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Quantification of drought and crop potential

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सार—भारत में वर्षाधीन खेती का क्षेत्र 9 राज्यों के 105 जिलों से मिलकर बना है जहां वर्ष भर में वर्षा 40 से 100 सें० मी० के बीच होती है। इस क्षेत्र में फसलों को सफलतापूर्वक उगाने के लिए वर्षा की नियंत्रक भूमिका है। कम वर्षा वाले वर्षों में फसल को एक खास स्तर तक सुनिश्चित करने के लिए सूखे के वर्षों की बारंबारता की जानकारी होना अति आवश्यक है, जिससे कि युक्ति संगत वैज्ञानिक आधार पर कृषि की योजना तैयार की जा सके। इसके लिए अन्य चीजों के अलावा विभिन्न प्रायिकता स्तरों पर सप्ताह दर सप्ताह की न्यूनतम वर्षा की जानकारी होना भी आवश्यक है। इस शोधपत्र में भारतीय मानसून सीजन के दौरान वर्षाधीन खेती वाले क्षेत्र में 87 स्टेशनों की पूरे सप्ताह की कुल वर्षा को लेकर अपूर्ण गामा बंटन की प्रायिकता निदर्श का उपयोग करके विभिन्न प्रायिकता स्तरों (10 से 90 प्रतिशत तक) पर वर्षा की न्यूनतम मात्रा की गणना की गई है।

वायुमंडलीय मांग के अनुसार पौधों के लिए जल की उपलब्धता के संदर्भ में वर्षा की एक ही मात्रा का प्रभाव अलग-अलग होता है। नमी उपलब्धता सूचकांक, सप्ताह की संभावित वर्षा और अन्तर्निहित वाष्पोत्सर्जन के अनुपात के रूप में ज्ञात किया गया है। फसल को उसकी बढ़वार के विभिन्न चरणों में जल की अलग-अलग मात्रा की आवश्यकता होती है और केवल प्रारंभिक चरण में ही कम से कम एक तिहाई मात्रा की आवश्यकता होती है। संभावित सूखे से प्रभावित क्षेत्रों का पता लगाने के लिए 50% स्तर के नमी उपलब्धता सूचकांक का उपयोग किया गया है। वह अवधि जिसमें नमी उपलब्धता सूचकांक 0.3 से ज्यादा या उसके तुल्य हो, फसल उगाने की अवधि मानी गई है। जब 50% प्रायिकता स्तर से इंगित नमी उपलब्धता सूचकांक 0.3 से कम या उस के तुल्य हो तब उसे सीजन के मध्य की जलीय प्रतिबल अवधि कहते हैं। इसका उपयोग समय और स्थान दोनों के संदर्भ में सूखे की संभावना वाले क्षेत्रों के मानचित्रण के लिए किया गया है। जलीय प्रतिबल अवधियों के अन्तराल के साथ-साथ उनकी संख्या के आधार पर सूखे की भीषणता का वर्गीकरण किया गया है। जहां आवश्यक समझा गया है, वहां अन्य प्रायिकता स्तरों पर भी सूखे की संभावना का विवेचन किया गया है।

वर्षाधीन खेती के क्षेत्र में वर्तमान निकर्ष का उपयोग करके समय और स्थान दोनों के हिसाब से सूखे की संभावना वाले क्षेत्रों का सीमांकन किया गया है। महाराष्ट्र में औरंगाबाद से कर्नाटक में बंगलूर तक के विस्तार वाला सूखे की संभावना के एक क्षेत्र का पता लगाया गया है। उधर गुजरात और पूर्वी राजस्थान में सूखा बार-बार पड़ता है।

ABSTRACT. The dry farming tract in India, where annual rainfall varies from 40 to 100 cm, comprises of 105 districts in nine States. In this tract rainfall is the limiting factor for successful raising of crops. In order to stabilising the crop at certain level even in a low rainfall year, it is essential to know the frequency of drought years so that agricultural planning is drawn up on a rational scientific basis. For the purpose, amongst other things, it is necessary to know the minimum week by week rainfall at different probability levels. In this paper the lowest amount of rainfall at different probability levels (10 to 90%) has been computed by fitting incomplete gamma distribution probability model to weekly rainfall totals of 87 stations in the dry farming tract during the Indian monsoon season.

