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An effective method of identification of drought in kharif season

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सार – भारत के वर्षाधीन खेती वाले क्षेत्रों में सूखे की घटनाएं प्रायः देखने को मिलती हैं। प्रस्तुत शोध–पत्र में छः स्थानों नामतः दिल्ली, जयपुर, अहमदाबाद, जलगाँव, अहमदनगर एवं अनंतपुर में दशमक पद्धति का प्रयोग किया गया है। इस कार्य के लिए खरीफ के मौसम की अवधि के 80 वर्षों (1901–80) की वर्षा के साप्ताहिक आँकड़ों का उपयोग किया गया है, अर्थात् फसल के विकसित होने के मौसम में वर्षा की अवधि जून से लेकर अक्तूबर के आरंभ तक बढ़ जाती है। कृषि, मौसम तथा जल वैज्ञानिक सूखों का पता लगाने के लिए तीसरे, पाँचवें और सातवें दशमक के तीन वर्गों का उपयोग किया गया है।

यह पता चला है कि दशमक पद्धति फसल के विकसित होने के दौरान वर्षा की घटना की संभावना को उत्तरोतर सशक्त बनाती है। मौसम के शेष भाग के लिए ऊपर बताए गए दशमक अथवा संभाव्यता के तीन स्तरों के साथ साप्ताहिक वर्षा के आँकड़ों को संयोजित करते हुए प्राप्त किया जा सकता है। फसल के संवर्द्धन के दौरान वर्षा के आकलनों के समूह भी मिलते हैं।

यह पद्धति 1981–96 के वर्षों की वर्षा के लिए स्वतंत्र आँकड़ा समूहों पर प्रयुक्त की गई है। सूखे के प्रकारों की स्पष्ट रूप से जाँच की गई है। कृषि संबंधी सूखा (जैसे कि अनंतपुर) के अतिसंवेदनशील क्षेत्रों की जाँच की जा सकती है।

ABSTRACT. Dry farming regions (DFRs) in India often witness incidences of drought. In the present study decile method has been applied to six stations *viz.* Delhi, Jaipur, Ahmedabad, Jalgaon, Ahmednagar and Anantapur. For this purpose weekly rainfall data for 80 years (1901-80) have been used, for the kharif period *i.e.* rainy crop growing season extending from June to early October. Three decile ranges *i.e.* 3rd, 5th and 7th have been used to identify agricultural, meteorological and hydrological droughts. The commencement of sowing operations and duration of agricultural season have also been determined and discussed.

The decile approach, it is suggested, enables progressive update of the probability of occurrence of rains during the crop growing season. This can be achieved by adding, weekly rainfall separately to the above deciles or three probability levels for remaining part of season. It gives sets of estimates of rainfall during the growing season.

The methodology was applied on the independent data set of rainfall for the years 1981-96. The types of droughts have been clearly identified. Most vulnerable areas of agricultural drought (like Anantapur) could be identified.

Key words – Commencement, Prognostication, Probability, Decile, Dry farming, Droughts, Kharif crops.

1. Introduction

Dry farming regions (DFRs) are defined as areas receiving annual rainfall between 40 & 100 cm. These are generally located in arid and dry sub-humid semi-arid eco-regions. These cover a large area of the country having low agricultural potential. The main reason for agriculture being a risky enterprise in this region is that it often faces frequent incidences of drought. Drought a phenomenon resulting from prolonged crop moisture stress is primarily a result of lack of average expected rainfall. Droughts are accompanied with high rates of evaporation; these cause a marked depletion of water bodies, a lowering of ground water table and a concurrent dehydration of the root zone of the soil, thus limiting potential moisture supply to crop plants. Among the various types of droughts *viz.*, meteorological, hydrological and agricultural; the agricultural droughts are most important, since these affect practically all sections of society and cause large scale suffering and distress. As agricultural production in

DFRs of India is mainly dependent upon monsoon rainfall, the occurrence of any drought in this zone results in large scale shortfall in agricultural output. Impact of drought cannot be totally eliminated but it can be minimized by a prediction of its likely occurrence through analyses of past rainfall records. Various prognostic approaches have been widely used by many research workers for drought prediction. (Palmer 1965, Bhalme *et al*., 1990, Parthasarthy *et al*. 1992).

