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Analysis and prediction of short period droughts during summer monsoon over India

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सार — तेईस वर्षों के विभिन्न स्थानों के उप-मण्डलीय वर्षा आंकड़ों के औसत का उपयोग करते हुए भारत के अर्धशुष्क भागों के मौसम विज्ञान संबंधी 7 उप-मण्डलों में पड़ने वाले सूखों की जलवायु संबंधी विशेषताओं का अध्ययन किया गया है । इन उपमण्डलों में शुष्क अथवा नम दिन का निश्चय करने के लिए पांच विभिन्न प्रभावसीमाओं का उपयोग किया गया है । उसी क्षेत्र के 6 स्टेशनों के लिए भी सूखे की संभावनाओं में समान विशेषताओं का अध्ययन किया गया है । उन स्टेशनों में सूखे की संभावनाओं की बारंबारता पर प्रथम और द्वितीय कोटि की मार्कोव शृंखलाएं आसंजित की गई हैं । जांच करने पर द्वितीय कोटि की शृंखला अधिक उपयुक्त पाई गई ।

19 वर्षों के लिए 220 स्टेशनों की दैनिक वर्षा के आंकड़ों का उपयोग करके विभिन्न भौगोलिक क्षेत्रों में स्थित अवदाब के आसपास वर्षा के संभावित चार्ट तैयार किए गए हैं । इन चार्टों की सहायता से सूखों को कम करने में अवदाबों की भूमिका की जांच की गई हैं ।

अन्त में, इन उप-मण्डलों में दैनिक वर्षा की मात्रा की प्रागुक्ति के लिए बृहद्‌माप के सिनॉप्टिक प्राचलों का उपयोग करते हुए सीढ़ी-दर-सीढ़ी जांच प्रणाली द्वारा बहुरैखिक समाश्रयण समीकरणों का विकास किया गया है । समान आकार के एक स्वतंत्र प्रतिदर्श के आधार पर परखने पर, इन समीकरणों ने वर्षा के शततमक की प्रागुक्ति में निपुणता संमक दर्शाए जिनका मान 0.22 से 0.54 के बीच था ।

ABSTRACT. Climatic characteristics of occurrence of dry spells over 7 meteorological subdivisions lying in semi-arid parts of India are studied by using 23 years of spatially averaged subdivisional rainfall data. Five different thresholds have been used to decide the occurrence of dry or wet day over the subdivisions. Similar characteristics in occurrence of dry spells have been studied for 6 stations lying in the same area. The Markov chains of order 1 and 2 have been fitted to the frequency of occurrence of dry spells over the stations and on testing, the chain of order 2 are found to fit better.

Composite charts of probability of occurrence of rain around depressions located in various geographical areas have been prepared by using daily rainfall data of 220 stations for 19 years. With the help of these charts the role of depressions in alleviating drought situation is examined.

Finally multiple linear regression equations are developed by stepwise screening method to predict the daily rainfall amounts over these subdivisions by using large scale synoptic parameters. When tested on an independent sample of equal size these equations showed skill scores varying from .22 to .54 in forecasting the terciles of rainfall.

1. Introduction

Demarcation of drought period, in general, depends on several factors like, soil moisture status, rainfall crop types and evapotranspiration. The droughts may be broadly classified in 3 types — meteorological, hydrological and agricultural. Meteorological drought occurs when rainfall is below certain requirement for prolonged periods. Even during the peak of southwest monsoon season, the rain does not occur on all days over a station particularly in arid and semi-arid parts of India. Rain occurs in spells and wet spells are intercepted by dry spells, sometimes long enough to cause drought.

In the present study a drought period is defined as a period when daily rainfall does not exceed certain threshold. We thus study characteristics of dry spells only, although all dry spells particularly short ones may not cause drought. We shall analyse frequency and persistence of dry spells during July-August for 6 stations (*see* Table 1 for position) and 7 meteorological subdivisions (SDs — Fig. 1) lying in the arid and semi-arid parts of India chronically affected by droughts. Further we develop regression equations for prediction of rainfall occurrence below certain threshold by using 6 synoptic predictors and test their performance on independent data.