The same amount of rainfall behaves differently, in terms of water availability to plants depending upon atmospheric demand. Moisture Availability Index (MAI) which is defined as ratio of probabilistic rainfall of a week to potential evapotranspiration has been computed. Crop requires various amount of water at its different growing phases and least one third of potential demand is necessary even in the early stage. Moisture availability index at 50% level has been used to map out drought prone areas. The period when MAI $\geqslant$ 0.3 has been taken as the crop growing period. The mid-season water stress period, *i.e.*, when MAI $\leqslant$ 0.3 has been found out from 50% probability level and this period has been used to map out drought prone area both in time and space. Severity of drought has been classified by the number of water stress periods as well as their durations. Drought proneness has also been discussed at other probability levels whenever necessary.

Applying the present criteria, drought prone area both in time and space in the dry farming tract has been demarcated. A drought prone area is found extending from Aurangabad in Maharashtra to Bangalore in Karnataka. Occurrence of drought is frequent in Gujarat and eastern Rajasthan.

1. Introduction

With the introduction of high yielding varieties and short duration cereal crops, rapid changes are taking place in farming systems and cropping patterns. Of the factors that influence and determine these changes, soil and climate are very important and so considerable effort has been put forth to understand the role and impact of climate on agricultural production.

In tropical countries, rainfall is the limiting factor for successful raising crop especially in the Dry Farming Tract. Extent from the northern most State of Kashmir to the southern most tip of the country (Kanya Kumari), this tract is bounded by the isohyets of 400 and 1000 mm. Here there is a chronic demand for water since the rainfall exceeds evapotranspiration during most of the growing period of crops. The mean temperature during the season is generally greater than 25 deg. C. Dry farming techniques are employed in about 65% of the area and the food production is about 40% of the total for the country as a whole. Rainfall over this tract is characterised by its inadequacy and uncertainty and so partial or complete failure of crops occur quite often leading to condition of acute scarcity. Therefore, the role of climatic elements especially that of rainfall becomes important so that scientific methodology could be developed for evolving suitable techniques for land and water management, development of farming systems and adoption of improved cropping patterns.

2. Review of literature

A preliminary step towards the assessment of the agricultural potential of a region is, perhaps, its division into agroclimatic zones. For this purpose, several methods have been proposed and various criteria have been formulated. The earlier attempts centred round average annual, seasonal or monthly rainfall and/or temperature (Koppen 1936, Prescott 1938, Burgos 1958, Trewartha 1968). Troll (1965) proposed a classification called the seasonal climates of the earth, utilising monthly rainfall and potential evapotranspiration. This method brought out climatic areas in broad terms, but failed to provide detailed and small scale information needed for agricultural purposes. Cocheme and Franquin (1967) used different degrees of monthly ratios of P'/PE where P' is the sum of precipitation and ground storage and PE is the potential evapotranspiration, for classification of climate. Raman and Murthy (1971) tried this for India. The method is not suitable for the purpose since the unit of period chosen is too long, especially in the context of short duration varieties of cereal crops. Moreover, this classification does not contain any risk factor and hence not very useful for agricultural planning. Hargeaves (1974) estimated monthly rainfall at 75% probability level and used ratio of this monthly assured rainfall to the average monthly potential evapotranspiration for classification of the agro-climate of Brazil. He introduced a risk factor employing probabilistic rainfall instead of monthly average. This ratio was designated as Moisture Availability Index (MAI). The importance of the continuity of the period when MAI $\geqslant$ 0.34 was emphasised.

This method also suffers from too long a period chosen for the time unit when applied to cereal crops. Moreover, the value 0.34 has been taken to be the same for all stages of the crop. Therefore, in this study, a methodology has been developed for agroclimatic classificatoin which is based mainly on the moisture availability index of Hargeaves, but with significant modifications.

