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A statistical study on incidence of drought in relation to agricultural production

PREM NARAIN, P. N. BHARGAVA and ASHA SAKSENA
Indian Agricultural Statistics Research Institute, New Delhi

सार — भारत का लगभग 75 प्रतिशत कृषि क्षेत्र वर्षा से सींचा जाता है। चूंकि हमारे खाद्य-उत्पादन का 42 प्रतिशत इन्हीं क्षेत्रों से प्राप्त होता है, अत: वर्षा के वितरण और मात्रा पर निर्भरता के कारण खाद्य उत्पादन में पर्याप्त अन्तर रहता है। कई राज्यों में ऐसे अर्द्ध शुष्क क्षेत्र पाये जाते हैं जहां वार्षिक अन्तर्निहित वाष्पोत्सर्जन औसत वार्षिक वर्षा से अधिक होता है। ऐसे क्षेत्रों में फसल का भविष्य अधिकतर मौसम के मिज़ाज पर निर्भर है। इन 2 क्षेत्रों में कुल वार्षिक वर्षा आमतौर पर 75 सें०मी० से भी कम होती है और वर्षा ऋतु में भी यहां कई बार लम्बे समय तक बिल्कुल वर्षा नहीं होती। तब ऐसे मौसम में वर्षा का वितरण उसकी मात्रा से अधिक महत्व का होता है। जल की वाष्पोत्सर्जन, अपवाह तथा गहन निकासी के रूप में होने वाली क्षति पैदावार के मौसम में वाष्पोत्सर्जन-जनित मांग उत्पन्न करती है, दूसरी ओर मिट्टी की आर्द्रता, भण्डार गुण और वर्षा की मात्रा आर्द्रता-पूर्ति सुनिश्चित करती है। इसलिये मिट्टी द्वारा आर्द्रता की प्राप्ति और उसकी क्षति के बीच प्रगामी संतुलन ही वह चीज है, जो फसल कृषि उत्पादन के लिए अनुकूल अथवा प्रतिकूल परिस्थितियां निर्मित करती है। इस प्रकार कोई व्यक्ति वर्षा-वितरण और अन्तर्निहित वाष्पोत्सर्जन मानों की सहायता से किसी क्षेत्र में फसल की किसी खास किस्म के सम्बन्ध मे एक विशेष अवधि के लिये सूखे की स्थितियों का निर्धारण कर सकता है।

इस आधार पर अनेक अनुसंधानकर्ताओं ने सूखे के विभिन्न पहलुओं का अध्ययन करने का प्रयास किया है। सूखे का निर्धारण और उसके पूर्वानुमान संबंधी उनके अध्ययन अधिकतर सूखे की घटनाओं, जल-उपलब्धता की अवधियों, सूखे के मानचित्र बनाने, पामर सूचकांक तथा स्पैक्ट्रम विश्लेषण पर आधारित रहे हैं। कृषि से संबंधित सूखे के निर्धारण के समय कृषि उत्पादन की मात्रा पर इन अध्ययनों मे विचार नहीं किया गया है।

इसलिये इस लेख में पश्चिमी भारत के एक निश्चित, अर्द्ध शुष्क क्षेत्र के लिये कृषि संबंधी सूखे की विशेषताएं और उसकी तीव्रता बताने के लिये वर्षा के आंकड़ों और ज्वार जैसी फसल के उत्पादन का विश्लेषण किया गया है। ज्वार के संबंध में सूखे की पुनरावृत्ति का भी अध्ययन किया गया है।

ABSTRACT. In India about 75 per cent of the cultivated area is rainfed and since about 42 per cent of our food comes from such areas, there is considerable variation in food production depending upon the amount and distribution of rainfall. Semi-arid areas where the annual potential evapotranspiration exceeds the mean annual rainfall exist in several of our States. In such areas crop fortune depends very much on vagaries of weather. The annual rainfall in these areas is usually less than 75 cm and there occurs sometimes prolonged dry spells within the rainy season. It is then the distribution of rainfall during a season more important than its amount. While the rainfall, coupled with the moisture storage property of soils ensure the moisture supply, the water loss taking place in the form of evapotranspiration, runoff and deep drainage places an evapotranspirative demand during the growing season. It is, therefore, the progressive balance between the receipt and expenditure of the moisture in the soil which creates favourable or unfavourable conditions for successful crop production. One can, thus, with the help of rainfall distribution and potential evapotranspiration values determine conditions for drought for a specific period in relation to a given variety of crop in the region.