2. Data

Daily rainfall data of 6 stations for 19 years (1955-73) and 7 SDs for 23 years (1955-77) are obtained from India Meteorological Department. Daily subdivisional average rainfall are prepared by averaging the daily rainfall of stations falling in the SD concerned. In all data of 59 stations are used to prepare

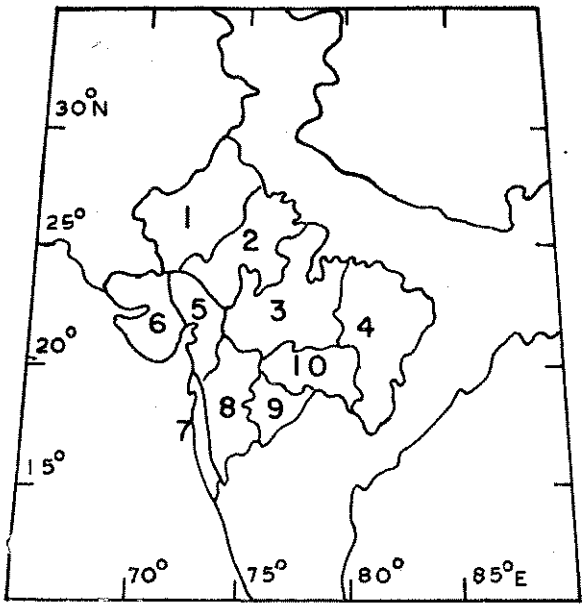

Fig. 1. Location of subdivisions for 7 SDs of interest (*see* Table 3)

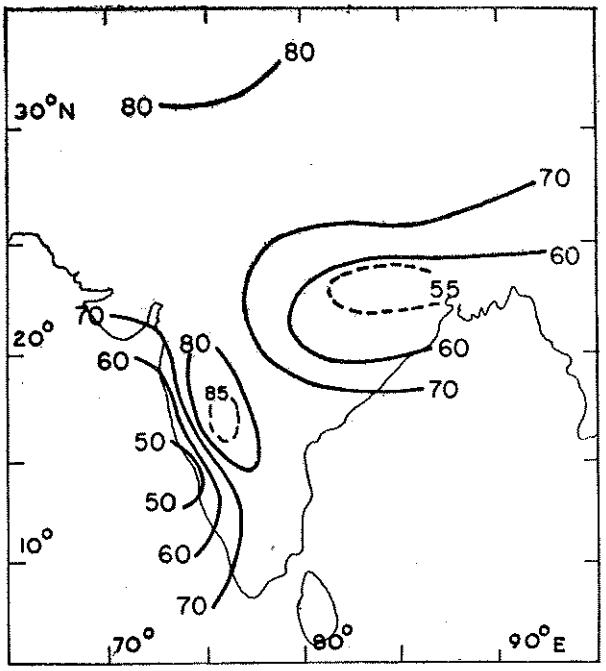

Fig. 2. Distribution of conditional probability of dry day followed by dry day (PD/D) × 100 for 2.5 mm threshold