3. Method

First, the period of the MAI is reduced to a week. Secondly different risk factors are introduced so as to enable the agricultural planner choose his own risk level. Finally it is assumed that a crop will be almost normal if it gets moisture varying from 0.3 to 0.7 of the potential evapotranspiration from germination to the completion of grain formation stage and hence the values of MAI $\geqslant$ 0.3 and $\geqslant$ 0.7 have been used depending upon the growth phase of the crop.

Rainfall distribution in the dry farming tract as well as in the low rainfall areas is generally skew, skewness being more the shorter the period. Therefore, the incomplete gamma distribution is fitted to the weekly rainfall series and the minimum assured rainfall that can be expected at each decile (10 , ... , 90) percent probability levels has been estimated. Moisture Availability Index (MAI) is then calculated. MAI is defined as a ratio of Assured Rainfall (AR) to Potential Evapotranspiration (PE). This definition has been used by Hargreaves (1974) and many other scientists to determine crop growing period. It has been observed that the MAI for many weeks and at most of the stations is 1.0 or more for 40% level of probability while it is very small or zero for 70% level. Therefore, it is felt that the use of these probabilities may lead to results that may not be realistic. The MAI's at 50% and 60% levels of probability show that all these give more or less same gradation. Moreover, 40% is considered to be too low for agricultural planning and at 60% level of probability the duration of the MAI's at 0.7 value becomes too small. Thus 50% probability satisfies the criterion of MAI values of 0.3 for early and 0.7 for subsequent stages of crop growth. The MAI obtained by using assured rainfall at 50% probability level is used as the bases for classification. MAI's obtained by using rainfall amounts at other levels of probability are also calculated and utilised for discussion, but not presented here. Based on the MAI's for the weeks 23 to 42 (4 June to 21 October), the dry farming tract of India has been classified into broad agroclimatic zones as given below:

Classification	No. of weeks	
	MAI at 0.3	*MAI at* 0.7
D	<10	<1
E	⩾10	⩾1
F	⩾11	⩾4
G	⩾14	⩾7

3.1. *Sub-divisions based on water stress period*

The mid-monsoon season water stress(*i.e.*, when MAI is less than 0.3) has been designated by the use of numerical suffixes in the ascending order of magnitude of the duration, to the above classification. Suffix 1 indicated that there is hardly one week's water stress while 2, 3 and 4 indicate 2 to 3 weeks', 4 to 5 weeks' and more than 5 weeks' water stress respectively.

TABLE 1

MAI, PE (mm) and accumulated assured rainfall (AAR) in mm

Stations	40% probability level: No. of weeks MAI ⩾.3	⩾.5	⩾.7	⩾.9	PE	AAR	50% probability level: No. of weeks MAI ⩾.3	⩾.5	⩾.7	⩾.9	PE	AAR	70% probability level: No. of weeks MAI ⩾.3	⩾.5	⩾.7	⩾.9	PE	AAR
1. Jullunder	12	10	9	8	415	395	10	8	5	4	341	254	5	3	0	0	174	77
2. Jind	11	9	8	3	415	296	8	6	1	0	290	156	0	0	0	0	0	0
3. Tonk	13	10	9	9	415	473	9	9	8	8	253	288	6	1	0	0	186	73
4. Banswara	15	14	13	13	393	725	14	12	11	10	353	484	9	9	7	3	214	171
5. Datia	14	13	13	11	435	641	13	12	11	10	392	484	9	6	6	3	265	199
6. Ujjain	15	15	14	12	440	679	15	13	11	10	440	466	9	7	4	1	236	146
7. Dhranga-dhra	11	8	5	3	392	268	6	4	1	0	189	120	0	0	0	0	0	0
8. Ahmeda-bad	14	12	11	11	436	531	12	11	10	5	363	330	9	2	0	0	274	98
9. Deesa	11	10	9	6	352	329	10	8	3	2	277	181	1	0	0	0	29	9
10. Patan	12	11	9	6	399	386	10	6	6	5	311	221	3	1	0	0	101	34
11. Bhuj	6	2	0	0	232	92	0	0	0	0	0	0	0	0	0	0	0	0
12. Jalgaon	16	14	12	11	562	528	14	11	9	6	476	401	9	6	1	0	307	170
13. Solapur	18	17	9	4	605	465	17	7	4	2	573	309	2	0	0	0	59	23
14. Ahmed-nagar	19	14	7	4	491	387	15	7	2	1	410	214	1	0	0	0	27	11
15. Dhond	13	3	2	2	416	241	5	2	2	2	183	84	1	0	0	0	28	9
16. Anantpur	17	5	4	3	629	217	5	4	2	0	156	87	0	0	0	0	0	0
17. Bijapur	17	8	4	2	630	332	7	4	2	2	212	124	2	1	0	0	57	26
18. Chitradurg	21	17	6	4	762	441	19	8	4	1	549	251	3	0	0	0	81	24
19. Coimba-tore	18	9	6	5	523	337	7	7	5	4	184	151	4	1	0	0	103	43
20. Kovilpatti	16	12	8	8	989	398	12	8	5	5	366	247	5	3	1	1	146	75

