Mausam, (1992), **43**, 1, 91-98

551.586.633 (548.2)

Agroclimatic classification for assessment of the crop potential of Karnataka

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(*Received 10 June 1988*)

सार — फसल के ढरें की योजना बनाने में और क्षेत्र के कृषि विभव का पता लगाने के लिए, यह आवश्यक है कि वस्तुनिष्ठ और प्रासंगिक आधार पर एक कृषि जलवायु विषयक वर्गीकरण किया जाए। इस शोधपत्र में जल उपलब्धता सूचकांक नामक एक सूचकांक की खोज को प्रस्तुत करने का प्रयत्न किया गया है। यह सूचकांक, फसल द्वारा न्यूनतम जल आपूर्ति के वितरण को दर्शाता है। साप्ताहिक वर्षा के तीन प्रारम्भिक मानों के लिए आर्द्र सप्ताहों के अधिकतर प्रसंभाव्य संख्या और तीन सप्ताहों से अधिक शुष्क बौछारों की प्रसंभाव्यता का प्रयोग किया जाता है। यह विकसित पद्धति कर्नाटक राज्य के शुष्क खेती वाले भू-भाग में प्रयोग की जाती है। इन सूचनाओं के साथ-साथ मृदा के प्रकार और विभिन्न फसलों की जल आवश्यकता जैसी सूचनाओं का प्रयोग करते हुए प्रत्येक कृषि जलवायु विषयक क्षेत्र में फसल के ढरें का मूल्यांकन किया जाए ताकि राज्य में फसल उत्पादन को स्थापित करने के लिए उपलब्ध नमी का अनुकूलतम प्रयोग किया जा सके।

ABSTRACT. To plan cropping pattern and to bring out agricultural potential of a region, it is essential that the agroclimatic classification is made on an objective and rational basis. Such an attempt has been made in this paper by devising an index called Water Availability Index (WAI). This index takes into account the distribution of the minimum water required by the crop. It utilises the most probable number of the wet weeks for three threshold values of weekly rainfall and probability of dry spells of more than three weeks. The methodology developed is applied to dry farming tracts of Karnataka State. Using these information alongwith the information of the soil types and water requirement of different crops, cropping pattern can be assessed in each agroclimatic zone, so that optimum use of the available moisture is made in stabilising the crop production in the State.

Key words — Water Availability Index, Initial and conditional probability, Dry & wet weeks, Dry farming tracts.

1. Introduction

To meet the growing demands of increasing population we have to increase food production from the limited arable land. During the last two decades modern technology involving the use of hybrid varieties, application of fertilizers and pesticides and irrigation has boosted up agricultural production. But under rainfed farming these techniques fail especially under drought or prolonged break monsoon conditions.

Therefore, to raise food production to an optimum level, long term planning for suitable cropping pattern on the basis of agroclimatic resources and constraints become necessary, particularly for dryland agriculture. Agroclimatic classification on a rational and scientific basis appears to be the only answer.

Most of the earlier classifications (Koppen 1936, Meher Homji 1964, Champion and Seth 1968, etc) used vegetation as an index of climate. In these methods a climatic region was recognised through the predominant grouping of plants growing on the earth's surface. Later, a group of climatologists tried to develop climatic/agroclimatic classification with a view to using them for maximising crop production (Thornthwaite 1948, Troll 1965, Miller 1971 etc).

Troll (1965) derived a classification based on humid and arid months using a probabilistic rainfall on monthly basis. Hargreaves (1974) devised the Moisture Availability Index (MAI) and subsequently Sarker and Biswas (1986) modified this method by (*i*) calculating MAI on weekly basis and (*ii*) introducing two risk levels. Khambete (1985) used the same method to classify dry farming tract of Karnataka. Classification made on the basis of 50% probability level was further subdivided depending upon the length of the water stress period. In this method constraint was put on the duration of the growing period and hence on the classification. With an aim to remove this constraint an attempt has been made in this paper to use conditional probabilities.

At present, agroclimatic zones are identified on the basis of annual isohyets and soil types. But for agricultural purpose indices based on weekly values that too of rainfall which is the most important limiting factor in tropical countries should be adopted. WAI so developed would, therefore, be the most appropriate one.