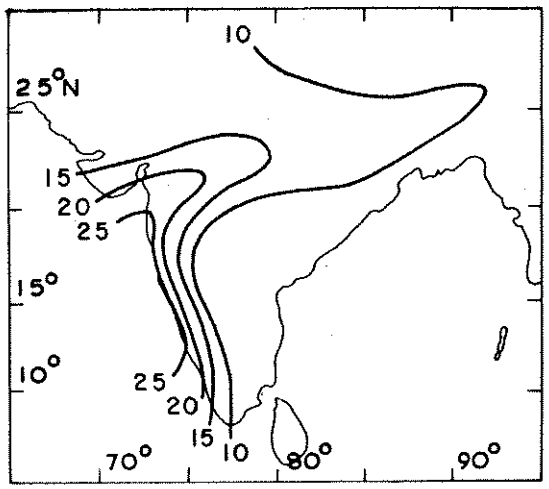

Fig. 3(a). (PD/D—PD) × 100

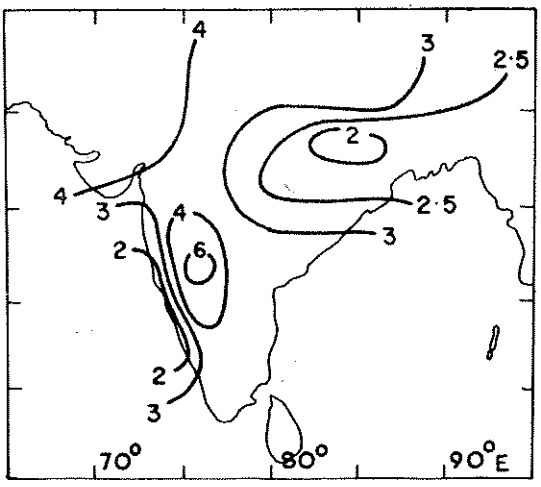

Fig. 3(b). Average length of dry spells in days

TABLE 1

Statistical characteristics of dry spells in station rainfall

Station (Lat., Long.)	PD	PD/D	Average length of spell in days	% of spells of 3 or less days	No. of spells of 7 or more days during the period	Test of Markov chain order: Chi sq.	d.f.	Prob. of exceeding by chance
Delhi (28.6N, 77.2E)	.66	.76	3.8	66	34	3.2	9	.95
Jaipur (26.5N, 75.8E)	.64	.77	3.9	59	34	9.7	9	.40
Ahmedabad (23.1N, 72.5E)	.64	.77	4.0	68	30	6.2	9	.70
Bhopal (23.3N, 77.3E)	.53	.68	3.0	76	23	5.6	8	.65
Poona (18.5N, 73.8E)	.63	.78	4.3	61	38	1.7	9	.99
Bijapur (16.8N, 75.7E)	.80	.85	6.1	54	45	3.9	9	.90

daily subdivisional rainfall of these 7 SDs. The daily synoptic parameters, *viz.*, 700 mb contour height and mean sea level pressure anomaly for the grid points lying over the concerned SD, 900 mb zonal wind shear between 20 deg. N and 28 deg. N latitude across 80 deg. E longitude, surface pressure difference between Colombo and Nagpur; and the monsoon trough axis location across various longitudes are obtained for 10 years (1966-75) for development and prediction of daily rainfall.

3. Frequency and persistence of dry spells in station rainfall

Singh *et al.* (1981) studied persistence in dry and wet days defined by using two thresholds (2.5 mm and 10 mm) during July and August for 22 stations representing various climatic regimes of India by computing unconditional and conditional probabilities of occurrence of dry and wet days and fitting Markov chain models of order one and two and logarithmic and modified logarithmic models using data of 19 years. They found that, in general, Markov Chain model order 2 fitted well to occurrence of dry spells. The conditional probabilities of a dry day following a dry day (PD/D) are shown in Fig. 2, and their difference from respective unconditional probabilities (PD) and

TABLE 2

Statistics of occurrence of dry days in subdivisional rainfall fo various thresholds

Subdivision	Threshold criterion	PD	PD/D	t-value for (PD/D—PD)	Average length of spell (day)	Longest spell in days
Rajasthan West	0.3	.52	.92	8.8	3.5	33
	2.5	.73	.83	5.9	5.8	35
	10.0	.93	.94	2.1	18.0	62
	8.0 (Evap)	.89	.92	2.5	13.0	62
	0.0 (Tercile)	—	—	—	—	—
Rajasthan East	0.3	.23	.64	14.4	2.8	13
	2.5	.43	.71	11.6	3.4	20
	10.0	.75	.83	4.8	5.8	29
	8.0 (Evap)	.69	.81	6.2	5.1	29
	1.0 (Tercile)	.31	.67	3.3	3.0	18
M.P. (West)	0.3	.06	.49	13.8	1.9	<10
	2.5	.23	.59	13.0	2.5	13
	10.0	.61	.77	7.8	4.3	31
	7.0 (Evap)	.48	.69	9.0	3.2	25
	3.8 (Tercile)	.31	.61	11.2	2.6	13
Gujarat	0.3	.21	.63	14.6	2.7	11
	2.5	.45	.72	11.4	2.6	27
	10.0	.74	.85	6.6	6.7	36
	8.0 (Evap)	.69	.83	7.5	5.8	36
	1.2 (Tercile)	.33	.69	13.3	2.2	15
Saurashtra & Kutch	0.3	.33	.71	14.4	3.4	21
	2.5	.63	.84	10.7	6.2	34
	10.0	.84	.92	6.1	12.3	53
	8.0 (Evap)	.81	.91	7.1	11.0	52
	0.2 (Tercile)	.28	.67	14.3	3.0	14
Madhya Maharashtra	0.3	.13	.47	11.6	1.9	10
	2.5	.47	.70	9.7	3.3	22
	10.0	.85	.89	3.2	8.9	52
	7.0 (Evap)	.76	.84	4.9	6.4	52
	1.3 (Tercile)	.33	.63	11.5	2.7	13
Marathwada	0.3	.28	.54	9.7	2.2	10
	2.5	.54	.71	7.9	3.5	33
	10.0	.79	.84	3.2	6.2	37
	8.0 (Evap)	.75	.82	4.1	5.4	37
	0.5 (Tercile)	.32	.56	9.0	2.3	10

average length of dry spell are reproduced in Fig. 3 from their paper. It can be seen that the average length of dry spells for the arid and semi-arid regions exceeds 4 days although about 40% of dry days occur isolated (*see* Table 1) and remaining 60% dry days occur in spells of 2 or more days. About 40% of spells exceed 3 days (Table 1), about 2 spells per year exceed a week and cause distress. Other statistics about occurrence and frequency of dry days like conditional probability of dry days, Chi-square statistics and its significance level obtained from testing Markov Chain of order 2 are given in Table 1. These results indicate that Markov Chain order 2 fits the dry spells satisfactorily.