3.2. *End of growing season*

Crop season may extend beyond the rainy season since crops can survive on stored moisture which can be estimated by water balance technique. Replay (1966) and Jenson (1968) observed that in many farm crops seasonal water used may range from 60% to 70% of PE. Venkataraman *et al.* (1976), from a study of the lysimetric data obtained from 35 stations representing various soil and climatic zones of the country, found that the cumulative seasonal evaporation is about 70% of the potential evapotranspiration. Therefore, it is assumed in this study that a difference between the total assured rainfall for the rainy season and two-thirds of the potential evapotranspiration of the same period will give the stored moisture which is available to the plants even after the rainy season.

Severity of drought proneness has been identified according to the duration of stress period. If the duration of the break in MAI ⩾ 0.3 is upto one week the drought is considered as mild, 2 to 3 weeks moderate and 4 to 5 weeks severe and more than 5 weeks chronic.

4. Application and discussion

Sarker *et al.* (1982) computed the minimum assured rainfall at various probability levels for one station from each of the 87 districts of the dry farming tract of India. PE values are obtained by interpolating both in space and time from the monthly average values worked out by Rao *et al.* (1971). MAI, PE and AAR at 50% level for some selected stations are given in Table 1. Duration of mid-season stress has also been indicated by adding the suffixes 1, 2 ....to the capital letters D, E etc. Applying the foregoing theory