Gibbs and Maher (1967) recognised that common statistical measures such as 'arithmetic mean', 'average' and 'normal' are often poor indicators of the occurrence of rainfall. They surmised that same rainfall amounts are not normally distributed, it could best be described by quoting the limits of certain proportion of the occurrences. The method they proposed is based on limits of each of 10 percent (or decile) of the ordered distribution of rainfall. The specific decile range within which an individual total rainfalls, provides a useful indication of its departure from average. Decile method of prognostication of drought (French 1987) in DFRs can prove to be best suited when terms such as below or above average etc. fail to explain the phenomenon.

In this paper an attempt has been made to explore use of the decile method in mapping agricultural, meteorological and hydrological drought in DFRs of India while an emphasis has been laid on agricultural droughts. Potential of this approach as a tool to monitor and forecast rainfall amount in specific interval will also be evaluated. A preliminary study of agricultural droughts based on deciles in India was earlier made by George and Kalyansundaram (1969) for the Bihar state of India.

2. Data and method of analysis

In this study 80 years (1901-80) rainfall data of 6 stations in the DFR of India *viz*. New Delhi, Jaipur, Ahmedabad, Jalgaon, Ahmednagar and Anantpur were used. The annual rainfall at these places ranges between 40 and l00 cm with most of the rain occurring in the monsoon season (June-September). This period coincides with the major period of growth and development of kharif crops in India which occurs between 23^{rd} (4^{th} - 10^{th} Jun) and 42^{nd} (15^{th} - 21^{st} Oct) meteorological weeks (MW). Rainfall recorded during this period have been considered for this analysis. The decile values have been determined for each MW for all the 6 stations. Previous studies on drought were mostly based on monthly or seasonal data (Sarker *et al*. 1982, Das 1987, Das and Chowdhury 1992 etc.). As a month is too long period to study for agricultural drought weekly rainfall data have been used in this study.

A study on agricultural droughts must take into account successful rate of sowing or transplanting of crops. This will determine the eventual growth of crops *i.e*. period from establishment to maturity/harvest. Critical growth periods needing rainfall for dependable yields is critically related to crop sowing and establishment. In the study reported here, estimates of ideal sowing week have been selected based on the week receiving 25% more rainfall than the previous week, provided the amount received is equal to or greater than 10 mm. This has been noted for each of the years (from 1901 to 1980) and an average week of sowing has been determined for all the stations. After locating the week of sowing, agricultural drought events in the growing season have been defined when: rainfall received in the consecutive two or more weeks is below 3^{rd} decile range provided the first week of this sequence received rainfall $\leq$ 25 mm, further when the rainfall recorded in this week exceeded the amount (25 mm), the first week following this week in which rainfall is in the 3^{rd} decile is ignored and the dry weeks are counted from the next week onwards.

The meteorological droughts have been defined when the seasonal rainfall total during kharif in a particular year is less than 5^{th} decile or when 50% or more weeks during this season received a rainfall amount less than the 5^{th} decile.

The hydrological droughts are defined: when the seasonal rainfall in a particular year lies in 7^{th} or lower decile range.

The decile method used in this study enables to progressively update the probability of rains with the progress of the crop growing period. Thus, in this prediction technique, within the crop growth cycle, need of water and amount of rainfall can be determined at any desired probability level. The growing season lying between the 23^{rd} to 42^{nd} standard weeks has been divided into five periods, designated as 'A', 'B', 'C', 'D' and 'E' each extending to four weeks. Initially decile values of these five periods were obtained. For progressive updates, actual rainfall for the period 'A' is added separately to three probabilities of rainfall *i.e*. deciles 7, 5 and 3 for the remaining period *i.e*. B+C+D+E. This gives the first set of estimates or expected amount of rainfall of the season for the three deciles. The second set of estimates is obtained at the end of period 'B'. In this case the combined actual