2. Data

Rainfall data of 101 stations for the period from 1901 to 1970 has been used in this study. Khambete and

TABLE 1

χ^2 Test of goodness of fit for the length of wet spells (14-48 weeks)

Station	10.0 mm			Threshold 18.0 mm			25.0 mm		
	P_{22}	χ^2	d.f.	P_{22}	χ^2	d.f.	P_{22}	χ^2	d.f.
Dharwar	0.6353	4.45	7	0.5250	2.25	5	0.4394	1.75	4
Hassan	0.6290	0.32	7	0.5066	2.67	5	0.4276	0.90	4
Chitradurga	0.5067	1.56	5	0.3697	0.07	3	0.2889	0.49	2
Muddebihal	0.4926	3.07	5	0.4061	0.83	3	0.3340	1.29	2
Mysore	0.5548	0.79	6	0.4313	5.18	4	0.3600	0.39	3

TABLE 2

Average number of wet weeks period 14-48 weeks threshold

Station	10.0 mm			18.0 mm			25.0 mm		
	O	M	Md	O	M	Md	O	M	Md
Dharwar	18.53	18.53	19	14.29	14.29	14	11.36	11.37	11
Hassan	19.45	19.45	20	14.57	14.55	15	11.37	11.36	11
Chitradurga	14.81	14.81	15	10.40	10.41	11	7.76	7.70	8
Muddebihal	12.84	12.83	12	9.16	9.16	9	7.01	7.02	7
Mysore	17.72	17.72	18	12.67	12.67	13	9.85	9.85	10

O — Observed value, M — Expected value, Md — No. of weeks observed having highest frequency of occurrence.

Kanade (1985) observed that the rainy period of Karnataka extends from April to November. Hence the study pertains to 14th to 48th standard weeks (*i.e.*, 2 April-2 December) when more than 95% of the annual rainfall ocurs in the State.

3. Methods of analysis

In this study a week is defined as "Wet" week when the rainfall during the week is equal to or greater than a threshold value. A week which is not wet is considered as "Dry".

A wet spell is defined as a continuous sequence of wet weeks bounded by dry weeks or either side.

For deciding the threshold value water requirement of the crop has to be considered. Potential evapotranspiration (PET) may be taken as a measure of maximum water requirement during most phases of the crops. In the normal course only 50% of weekly PET would have been taken as the threshold value. But it has been shown (Riplay 1966, Virmani *et al.* 1978, Venkataraman *et al.* 1976, Biswas & Sarker 1978 etc) that the crop growth is normal if it gets moisture varying from 0.3 to 0.7 of PET from germination to grain formation stage. Therefore three different threshold values are assumed here, *viz.*, 30, 50 and 70% of weekly PET. It has been observed (Khambete 1985) that the three threshold values in Karnataka are generally equivalent to 10.0 mm, 18.0 mm and 25.0 mm of weekly rainfall.

3.1. *Application of Markov Chain of order one*

Several authors (Ramabhadran 1954, Neumann 1955 etc) have found dry and wet spells to have geometric or related distributions. These distributions generally follow Markov Chain Model (Gabriel and Neumann 1962). Order one of this model has been applied to compute wet and dry sequence in this study.

3.1.1. *Application to the wet sequences*

It has been demonstrated (Khambete 1985) that Markov Chain of order two cannot be applied to the weekly rainfall in the dry farming tract. Hence, Markov Chain Model of order one has been applied to the sequences of wet weeks.

Once a wet spell (X_s) starts, the probability that it will last for K weeks is given by :

$$P(X_s = K) = (1 - P_{22})\, P_{22}^{K-1}, \quad K = 1, 2, \ldots\ldots \qquad (1)$$

where, P_{22} is the conditional probability of a wet week given that previous week is wet. Eqn. (1) follows geometric distribution with mean $\bar{X}_s$ and variance V_s, where,

$$\bar{X}_s = \frac{1}{1 - P_{22}} \quad \text{and} \quad V_s = P_{22}/\,(1 - P_{22})^2 \qquad (2)$$

The value of P_{22} alongwith χ^2 values for three thresholds and for some selected stations are given in Table 1. It is seen that the χ^2 values are not significant for any of the stations. Hence, a Markov Chain Model of order one can be fitted to the wet spells in the dry farming tract of Karnataka.