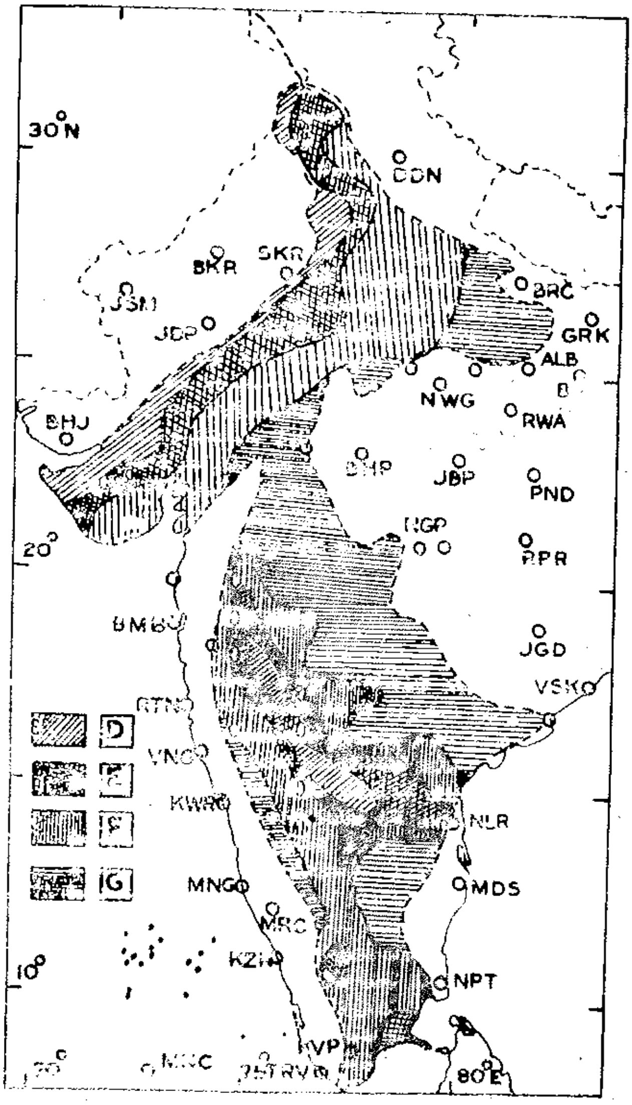

Fig. 1. Agroclimatic classification (dry farming tract of India)

of agro-climatic classification to the dry farming tract of India, the area has been divided into four agro-climatic zone — D, E, F and G and these are depicted in Fig. 1.

4.1. *Crop potential zones*

Area D —Areas in which the number of weeks with MAI $\geqslant$ 0.3 is less than 10 and values $\geqslant$ 0.7 is less than 1 are designated as D. From Fig. 1 it can be seen that this area occurs in three places in the tract. The first part extends from the Jamnagar district of Gujarat to Ferozepur in Punjab. The second lies in parts of Maharashtra and third in Karnataka. This area is having lowest crop potential in the tract.

There may be a break of MAI of 1 week duration and in many cases it may be 4 to 5 weeks. AAR is of the order of 80 to 100 mm in the western part in the tract in Gujarat and 200 to 250 mm in Punjab (Table 1) at 50% level. In this zone crop production is highly speculative when irrigation facilities are not available. But in some parts of this zone where AAR is of the order of 200 to 250 mm and there is no break in MAI, short duration crops could be raised.

At 40% level AAR is about 220 to 250 mm as in some parts of Gujarat, Maharashtra and Karnataka. There is a possibility of raising short duration crop in 40% of the years.

At 30% level the AAR is of the order of 500 mm at some of the stations and the crop prospect is high.

As rainfall is the limiting factor, there is little scope for commercial crops in this zone. But in the areas where break in MAI is more than two weeks, pasture development and cattle rearing could be recommended.

Area E — This area extends from Gujarat to Punjab along the eastern side of the area D there. A second part is seen extending from the Ahmednagar district through the southern districts of Maharashtra and part of Karnataka to the coastal area of Andhra Pradesh. The AAR is of the order of 350 to 375 mm with the duration of MAI at more than 0.3 from 10-13 weeks and more than 0.7 from 1 to 5 weeks. Therefore, crop potential is not very high in this zone.

At 40% level many stations receive about 460 mm of rain and so some soil moisture may be available at the end of rainy season. A medium to long duration crop could be raised as this can thrive on stored moisture for a few weeks even after the rainy season.

Area F — This area occurs at two places in the tract, the northern part comprises of vast areas of Gujarat, Rajasthan, Uttar Pradesh and a small portion of Haryana and Punjab. The southern part spreads from the Nasik district of Maharashtra to the southern tip of the country in Tamil Nadu, occupying quite a large area of Karnataka and Andhra Pradesh. The assured rainfall at 50% level is about 230-450 mm and there is hardly any break in MAI in southern Maharashtra and parts of Rajasthan. Therefore, there is a good prospect of raising a medium duration of crops once in two years.

Area G — This area falls on parts of Uttar Pradesh, Madhya Pradesh, Gujarat and Tamil Nadu and on considerable areas of Maharashtra and Andhra Pradesh.