TABLE 1

Rainfall (mm) for three selected deciles

Station	Decile	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
New Delhi	Third					04	09	15	11	15	15	07	07	03							
	Fifth	03	5	9	12	35	54	66	63	54	31	28	35	31	27	7					
	Seventh	05	07	15	21	38	59	70	67	82	71	41	43	49	43	38	09	09	01		
Jaipur	Third					06	13	16	11	09	06	08	13	02	01						
	Fifth					06	17	34	35	39	31	19	24	32	16	13					
	Seventh			13	28	35	61	75	80	55	70	50	65	52	30	25	09				
Jalgaon	Third		01	07	17	34	24	20	21	18	15	06	07	06	08	02	01				
	Fifth		11	21	42	47	46	44	32	41	31	22	27	16	27	09	11				
	Seventh	16	38	51	79	75	75	62	70	76	57	33	48	40	47	39	29	19			
Ahmednagar	Third	05	07	04	04	04	02	03	02	03	01	01	01	01	03	04	12	04			
	Fifth	20	18	13	15	12	06	10	10	06	03	04	04	05	09	15	34	16	09		
	Seventh	38	36	29	38	31	23	19	14	18	11	12	19	17	31	43	55	62	23	19	
Anantapur	Third	01			01							01		01			04	06	01	02	
	Fifth	07	01	01	04	03	03	04	04	03	01	05	04	04	04	09	36	17	18	14	
	Seventh	20	06	06	11	07	08	14	10	13	05	18	13	13	17	39	71	42	31	37	18
Ahmedabad	Third			01	10	12	15	11	16	10	08	07	05	04	01						
	Fifth		03	06	33	36	45	28	39	32	21	17	17	13	10	04	03				
	Seventh	05	17	31	53	68	71	77	81	84	71	52	52	60	56	31	17	06			

rainfall of period 'A+B' is added to the deciles 7, 5 and 3 for the remaining period, 'C+D+E'. The second set indicates the total rainfall of the season estimated at the three deciles. This process was repeated at the end of each period using the actual rainfall for that period and the probabilities of rainfall for the remaining periods of the season. Thus four sets of estimates can be obtained at the end of period 'A', 'A+B', 'A+B+C' and 'A+B+C+D', for each deciles and can be compared with each other.

After a determination of the week ideal for the commencement of sowing, the week of cessation of rainfall from plant physiological point of view, needs to be identified. This would then give approximately the length of growing season (LGS).

The end of the growing season has been assumed as that week towards the end of kharif if season which receives less than 25% of rainfall than the previous week, provided it is $\leq$ 10 mm.

3. Results and discussion

3.1. *Commencement and cessation of growing season*

Raman (1974) used daily rainfall to determine the commencement date of the kharif sowing operations in Maharashtra. His method, however did not take into account the evapotranspirative demands of the crop. Raj (1979) proposed a method to determine sowing as that day

