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On prediction of droughts in the Indian arid region

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सार — सूखा शुष्क क्षेत्रों में बार-बार पड़ता है और सूखे की प्रागुक्ति का वनरोपण, बालू के टीले के स्थिरीकरण और चरागाहों की स्थापना आदि में बड़ा ही महत्व है। केन्द्रीय शुष्क क्षेत्र अनुसंधान संस्थान, जोधपुर में जलवायु के उतार चढ़ावों एवं परिवर्तनशीलता के आधार पर भारतीय शुष्क क्षेत्र में सूखे की पूर्वानुमान संबंधी तकनीकों के विकास के क्षेत्र में कुछ प्रयास किए गए हैं।

भारत के शुष्क क्षेत्र का जलवायु स्पेक्ट्रम अतिशुष्क से अर्धशुष्क अवस्थाओं तक फैला है। प्रथम कोटि के मारकोव चैन निदर्श के आधार पर प्रतिबंधित प्रायिकताओं के सिद्धान्त का उपयोग करके वर्ष 1901 से 1970 के दौरान हुए जलवायु के उतार-चढ़ावों का अध्ययन किया गया है। यह देखा गया है कि आगामी वर्ष में घटित होने वाली अतिशुष्क परिस्थितियों के बारे में 92 प्रतिशत विश्वास्यता तक पूर्वानुमान किया जा सकता है, जबकि जलवायु विषयक प्रागुक्ति 83 प्रतिशत विश्वास्यता के साथ की जा सकती है।

हो सकता है कि सूखे के आगमन से पूरा क्षेत्र एक साथ प्रभावित न हो और उसके केवल कुछ हिस्सों में स्थानीय सूखा पड़े। कुछ अन्य वर्षों में सम्पूर्ण क्षेत्र में सूखा पड़ता है और अध्ययनों से पता चला है कि ऐसे वर्षों में भी सूखे की तीव्रता और उसके घटित होने का समय एक क्षेत्र से दूसरे तक एक जैसा नहीं रहता है। पश्चिमी राजस्थान में सूखा पड़ने और उसके विस्तार का अध्ययन यह दर्शाता है कि सूख की स्थिति सर्वप्रथम उत्तरपूर्वी क्षेत्र में जुलाई में पैदा होती है और अगस्त के महीने में दक्षिण-पश्चिम की ओर फैल जाती है। फिर सितम्बर के महीने में पूर्व दिशा में गमन के साथ समाप्त हो जाती है। भीषण सूखे के वर्षों में इसी रूपरखा की आवृति होती देखी गई है। प्रस्तुत शोधपत्र में उपरोक्त तकनीकों के अनुप्रयोगों के बारे में चर्चा की गई है।

सूखे का बड़े पैमाने पर पूर्वानुमान अभी तक शत प्रतिशत विश्वास्यता सहित संभव नहीं हो पाया है। अत: विभिन्न तकनीकों का उपयोग करके एक मिश्रित विधि की सहायता से सूखे की प्रागुक्ति आवश्यक विश्वास्यता सहित की जा सकती है।

ABSTRACT. Drought is a recurring feature in the arid regions and prediction of droughts has got great relevance with respect to planning for afforestation, sand dune stabilisation, establishment of grasslands etc. Some attempts have been made at the Central Arid Zone Research Institute, Jodhpur to develop techniques for prognostication of droughts in the Indian arid region on the basis of climatic fluctuations and variability.

The climatic spectrum of the Indian arid region extends from extremely arid to semi-arid conditions. Through application of the theory of conditional probabilities based on first order Markov chain model, the climatic fluctuations during the years 1901-1970 were studied. It was observed that the occurrence of extreme arid conditions in the succeeding year could be predicted with 92 per cent confidence while climatic types can be predicted with 83 per cent confidence.