Several research workers have attempted to study the various aspects of drought on this basis. Their studies mostly relate to occurrence of dry spells, water availability periods, drought mapping, Palmer indexing and spectrum analysis for assessing and forecasting of drought. These studies have not taken into account the crop yields in determining the agricultural drought.

In the present paper, therefore, data on rainfall and yield of a crop like jowar have been analysed for certain, semi-arid areas of western India for characterising the agricultural drought and its intensity. The recurrence of drought in relation of jowar has also been studied.

1. Introduction

In India, about 75% of the sown area is dependent on rainfall for cultivation. More than 40% of food production and the raw materials like cotton and oilseeds come from these areas. The amount and distribution of rainfall in these areas make the country surplus or deficit in regard to agricultural production. Bulk of such areas, mostly falling in the semi-arid tropics, is characterised by an annual rainfall of less than 750 mm, long dry spell, short rainy season and

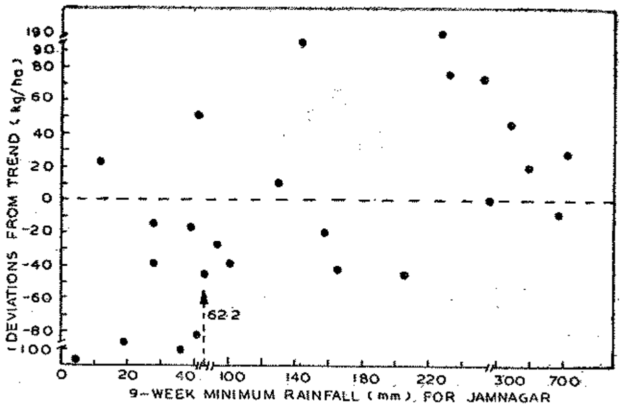

Fig. 1. Data observed in determining threshold value for 9-week rainfall total for Jamnagar

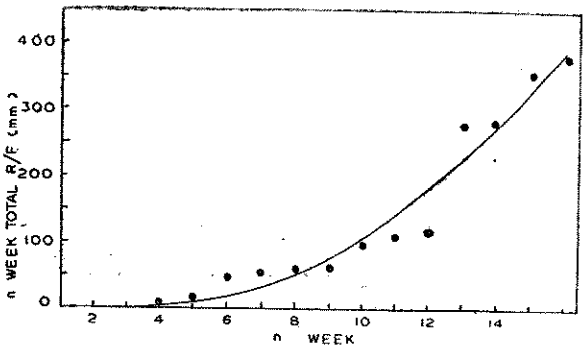

Fig. 2. Drought base line fitted to threshold values for Surendra Nagar

high rate of evapotranspiration. The occurrence of inadequate rainfall and the resulting drought at a particular place and time in relation to a given crop is, however, beset with uncertainty. One has, therefore, to use probability concepts and statistical methods for understanding the behaviour of agricultural drought.