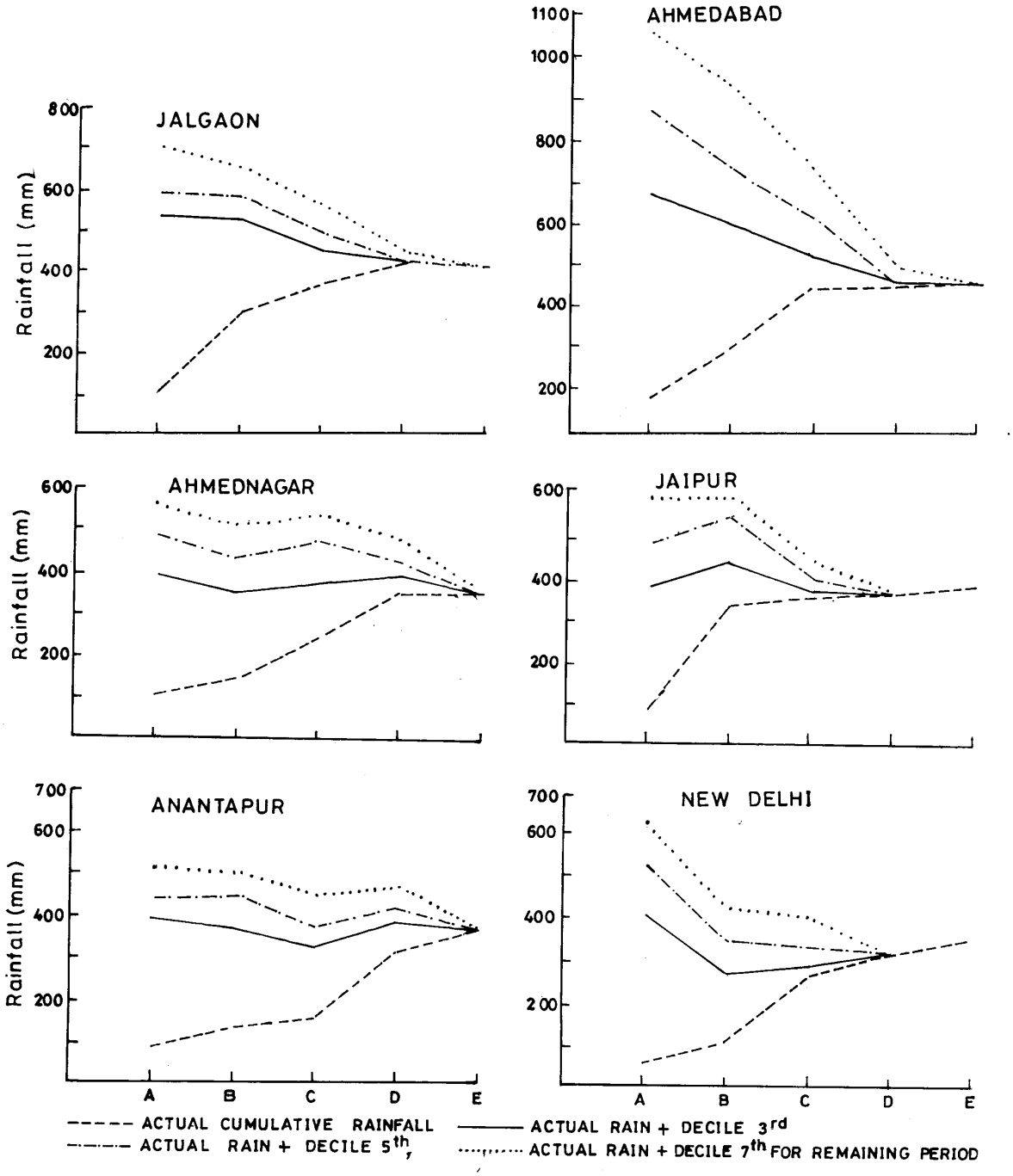

Fig. 1. Prediction of rainfall trend for the year 1986

in 7-day spell when (*i*) total rainfall is greater than 5e + 10 mm and (*ii*) at least 4 of the 7 days have rainfall not less than 2.5 mm each, where 'e' represent daily evaporation (mm).

In the present study, our analysis indicates that the 27th MW (11 to 17 Jun), is ideal to start sowings in Jalgaon and Ahmednagar, whereas for Ahmedabad, Jaipur, Delhi and Anantapur the preferred week of sowing would be 25th MW (18 to 24 Jun).

Similarly the growing season ends first in Jaipur in 39th MW (24 to 30 Sep) and for the rest of the stations, (except Anantapur) in 40th MW (1 -7 Oct). At Anantapur

TABLE 2

Estimation of growing season rainfall on the basis of decile rainfall values

(a) Decile rainfall values (mm) for Ahmednagar at different stages of the growing period

Decile	Stages							
	A	B	C	D	E	(B+C+D+E)	(C+D+E)	(D+E)
3	78	35	26	76	47	292	209	137
5	102	72	52	109	75	384	290	234
7	146	114	79	182	130	458	373	295

(b) Actual cumulative rainfall values (mm) for Ahmednagar in 1986 at different stages

A	B	C	D	E
103	103+40	143+99	242+109	351+4
	= 143	= 242	= 351	= 355

(c) Prediction of growing season rainfall on the basis of decile 5 for Ahmednagar at different stages in 1986

Stages	A	B	C	D
Predicted rainfall (mm)	103+384 = 487	143+290 = 433	242+234 = 476	351+75 = 426

the crop season terminates a week latter 40th MW (1- 7 Oct).Thus, the effective length of growing season, in DFRs spread over a period of 14-15 weeks.