Drought incidence may not be affecting whole of the region simultaneously and some parts might experience localised droughts. However, in some years the whole region experienced drought conditions and studies reveal that even in such years the drought intensity and its time of occurrence varied from region to region. Studies on the incidence and spread of droughts over western Rajasthan indicate that drought condition originate first in the northeastern region, during the month of July spread in a south-westerly direction during the month of August and dissipate with an easterly movement in the month of September. This pattern is observed to repeat during the years of severe drought. In the present paper, the applicability of the above techniques have been discussed.

Long range prediction of droughts is not yet possible with 100 per cent confidence. Therefore, a combination approach using different techniques might provide the necessary confidence in prediction of droughts.

1. Introduction

Landsberg (1974) summarising the global research work on droughts pointed out that no radical one sided trends or well defined cycles of rainfall can be identified to enable forecasting of droughts. Droughts are a recurring phenomena in the arid regions and prediction of droughts as such holds great importance in respect to planning and execution of programmes like afforestation, sand dune stabilization and establishment of grasslands etc. As droughts do not occur all of a sudden as

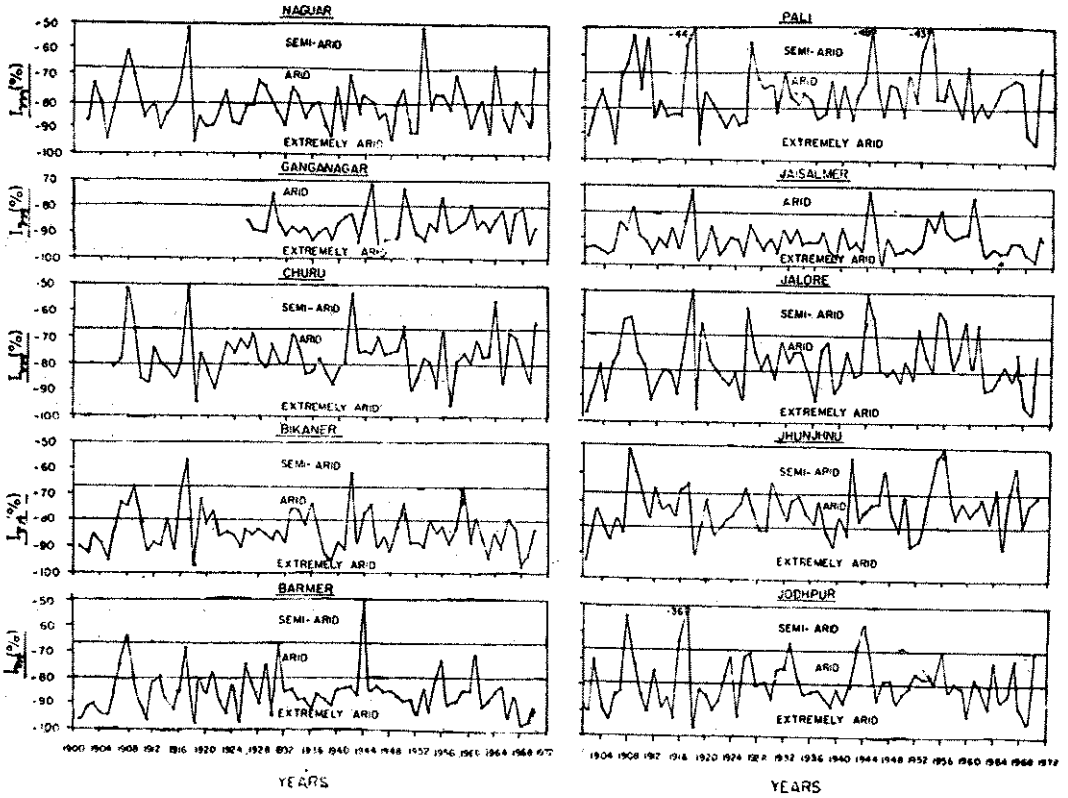

Fig. 1. Climatic shifts in different regions of western Rajasthan during 1901-1970