4. Persistence in dry spells of subdivisional rainfall

Since the persistence in dry spell may depend on the threshold value chosen (Mccalla 1978, Blairfish

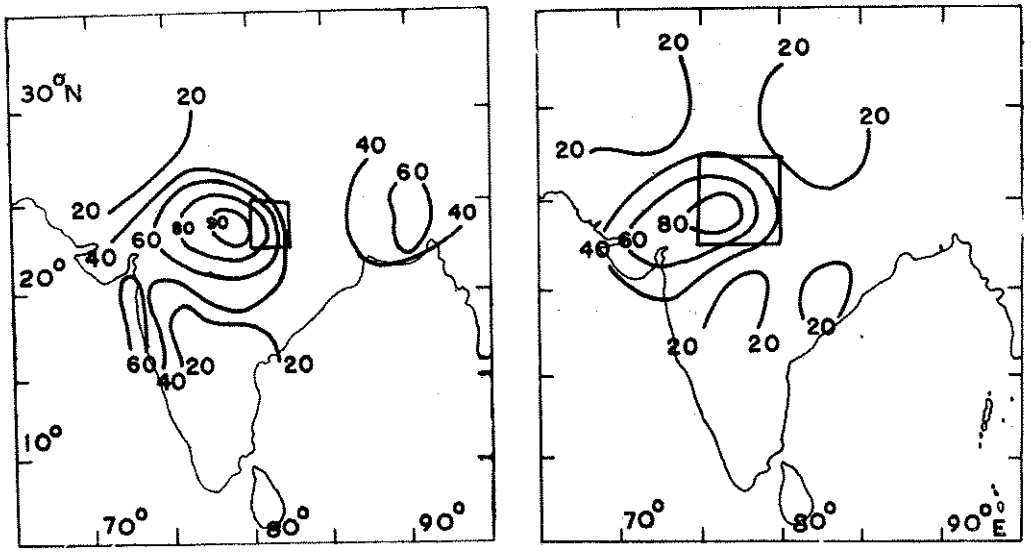

Fig. 4. Probability of 24-hr rain > 2.5 mm in percentage in association with depressions. Rectangles mark areas in which the depressions lie at 03 GMT of a day

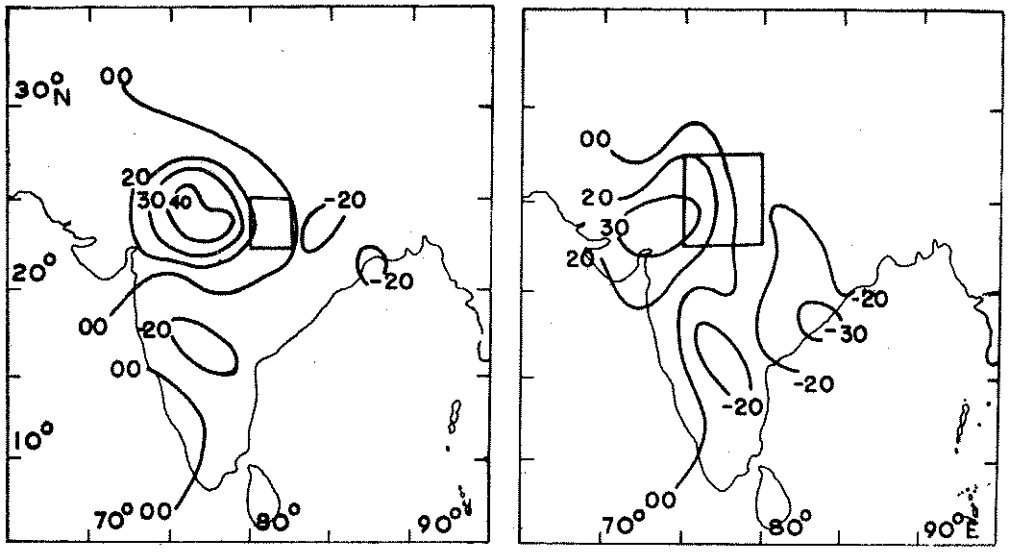

Fig. 5. Difference between probability of rain associated with depression *minus* climatic probability in percentage for the same depression cases as in Fig. 4