It is known that an agricultural drought is caused mainly by the rainfall deficiency spread over a long duration during the crop season. The intensity of drought is, however, related to the length of duration during which the total rainfall is deficient in relation to that required by the crop for its growth. In the past, a number of studies were conducted at the IASRI, New Delhi by examining the data on potential evapotranspiration and rainfall in relation to crop yields for determining the expected number and length of dry spells and the probabilities of occurrence of rainfall as well as the recurrence of deficiency in soil moisture (Bhargava *et al.* 1973, 1974, 1977; Narain *et al.* 1979; Saxena *et al.* 1979). However, very little attention was paid to study the effect of varying duration of drought on crop production. Barger and Thom (1949) developed a method for characterizing drought intensity of varying durations for six Iowa countries in USA. In the present paper, an attempt has been made to use this method for obtaining the minimum rainfall amounts for jowar crop for different durations below which a drought is said to exist in respect of three districts falling in arid and semi-arid regions of western India. The relative occurrence of drought for these areas has also been discussed.

2. Extent of data and its processing for analysis

For the purpose of the study, three districts, namely, Jamnagar & Surendra Nagar each located in Gujarat State and Jalgaon in Maharashtra State were selected. These districts fall in the arid and semi-arid regions of the country. An important crop of this region is jowar (*Andropogon Sorghum*). The yield of this crop is affected, besides rainfall, by other climatic factors such as temperature, humidity, as well as chemical and physical properties of the soil etc. All these are reflected in the final yield and, therefore, the characterization of drought includes all such influences which are accompanied by spells of low rainfall. The weekly rainfall data as well as the yield for jowar crop used in this study related to different number of years as shown in Table 1.

It is observed from Table 1 that there was a sufficient length of records available in respect of Jalgaon and Jamnagar whereas for Surendra Nagar, a continuous length of records for yield and rainfall were available only for 14 years. The daily rainfall records were obtained from India Meteorological Department, Pune whereas yield records pertaining to kharif season were extracted from Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi.

As a first step to carry out the analysis of the data, the contribution due to trend in yield was removed by fitting a simple linear regression by the method of least squares. It was found that there was no trend in case of Jalgaon and Surendra Nagar but a trend was noted in Jamnagar and, therefore, the yield data

TABLE 1

Extent of data

District	Lat. (°N)	Long. (°E)	Years of record rainfall	yield	both	Soil series
Jamnagar (Gujarat)	22°29′	70°04′	1901-75 (75 yr)	1950-78 (29 yr)	26 yr	Medium black, coastal alluvium
Surendra Nagar (Gujarat)	22°59′	71°28′	1901-69 (69 yr)	1956-78 (23 yr)	14 yr	Sandy and medium black
Jalgaon (Maharashtra)	21°03′	75°34′	1946-77 (32 yr)	1950-78 (29 yr)	28 yr	Medium to deep black

TABLE 2

Standard climatological weeks

Week No.	Dates included	Week No.	Dates included
25	18-24 June	33	13-19 Aug
26	25 June -1 July	34	20-26 Aug
27	2-8 July	35	26 Aug. -2 Sept
28	9-15 July	36	3-9 Sept
29	16-22 July	37	10-16 Sept
30	23-29 July	38	17-23 Sept
31	30 July - 5 Aug	39	24-30 Sept
32	6-12 Aug	40	1-7 Oct

was adjusted for trend values for this district. The term drought used in this study relates to one or more week period (within the crop season) during which the total rainfall is deficient for normal crop yield. For this purpose, it is important to define the period for which the deficiency in rainfall would affect the crop production. The entire crop season extending from mid-June to early October was considered as the period of study. Though there were some differences in the crop season of different districts, by and large, the period suggested above coincides with the crop growth period in general. Another reason for taking the entire period for study was that there is no information available on the portion of the crop season during which the crop is most affected by drought. It was, therefore, considered worthwhile to examine a relatively longer period. To facilitate the identification and comparison, a standard climatological week system was adopted in tabulating the n-week rainfall totals, *i.e.,* from 25th to 40th standard week. These standard weeks are shown in Table 2.