floods do, but are usually the ultimate result of a set of weather sequences that require extended periods of time to develop (Linsley *et al.* 1959), some chances exist, to understand the pattern of drought incidence, spread and decay over a given region which could be of some predictive value. Such attempts have been carried out with some success over the Deccan plateau (Subrahmanyam and Sastri 1971) and over western Rajasthan and northwest India (Rama Krishna and Sastri 1980, Sastri and Malakar 1981, Sastri and Rama Krishna 1981 and Sastri *et al.* 1981). Further, a knowledge of the climatic fluctuations over a given region enables us to estimate the conditions under which extreme aridity is likely to prevail, based on the conditions that prevailed during the preceding year. Such a combination approach can provide the necessary confidence in knowing the possibility of occurrence of droughts. The present paper deals with the application of such a combined approach for understanding the pattern of droughts over the Indian arid region.

2. Materials and methodology

The monthly water balance computations for the period 1901 - 1970 were carried out in respect of the 11 stations representing the respective districts of western Rajasthan, using the book-keeping procedure of Thornthwaite and Mather (1948) and incorporating the potential evapotranspiration (PE) values estimated using Penman's equation. The climatic variability at these stations was studied using the moisture index (I_m) of Thornthwaite estimated as :

$$I_m = \frac{\text{Annual water surplus—Annual water deficit}}{\text{Annual water need (PE)}}$$

Utilising the above index (I_m), the climatic shifts were considered to have been towards :

Semi Arid (SA) if I_m lies between —33.3 & —66.6%

Arid (A) if I_m lies between —66.7 & —80.0%

Extremely Arid (EA) if I_m is less than —80.0%

After classifying the climatic conditions that prevailed during different years considered, the conditional probabilities for the occurrence of sequences of extremely arid, arid and semi-arid conditions were estimated

TABLE 1

Conditional probabilities (in per cent) for the occurrence of arid and semi-arid conditions in western Rajasthan

Station	Probabilities (P) of occurrence of arid and semi-arid conditions					
	(A/EA)	(SA/EA)	(A/A)	(SA/A)	(A/SA)	(SA/SA)
Barmer	16	2	0	20	50	0
Bikaner	23	2	25	6	15	0
Churu	52	4	53	17	40	0
Ganganagar	18	0	0	50	0	0
Jaisalmer	8	—	0	—	—	—
Jalore	33	17	29	14	33	25
Jhunjhunu	50	15	55	17	54	31
Jodhpur	27	7	28	5	57	29
Nagaur	29	7	25	10	25	0
Pali	46	16	52	12	40	30
Sikar	25	31	54	32	36	32

based on the first order "Markov chain model". The conditional probabilities were estimated for the following situations:

(*i*) P(EA/EA), P(A/EA) and P(SA/EA) to represent the probability of occurrence of EA, A and SA conditions respectively during an year that follows in year with EA conditions.

(*ii*) P(EA/A), P(A/A) and P(SA/A) to represent the probability of occurrence of EA, A and SA conditions respectively during an year that follows an year with A conditions.

(*iii*) P(EA/SA), PAA/SA) and P(SA/SA) to represent the probability of occurrence of EA, A and SA conditions respectively during an year that follows an year with SA conditions.

For identifying the pattern of drought, the incidence and spread of droughts over western Rajasthan were studied in depth during typical years which experienced severe drought. For depicting the spread of drought, the departures of actual monthly water deficiencies from normal values were calculated and were expressed as a per cent ratio of water need (PE), in units of 'one tenths' (referred to as 'D' in the rest of the text).

3. Results and discussion

The climatic spectrum of the Indian arid region extends from extremely arid to semi-arid conditions as shown in Fig. 1. The annual moisture index values generally remained below normal in large number of years. In general fluctuations from arid to extremely arid conditions exist in these regions which are offset by a large positive departure, only occasionally.