TABLE 3

Main results of regression equations for development and test sample. Figures in parantheses against SD name correspond to the SD numbers shown in Fig. 1

Subdivision	Variance explained on development sample	Test on independent sample		
		Heidke skill score	Post agreement(%) for dry tercile	Prefigurance of dry tercile
Rajasthan West (1)	24	.34	75	70
Rajasthan East (2)	51	.25	79	60
M.P. West (3)	57	.39	81	64
Gujarat (5)	46	.54	81	76
Saurashtra & Kutch (6)	62	.49	82	74
Madhya Maharashtra (8)	45	.33	71	62
Marathwada (9)	37	.22	75	54

1975), we try 5 different thresholds to study the persistence in dry spells. Three thresholds (.3 mm, 2.5 mm and 10 mm) are fixed for each SD and two, *viz.*, evapotranspiration eye estimated from maps of Rao *et al.* (1971) and terciles obtained by preparing cumulative distribution of the daily rainfall data, vary from SD to SD. PD, PD/D, t-value obtained from testing the significances of (PD/D — PD), Chi-square statistics as test of dependence of rainfall on previous day obtained from 2×2 contingency tables after classifying the daily rainfall in two states dry or wet, average length of dry spells and largest length of dry spells are presented in Table 2 for different thresholds. The difference between PD/D and PD is significant for all SDs and all thresholds. Average evapotranspiration seems to be too stringent criterion particularly for arid regions. The average length of wet spell varies from 3 to 18 days and largest dry spell varies from 14 to 62 days among the SDs for this criterion, 10 mm is still more stringent. Thus a threshold of 2.5 mm which is about 1/3 to 1/2 of actual evapotranspiration values appear to be quite reasonable for defining drought spells because before the beginning of dry spells there is always some residual moisture in the soil and hence Venkataraman (1981), Khambete and Biswas (1978) have used 20 mm and 18 mm as weekly rain requirements for these regions. PD and PD/D agree quite closely for all SD (except for west Rajasthan and Saurashtra & Kutch) for 2.5 mm criterion and terciles, the latter obviously shows PD equal to .33.

5. Role of synoptic systems

Usually monsoon depressions and lows, monsoon trough, trough of low pressure off the west coast and disturbances in westerlies are the main agencies for active or vigorous monsoon conditions as documented in forecasting manual reports published by India Meteorological Department (IMD). Although lows are more frequently responsible for active monsoon conditions, depressions play an important role in changing rainfall pattern over large parts of country and breaking the dry spell. Probabilities of exceeding 2.5 mm rain in 24 hr over the country and their difference from climatology when depressions lie in the areas around 80 deg. E longitude are shown in Figs. 4 and 5 respectively.

These rainfall composites are prepared by using data of 220 stations uniformly distributed over the country using 19(28) depression cases when depressions lie to east (west) of 80 deg. E. It is obvious that associated with depressions the probability of 2.5 mm or more rain exceeds .5 over large areas. The climatic probabuity of rain over these areas is about .3.

6. Regression equations for forecasting quantities of daily rainfall

We have developed multiple linear regression equation after screening 6 parameters, *viz.*, 5 synoptic parameters listed in section 2 and previous day rainfall for the corresponding SD to account for persistence, to predict SD rainfall amount in subsequent 24 hr. The values which exceed mean *plus* 3 standard deviation in original predictand series are winsorised and the new predictand series is normalised by cube root transformation. The equations are developed on data of 336 days and tested on independent samples of 144 days. Variance explained on development sample, and verification scores on independent samples like Heidke skill score for forecasting rainfall into 3 equally probable categories and post agreement and prefigurance for forecasting lower dry tercile are given in Table 3. All the scores show significant positive skill. Attempts to forecast longer period rainfall are being made.

7. Conclusions

From the study following main conclusions can be drawn :

(*i*) Both station as well as subdivisional rainfall in the arid and semi-arid parts of India show persistence in occurrence of dry days. Markov

Chain of order 2 fits the spells of dry days satisfactorily.

(*ii*) Depressions lying near 80 deg. E or further west cause widespread rainfall over the area considered in the study.

(*iii*) Positive skills can be achieved in forecasting quantities of subdivisional rainfall one day ahead by use of synoptic parameters.

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