought	1.7	3.4	3.1	3.3	11.5
Flood	3.0	2.5	2.5	5.4	13.4

group of drought years can be distinguished from that in the group of flood years. Table 5 gives the mean frequency of formation of storms/depressions in the Bay of Bengal and the Arabian Sea in the monsoon months in the years of well-marked drought/flood over the Peninsula. Since the systems forming south of latitude 20 deg. N are likely to have greater influence on the rainfall over the Peninsula, the frequency of such systems has also been given in the Table. It can be seen that the total frequency of the systems in flood years is definitely more in June; in July and August, it is less and in September, it is more, the total for the season being more in flood years. The frequency in respect of the systems forming south of latitude 20 deg. N is more during flood years in each of the months, being appreciably so for June. Of the systems forming over the Bay and the Arabian Sea, the proportion of systems forming south of 20 deg. N is more in June, July and August, being appreciably so in June.

The depressions which cross longitude 85 deg. E south of latitude 25 deg. N and continue to move in a westerly direction south of 25 deg. N are likely to contribute to the Peninsular rainfall rather significantly. If the period for which depressions move south of 25 deg. N after crossing 85 deg. E is longer they are likely to contribute more to the Peninsular rainfall. Table 6 gives the mean frequency of depression days south of 25 deg. N and west of 85 deg. E in each of the monsoon months in the years of drought/flood. It is seen that in flood years the frequency is appreciably more during June and September; the same is, however, less in July and August. For the season as a whole, the frequency is higher during flood years by about 15 per cent.

The examination of storms/depressions shows that the systems during well-marked drought over Peninsula have some characteristics which are different from those for well-marked flood.

6. Conclusions

(*i*) In accordance with the objective criteria which take into account the mean and variability of rainfall over an area, the years of well-marked drought over the Peninsula are, 1876, 1891, 1899, 1905, 1913, 1918, 1920, 1952 and 1972. The occurrence of the well-marked drought is found to be random.

(*ii*) Higher frequency of days with trough axis over the foot-Himalayas is seen to be associated with large-scale drought.

(*iii*) The proportion of depressions forming over the Bay of Bengal and the Arabian Sea south of latitude 20 deg. N is smaller during drought years.

(*iv*) The frequency of depression days south of 25 deg. N and west of 85 deg. E is smaller during drought years.

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