Based on agronomic conditions, it was assumed that the earliest date on which a drought for the crop could begin would be 25th standard week (18-24 June), whereas all droughts must end with the last date of the 40th standard week (1-7 Oct). Also, a drought could begin no later than 17 through 23 Sep (week 38). Thus the maximum duration could be 16 weeks and minimum duration could be 3 weeks. The rainfall for each standard m-th week with $25 \leqslant m \leqslant 40$ were prepared. From these weekly rainfall, n-week rainfall totals for $1 \leqslant n \leqslant 16$ beginning during the m-th week were tabulated for each year in each district. These totals give the total amount of rainfall received during any given number of consecutive weeks beginning during the crop growing season. Corresponding to each n, the smallest n-week total from amongst those relating to different values of m was obtained for each year. For instance, if $n=9$, we would have 8 rainfall totals for $m=25$ to 32 from which the minimum could be chosen for each year. Such minimum values for $n = 1$ to 16 for each year give the driest periods for that year. These periods begin and end during the jowar growing season but do not include the same standard weeks from year to year. Only the duration remains the same but not the dates of beginning and ending.

3. Drought thresholds

For determining the drought threshold, *i.e.,* the minimum amount of rainfall below which a drought may exist, the yield adjusted for trend, if any, was plotted against the minimum rainfall values for the corresponding week for each year as in Fig. 1 with $n=9$ for Jamnagar. Each point in Fig. 1 represents one year. It may be seen that only two years out of ten years having a minimum 9-week rainfall of less than or equal to 62 mm have yields with a positive deviation from the trend. When the rainfall amount is greater than 62 mm, 9 years have positive yield deviations and 6 years have negative yield deviations. The point beyond which increasing rainfall becomes relatively ineffective in determining yield should be such that at least half of the yields are above the trend line. Thus, 62 mm can be taken as the threshold value below which drought existed. This criterion is, therefore, adopted for fixing the threshold value of drought, *i.e.*, that amount of n-week rainfall total beyond which progressively at least half of the points lie above the line with normal yield and preceding which either none or very few years have yields above the line. In this manner, the drought threshold for all n, *i.e.*, the minimum required rainfall amount of n-week duration were determined for each district. These amounts of rainfall below which a drought is said to exist are given in Table 3.

4. Drought base regressions

It is apparent from Table 3 that drought thresholds increase with n. This relationship is shown in Fig. 2 for Surendra Nagar district. It appears to be of a parabolic type of relation as revealed by the goodness of fit of the curve. The parabolic trends were, therefore, fitted for all the districts. The fitted equations along with R^2 values are given in Table 4.

It is to be noted that the value of R^2 in each case is very high. The coefficients of X^2 were also significant indicating a good fit to the observed values. From these fitted regression lines for each district and corresponding to each value of n the rainfall values were read which provide the estimates of 'drought base values'. These amounts are further shown in Table 3.

The amount of deficit in rainfall for n-week from the base value would constitute a measure of drought intensity with n-week duration. If the n-week rainfall is higher than the base value corresponding to n, the rainfall is not considered as deficient. It is quite likely that a number of deficits, each for different duration, may be recorded during a dry year. Shorter periods would often be contained within longer periods of droughts. The greatest single deficit, regardless of the duration involved, is taken to be the measure of drought intensity for that season.

5. Correlation of rainfall deficit with jowar yield

In order to test the accuracy of the drought base values in depressing the crop yields for each district, the correlations between the maximum rainfall deficiency and the yield/deviation of yield from trends, as the case may be, for each year were worked out. These correlations were compared with the corresponding correlations worked out by including the years in which no rainfall deficit was noticed. The results are given in Table 5.

TABLE 3

'n' week drought threshold and base value in mm at various districts

n	Jalgaon		Jamnagar		Surendra Nagar	
	Threshold	Base	Threshold	Base	Threshold	Base
1	0	—	0	—	0	—
2	2	—	0	—	0	—
3	18	20	7	3	0	1
4	32	45	12	6	6	1
5	62	71	13	11	15	7
6	76	100	26	19	47	17
7	108	130	37	31	54	32
8	149	162	43	44	59	52
9	181	196	62	61	63	77
10	266	231	62	81	99	108
11	285	269	79	103	110	143
12	352	308	124	128	118	183
13	358	349	191	156	278	228
14	399	391	200	187	283	278
15	420	435	212	220	356	333
16	458	482	251	257	384	392