3.2. *Decile rainfall features*

Rainfall received at the third, fifth and seventh deciles is shown in Table 1. At the third decile level, normally very low rainfall is observed at Ahmednagar and Anantapur, both traditionally drought prone areas in the country. At Jalgaon rainfall of >10 mm occurs between 26th (25 Jun - 1 Jul) to 32 MW (6 - 12 Aug) and MWs 26 to 31 (30 Jul - 5 Aug) at Ahmedabad in the third decile. Further north, this magnitude of rainfall gets progressively delayed. Thus at Jaipur, rainfall ≥ 10 mm is received between MW 28 (9-15 Jul) MW 30 (23 - 29 Jul) and at Delhi, in MWs 24 - 32. This is the period of active monsoon over India.

At the 5th decile, or 50% level of probability, Anantapur gets rainfall ≥10 mm only after MW 38 (17 - 23 Sep). This location in Rayalseema, as we know, receives more rainfall in the retreating phase of monsoon. Ahmednagar can be said to receive ≥10 mm rainfall, generally in two spells. First one between 23rd to 30th MW *i.e.* (4th - 10th Jun to 23rd - 29th Jul) and the second one from MW 37 (10 - 16 Sep) to MW 39 (24 - 30 Sep). As such, for growing crops at 50% success level, the crop should be sown so that the crop demand for water does not fall between MWs 31 - 36 at Ahmednagar. The entire period from MW 24 (11 - 17 Jun) to MW 38 (17 - 23 Sep) at Jalgaon can be said to uniformly receive ≥10 mm rainfall with MW 26 (25 Jun - 1 Jul) -MW 32 (6 - 12 Aug) getting weekly rain of 30 mm or more. Ahmedabad and Delhi also get rainfall exceeding 10 mm at 5th, decile between 26 - 38 and 26 - 37 MWs, infact nearly the whole period getting heavier rain of ≥30 mm. Rainfall at 50% probability level, ≥10 mm is confined to MW 28 (9 - 15 Jul) to MW 36 (3 - 9 Sep) at Jaipur.

In the seventh decile or at 30% probability level, rainfall ≥10mm is received sporadically at Anantapur till MW 33 (13 - 19 Aug), after which, rainfall of this magnitude can occur almost throughout rest of the rainy season. At the other locations considered in DFR, barring a week or so in the beginning of the period during MWs (23 - 42) and for nearly 5 - 6 weeks towards the end, the entire crop season can be assumed to get rain of ≤10 mm per week.

3.3. *Rainfall decile and predicting the nature of agricultural growing season*

The methodology enunciated above enables to progressively improve upon prediction of rainfall during

TABLE 3

Identification of droughts and their types at six selected locations (Datum Period : 1981-96)

Station	Agricultural	Meteorological	Hydrological
New Delhi	1981, 1987	1981, 1986, 1987	1984
Jaipur	—	1982, 1984, 1986, 1987, 1993	1986, 1987, 1988, 1989
Ahmedabad	1986, 1987, 1993, 1995	1982, 1986, 1987, 1991, 1992, 1993	1988, 1993
Jalgaon	1985, 1986	1982, 1984, 1985, 1986, 1987, 1989, 1991	1986
Ahmednagar	1982, 1984, 1985, 1986, 1993	1982, 1984, 1985, 1986	—
Anantpur	1981, 1982, 1984, 1985, 1986, 1987, 1989, 1990, 1991	1982, 1984, 1986, 1987, 1990, 1991,1992	1987, 1993