The probabilities of occurrence of extremely arid conditions P(EA) and EA conditions followed by EA, A and SA conditions are shown in Fig. 2. The similarity between the pattern of P(EA) and P(EA/EA) indicates that the probability of occurrence of EA conditions will almost remain the same even when EA conditions prevailed during the preceding year.

The patterns of P(EA/A) and P(EA/SA) indicate that the chances of occurrence of EA conditions following an year with A conditions are highest in Jaisalmer region and are low in the Sikar region on the eastern side. The chances of occurrence of EA conditions following SA conditions, however, are higher in the region comprising Bikaner, Churu and Nagaur districts.

The conditional probabilities thus obtained can be A and SA conditions in different regions are presented in Table 1.

The values of P(A/A) are zero at Barmer, Ganganagar and Jaisalmer suggesting that arid conditions will not prevail during two consecutive years in these regions. Similarly two consecutive years do not experience semi-arid conditions in the Bikaner, Barmer, Churu, Ganganagar, Nagaur and Jaisalmer region. In the other regions SA conditions following a year with SA conditions may occur once out of 3 or 4 occasions.

The conditional probabilities thus obtained can be used to assess the conditions that are likely to prevail, in a given region, in advance. Assuming that events with higher probability are likely to occur, the fluctuations in climatic conditions during the five-year period

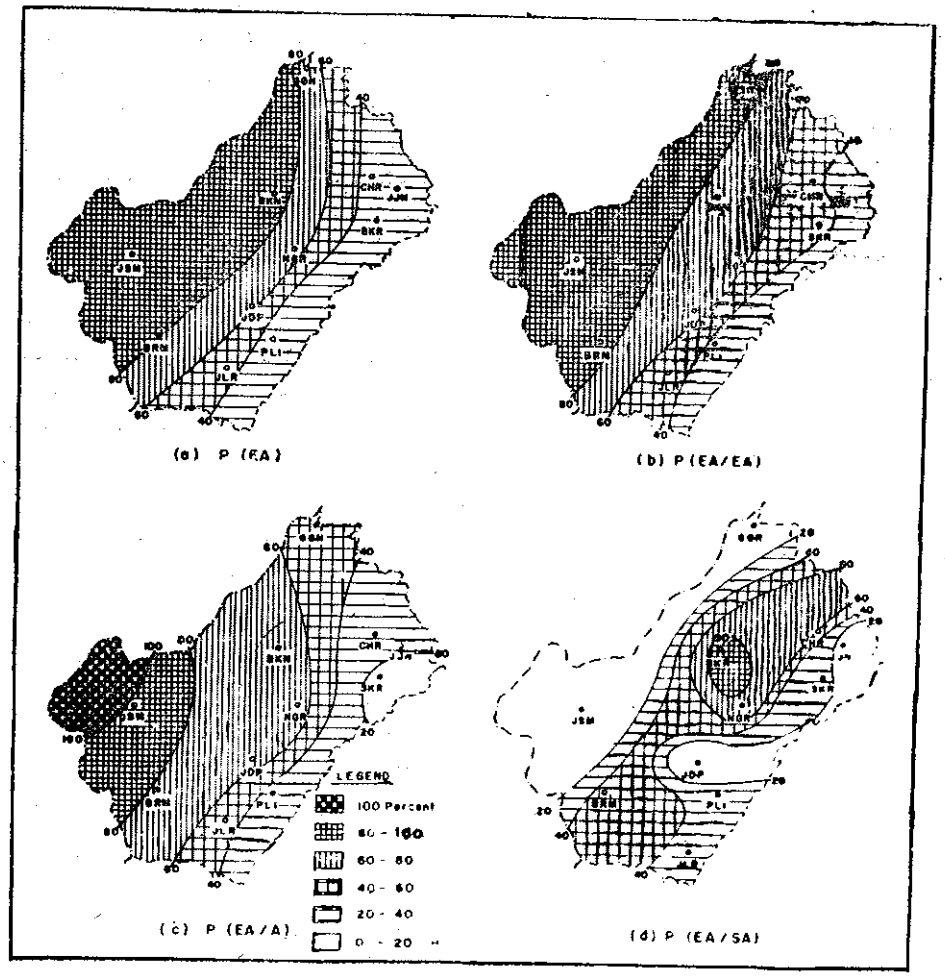

Fig. 2. Probability and conditional probabilities of occurrence of extrema aridity over western Rajasthan