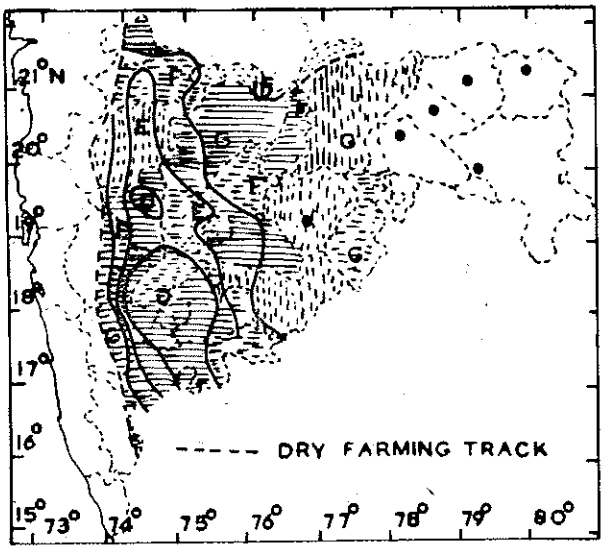

Fig. 2. Agroclimatic classification of Maharashtra

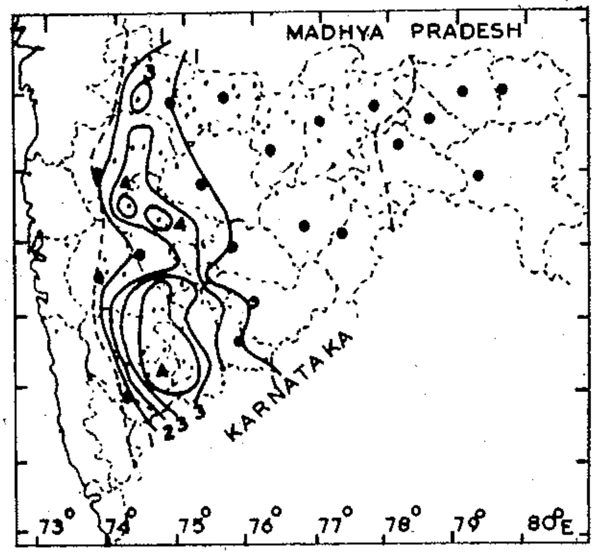

Fig. 3. Agroclimatic zones of Maharashtra sub-divided by super-imposition of soil characteristics

The area in Tamil Nadu gets rain during the northeast monsoon and so the growing season is different from rest of the region.

The duration of the MAI $\geqslant$ 0.3 ranges from 14 to 19 weeks and from 7 to 13 weeks when the value is $\geqslant$ 0.7. The AAR ranges from 330 to 480 mm. Also some stored moisture will be available at some of the stations. Hence, this area has the highest crop potential and a crop 13-18 weeks duration can be raised once in two years.

Crop prospects are very high at 30% level as the AAR ranges from 460 to 850 mm and so two short duration crops or a mixed crop could be raised.

4.2. *Application to Maharashtra*

The theory developed above was applied to the dry farming areas of Maharashtra taking Talukwise stations numbering 84 and agroclimatic zones D, E, F and G are demarcated and shown in Fig. 2. Within the same agroclimatic zone, the soil characteristic can vary significantly which may determine the cropping pattern there. Therefore, information on soil types are superimposed on the map.

Based on the duration of water stress when MAI $\geqslant$ 0.3 the area could be demarcated into those of varying degrees of drought. This is not reflected in Fig. 1, but a micro analysis of this region brings out clearly the pockets of severe drought-proneness. In Maharashtra this area comprises of six Talukas (Fig. 3), *viz.*, Dhond, Baramathi, Indapur, Malsiras and parts of Karmala and Dahiwadi.

5. Conclusion

The proposed agroclimatic classification based on Moisture Availability Index (MAI) incorporates certain significant modifications of the earlier ones by reducing the period to a week and also by including risk factors. This has been found adequate to demarcate agroclimatic zones of various crop potentials in the dry farming tract of India. The degree of success of raising crops in these zones could be ascertained, as for instance in the zone D which is of the lowest crop potential, any attempt to raise crops will be highly risky. This classification also helps us to determine the time of irrigation to get optimum yield.

The zoning is helpful to choose a type of cropping pattern that would increase or stabilize the yield, especially in the climatically vulnerable areas.

The degree of drought-proneness of areas could be established by considering the duration of water stress when MAI $\geqslant$ 0.3. Thus in the dry farming tract of Maharashtra the core of drought-prone area could be identified.

The agroclimatic zones in Maharashtra have been further subdivided by the super-imposition of soil characteristics (Fig. 3) which clearly brings out crop potential.

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