the growing season at three probability or decile levels 3rd, 5th and 7th for this purpose. Fig. 1 shows the graph of actual cumulative rainfall and three updated rainfall probabilities during the growing season from the initial phase of season 'A' till the end of the season 'E'. As described above the actual rainfall at any stage (*i.e*. from 'A' to 'E') is added to the selected decile value of remaining part of the season, and plotted at the end of each period. The curves indicate a clear trend of what the outcome of seasonal rainfall is likely to be as the crop is growing. The methodology of predicting the nature of rainfall for the growing season at each of the stages (from 'A' to 'E') has been shown for a typical drought year 1986. It is seen that at 3rd decile range, Ahmednagar shows about 400 mm of rainfall predicted at the stage 'A' for the entire growing season. This amount has been estimated by adding the actual rainfall at stage 'A'' with the probability of rainfall at decile 3 for the remaining period of the season *i.e*. (B+C+D+E) stages. The estimated totals can be compared with the actual rainfall amount during A to E stages. This gives a first set of estimates of rainfall in the growing season.

At the end of stage B, the combined actual rainfall for (A+B) stages is added to the rainfall decile 3 for the remaining period of (C+D+E) of the growing season. Thus Ahmednagar shows about 350 mm of rainfall predicted at stage 'B'. This process is repeated at the end of each stage, using the actual cumulative rainfall for that stage and the probabilities of rainfall (deciles rainfall) for the remaining stages of the growing season. Thus we find 380 mm of rainfall predicted at stage 'C' and 400 mm predicted at stage 'D'. Finally the actual total rainfall of 350 mm is found at the end of stage 'E'. This shows that the amount of rainfall predicted at each of the stages 'A', 'B', 'C' and 'D' and the actual rainfall total at end of 'E' is more or less comparable. The same procedure has been repeated at 5th and 7th decile ranges upto end of period 'D'. In 5th and 7th decile ranges, the actual rainfall total seen at the end of period 'E' is much less than predicted rainfall at different stages of the growing period. This type of situations are also noticed at Anantapur and Jaipur. The larger differences in probabilistic rainfall upto end of period 'D' and actual rainfall at 'E' is seen at Jalgaon and Ahmedabad and upto period 'B' at New Delhi. Table 2 shows how the predicted rainfall amounts for decile 5 have been estimated for Ahmednagar at different stages on the basis of the 5th decile rainfall values and actual cumulative rainfall for the respective stages.

3.4. *Use of deciles for drought identification*

In DFRs of the country, the incidence of frequent, often severe drought, is not an uncommon phenomenon. A considerable amount of research is available on seasonal or meteorological drought. (Wilhite 1993 and Redmond 2000). However, on the subject of agricultural or hydrological drought, very few studies seem to have been conducted, particularly in the former, in view of complexities involved (Chowdhury and Gore 1989, Das 2000).

The decile system used in the present study helps to distinguish one type of drought from another. The technique has been applied for independent data from

1981 to 1996. The results of these analyses are given in Table 3.

A glance at the table reveals that meteorological drought need not, simultaneously, give rise to agricultural drought and *vice versa* in the DFRs of India. Pooling together data of all six stations as an independent data set, the number of station-years having meteorological and agricultural droughts were 32 and 22 respectively. Instances of simultaneous occurrence of agricultural drought with meteorological drought were 16, giving the 50% probability for the agricultural drought to be experienced when the meteorological drought is already in progress. A well distributed rainfall, may be low in quantum, giving rise to meteorological drought, but if it occurs in the crucial periods, it may result in good growth and yield of crops. On the other hand, chances of occurrence of meteorological drought when agricultural drought is being felt in DFRs are rather high *i.e*. 16/22 or nearly 75%. Some of the well-documented droughts (meteorological) between 1981-96 like 1982 and 1987 are clearly brought out in the analysis. Thus, it is seen from the table, the instances of meteorological drought, are comparatively more than the further. A comparatively fewer number of instances of hydrological drought except for Jaipur is another striking feature, emerging from the Table 3. Several cases of drought (both agricultural & meteorological) noted at Anantapur emphasize the precarious nature of agricultural production at this location. The decile method, therefore, offers a novel approach to monitor rainfall situation with the progress of the crop growth and is useful to identify any of the three types of drought.