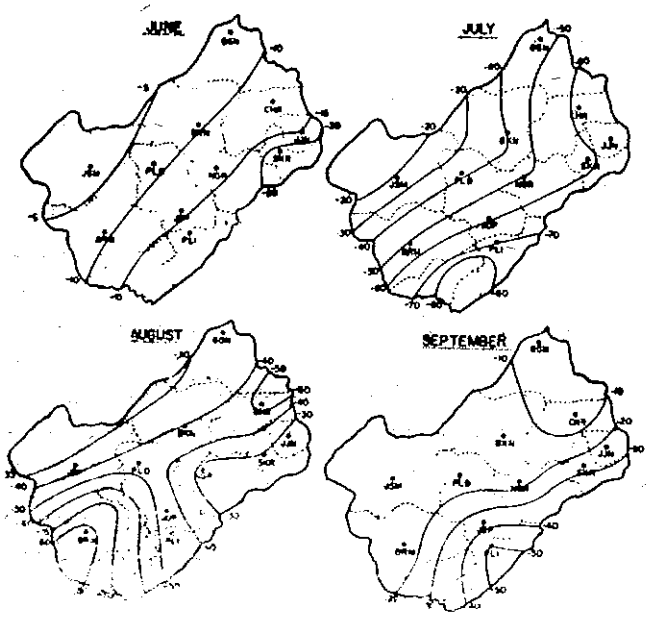

Fig 3. Spread of drought over western Rajasthan during the year 1918

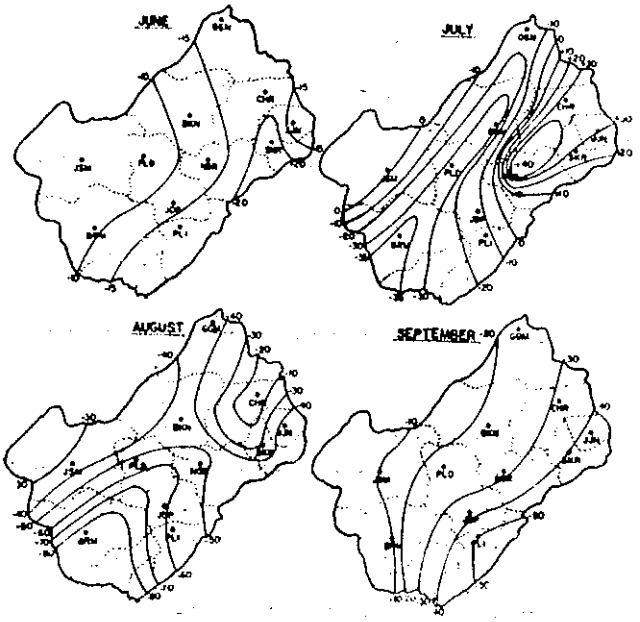

Fig. 4. Spread of drought over western Rajasthan during the year 1968

at these 11 stations (1965-1969) were tested. The analysis revealed that out of the 39 occasions when EA conditions prevailed the methodology enabled the expectation of the EA conditions on 36 occasions thus providing 92 per cent confidence. The expected conditions on the whole occurred in 46 out of 55 occasions indicating 83 per cent confidence.