TABLE 4

Parabolic equations fitted to drought threshold data

Station	Parabolic equation	Values of R^2
Jamnagar	$Y=11.55-7.08X+1.40X^2$	0.97
Surendra Nagar	$Y=29.52-16.98X+2.48X^2$	0.95
Jalgaon	$Y=-44.07+18.65X+0.89X^2$	0.98

TABLE 5

Coefficients of correlation of maximum rainfall deficits with yield deviations

District	All years	Drought years
Jamnagar	−0.57*	−0.68*
Surendra Nagar	−0.62*	−0.83*
Jalgaon	−0.23	−0.31

*Significant at 5%

TABLE 6

Probability of the occurrence of droughts of nine week duration

District	m		
	25	28	31
Jamnagar	0.08	0.12	0.19
Surendra Nagar	0.06	0.09	0.22
Jalgaon	0.01	0.02	0.06

It is noted from the table that the correlation coefficients are high and also significant at 5% level in two out of three cases. In the case of Jalgaon, the poor correlations suggest prominent influences of factors other than the rainfall. In each of the three cases, the correlations are increased by omitting the years for which no deficit was noticed. The variation in yield explained by drought deficits ranges from 40 to 70%. Such a high variability in yield attributable to rainfall deficiency suggests that the drought base values obtained for different durations can be used with sufficient accuracy for evaluating the intensity of agricultural drought in the region.

6. Probability of the occurrence of drought

The drought base values obtained in Section 4 give estimates of the minimum amount of rainfall required for crop growth during a given number of consecutive weeks in a particular district. As such, corresponding to each value of r, the observed rainfall total in a given year, if found below the corresponding drought base value, will indicate the existence of a drought. The relative frequency of such cases when determined over a long period of time would, therefore, provide an estimate of the probability of the occurrence of drought. Since the period of n-weeks can begin with any week m where $25 \leqslant m \leqslant 40$, such probabilities for droughts of varying durations can be computed for each value of m during the crop season. For the sake of illustration, however, we have determined values for the case when $n=9$ and $m=25$, 28 and 31. The results are presented in Table 6. For computing these probabilities, data of rainfall of 75 years, 69 years and 32 years respectively for Jamnagar, Surendra Nagar and Jalgaon were considered.

It is observed from this table that in the case of Jalgaon, the probabilities are very small, there being hardly any drought. This should otherwise be expected since for this district the correlation between rainfall deficit and the yield of crop was found to be very poor as well as insignificant. In the case of Jamnagar and Surendra Nagar, the probabilities vary between 0.06 & 0.22. The probability consistently increases as m increases from 25 to 31. The relatively high value of the probability for $m=31$ as compared to those for other values of m indicate that a drought of 9-week duration is expected to occur more frequently during August to September of the season. One can, therefore, say that the drought of 9-week duration during the period early August to September end is expected to occur once in 5 years in the case of Jamnagar and once in 4 years in the case of Surendra Nagar.

7. Summary

In India about 75% of the total cultivated area is under rainfed and the occurrence of drought is also more or less quite frequent in most of these areas. The assessment of drought is, therefore, of great significance for crop planning. In the past, no attempt seems to have been made to assess drought hazards in dryland areas. In the present paper, therefore, an attempt has been made to characterize the drought in three districts falling in arid and semi-arid regions in western India in relation to jowar crop. For this purpose, the estimates of the minimum amount of rainfall which is just sufficient for crop growth during a given number of consecutive weeks were worked out. The occurrence of rainfall below these drought base values gives rise to drought conditions. These values were subsequently used to determine the probability estimates of the occurrence of drought of varying durations. It is observed that in Jamnagar and Surendra Nagar, the occurrence of drought of 9-week duration during early August and end of September is relatively more frequent and is expected to occur once in five and four years respectively.

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