4. Conclusions

(*i*) In the peninsular Indian region sowing operations can be commenced in MW 24 (11-17 Jun) - and a week later in the north.

(*ii*) The length of the growing season extends to 14-15 weeks duration in dry farming regions of India.

(*iii*) At the 50% probability level (5^{th} decile), the period of rainfall $\geq$10 mm extends from MW 24 (11 - 17 Jun) to MW 38 (17 - 23 Sep). The period decreases as we go northward from the south.

(*iv*) Because of the in-built complexities in agricultural system, probability of simultaneous occurrence of agricultural drought with meteorological drought is 50%. Meteorological droughts, concurrently occur with agricultural droughts in 3 out of every 4 episodes.

(*v*) Anantapur appears to be most vulnerable to agricultural and meteorological droughts out of the 6 locations studied.

(*vi*) The updated rainfall data can be used in growth models to predict crop and pasture yields and to assist in decisions on investments in farming operations.

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References

Bhalme, H. N., Sikden, A. B. and Jadhav, S. K., 1990, "Coupling between the El-nino and planetary scale waves and their linkage with the Indian Monsoon rainfall", *Meteorology and Atmospheric Physics*, **44**, 293-305.

Chowdhury, A. and Gore P. G., 1989, "An index to assess agricultural drought in India", *Theoretical and applied climatology*, **40**, 103-109.

Das, H. P., 1987, "Some aspects of climatological resources and its application to agriculture in Madhya Pradesh", Ph.D. Thesis, University of Poona, 42-50.

Das, H. P., 2000, "Monitoring the incidence of large scale drought in India. in : Donald A. Wilhite (Ed.), Drought A global assessment. Vol. 1, Routledge London and New York, 181-195.

Das, H. P. and Chowdhury, A., 1992, "Variability in rainfall dispersion in Madhya Pradesh", *Mausam*, **43**, 1, 29-36.

French, R. J., 1987, "Adaptation and Planning for drought adjustments in drought prone areas : An overview – (Wilhite and W. E. Esterling) (Eds)", West view Press, 369-382.

George, C. J. and Kalyansundaram, V., 1969, "A use of monthly rainfall deciles for assessing agricultural droughts in Bihar State", Prepublished Scientific Report No. 96, India Meteorological Department, Pune, 1-20 + 9 Annexures.

Gibbs, W. J. and Maher, J. V., 1967, "Rainfall deciles as drought Indicators", Commonwealth Bureau of Meteorology, Bulletin No. 48, Melbourne, Australia.

Palmer, W. C., 1965, "Meteorological drought, Research paper No. 45", US Weather Bureau, Washington, D.C. 6-8.

Parthasarthy, B., Rupakumar, K. and Munot, A. A., 1992, "Forecast of rainy season foodgrain production based on monsoon rainfall", *Ind. J. Agri. Sci.*, **62**, 1, 1-8.

Raj, P. C., 1979, "Onset of effective monsoon and critical dry spells", IARI Res. Bull. No. 11 (New Series), 3-6.

Raman, C. R. V., 1974, "Commencement of sowing rains over Maharashtra state", Pre-pub. Sc. Report. Ind. Met. Deptt., Pune, p3 + 13 Figures.

Redmond, K. T., 2000, "Integrated climate monitoring for drought detection", In : Donald A. Wilhite (Ed.), Drought A global assessment, **1**, 145-158.

Sarker, R. P., Biswas, B. C. and Khambete, N. N., 1982, "Probability analysis of short period rainfall in dry farming tract in India", *Mausam*, **33**, 3, 269-284.

Wilhite, D. A., 1993, "The enigma of drought", in D.A. Wilhite (ed.), Drought assessment, Management and Planning : Theory and Case Studies, Boston, MA : Kluwer Academic Publishers, 3-15.