Apart from such a knowledge on the drought vulnerability of a region, it is of utmost importance to planners, also to know, the pattern of spread of drought in a region. This can enable them to plan timely measures to combat the intensity of drought and to effectively mitigate the drought effect as the regions that are further likely to be affected by drought are known in advance once the drought spell begins. In the Indian arid zone, often some part or the other experiences localised drought. However, in some years the whole region experiences drought conditions. Studies reveal that even in such years the drought intensity and its time of occurrence varied from region to region. To project a pattern of drought spread in the western Rajasthan, two case studies are presented, one pertaining to the extreme arid conditions that prevailed over entire Rajasthan during the earlier part of the century, *i.e.*, 1918 and the other during the later part of the century, *i.e.*, in 1968. Diagrams depicting the spread of drought based on the departures of actual monthly water deficiency from normal values (D) are presented for the four consecutive months, June to September which is the main rainy season in this region (Figs. 3 and 4).

A perusal of these figures clearly indicates that the zone of maximum drought intensity changed both its intensity and location in different months indicating a sequential pattern of drought spread and decay over the region. A critical appraisal of the figures reveal two interesting and very useful features that control the incidence and spread of droughts over western Rajasthan. Firstly it can be seen that droughts have a general tendency to originate in the northeastern region around Churu and Jhunjhunu during July, spread in a southwesterly direction into Barmer region during August and dissipate with an easterly movement into Pali region during September. Secondly the effect of drought is more discernible and occurs early in regions receiving comparatively higher rainfall than in regions of lower rainfall. Similar patterns of drought incidence and spread were observed during the recent droughts of 1979 and 1980 over western Rajasthan (Sastri *et al.* 1981, Sastri & Malakar 1981) which also supports the view that the incidence of drought over western Rajasthan is not a sporadic event but follows a pattern of spread and decay. This type of analysis when combined with the information on the drought vulnerability of a given region provides the necessary confidence for the prediction of drought occurrence and spread over the Indian arid region. Such a combined approach apart from enabling the prediction of drought in advance also identifies the likely regions to be affected by drought in the Indian arid zone so that ameliorative measures can be taken up in time. These techniques can also be applied for other regions to assess their predictive utility and when analysed critically over small periods of time like week or so may prove as a very useful tool in agricultural and hydrological planning to combat the droughts.

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References

Landsberg, H.E., 1974, Drought—Summary of lectures and discussion, Geneva, June 1974. W.M.O. Bulletin XXIII (4), 226.

Linsley Jr, R. K., Kohler, H. A. and Spilhaus, J. L. H., 1959, *Applied Hydrology*, McGraw Hill Co., New York.

Penman, H.L., 1948, Natural evaporation from open water, bare soil and grass, *Proc. Roy. Soc. London*, A **193**, 120-145.

Rama Krishna, Y. S. and Sastri, A.S.R.A.S., 1980, Studies on incidence of droughts over western Rajasthan, *The Nat. Geogr. J. of India*, **26** (1&2), 44-49.

Sastri, A.S.R.A.S. and Malakar, A.R., 1981, Climatological analysis of drought over northwest India during the year 1979, *Mausam*, **32**, 3, pp. 259-262.

Sastri, A.S.R.A.S. and Rama Krishna, Y.S., 1981, Drought during 1979 over western Rajasthan—A climatic perspective, *Ann. Arid Zone*, **21**, 1, pp. 41-47.

Sastri, A.S.R.A.S., Ramana Rao, B.V. and Rama Krishna, Y.S., 1981, Climatic analysis of droughts : A case study for 1980 in western Rajasthan, *EDOJARAS*, Hungary **85**, 3, pp. 143-148.

Subrahmanyam, V.P. and Sastri, C.V.S., 1971, New techniques in drought analysis, *Ann. Arid Zone*, **10**, 120-135.

Thornthwaite, C.W., 1948, An approach towards rational classification of climates, *Geogr. Rev.*, **38** (1), 55-94.

Thornthwaite, C.W. and Mather, J.R., 1955, The water balance, Publ. in Clim. Drexel Inst. Tech. Rep 8(1) : 104 pp.