TABLE 3

χ^2 test of goodness of fit for dry spells
Period : 23-25th week
threshold 10.0 mm

Station	P_{12}	χ^2	d.f.
Dharwar	0.6190	1.65	2
Hassan	0.5123	0.56	3
Chitradurga	0.4637	6.85	4
Muddebihal	0.3826	1.47	5
Mysore	0.4799	1.82	4

3.1.1(a). *Most probable number of wet weeks*

These are the wet weeks with highest probability of occurrence. When the distribution of wet weeks (X_w) is normal the most probable number of wet weeks can be computed from normal distribution. The most probable number of wet weeks are the same as the expected number of wet weeks for all the three thresholds.

3.1.1(b). *Expected number of wet weeks*

The distribution of total number of wet weeks (X_w) in a n week period tends to normality when n is large. The expected number of wet weeks is then given by :

$$E_{(Xw)} = \frac{n \cdot P_{12}}{1 - P_{22} + P_{12}} \tag{3}$$

and the variance is given by :

$$V_{(Xw)} = \frac{n \cdot P_{12}\,(1-P_{12})\,(1+P_{22}-P_{12})}{(1-P_{22}+P_{12})} \tag{4}$$

where, P_{12} is the conditional probability of wet week given that previous week is dry. In this paper the expected number of wet weeks during 14-48 (2 Apr-2 Dec) weeks has been computed and compared with the average number of wet weeks observed during this period. For a few representative locations it is presented in Table 2. It is clear that Markov Chain Model gives very good estimates of the average number of wet weeks for all the threshold values.

3.1.2. *Application to the dry sequences*

Let X_d denote the sequence of dry weeks. Assuming that, once a dry spell commences, the probability that it will last exactly m weeks is given by :

$$P(X_d = m) = P_{12}\,(1-P_{12})^{m-1},\ m = 1,2\ldots\ldots \tag{5}$$

$P(X_d)$ also follows a geometric distribution,

where mean length of dry sequences ($\bar{X}_d$) is given by :

$$\bar{X}_d = 1/P_{12} \tag{6}$$

and the variance $V(X_d)$ is given by

$$V(X_d) = \frac{1-P_{12}}{(P_{12})^2} \tag{7}$$

the probability that a dry spell will last more than consecutive m weeks is :

$$P\,(X_d > m) = (1-P_{12})^m \tag{8}$$

TABLE 4

Agroclimatic classification by water availability index

Classification	Most probable number of wet weeks		
	W_{10}	W_{18}	W_{25}
D	$\geqslant 10$	$\geqslant 6$	$\geqslant 4$
E	$\geqslant 12$	$\geqslant 8$	$\geqslant 6$
F	$\geqslant 14$	$\geqslant 10$	$\geqslant 8$
G	$\geqslant 17$	$\geqslant 13$	$\geqslant 10$

Sarker and Biswas (1986) have shown that if the rainfall is atleast 0.3 of weekly PET crop does not wilt. As mentioned earlier this is equivalent to 10.0 mm rainfall. As such dry spells have been studied only for 10.0 mm threshold rainfall. The probability (P_{12}) has been computed for the period 23-35 standard weeks (4 Jun-2 Sep) which correspond to active rainfall period in the state. For selected stations this is shown in Table 3 alongwith χ^2 values. No value is significant at 5% level. It is evident that Markov Chain Model of order one can be applied to the dry spells also.

3.2. *Agroclimatic classification and water availability index*

In this study an index based on number of wet weeks with highest probability termed as Water Availability Index (WAI) is used.

For defining the Water Availability Index say for 10.0 mm threshold, the most probable number of wet weeks for 10.0 mm threshold is computed, and designated as W_{10}. The Water Availability Index for 18.0 mm and 25.0 mm threshold are similarly designated as W_{18} and W_{25}. In the normal distribution, most probable values and expected values are the same. As such these values are computed using Eqn. (3) above. The values are the same as those at 50% probability level.

As it is seen earlier, crop requires for its normal growth, moisture equivalent to 0.3 PET to 0.7 PET. Therefore, all the three WAI values are used in the classification. To define different zones, suitable combination of three thresholds a given in Table 4 has been used.

3.3.1. *Probability of dry spell*

In any rainy spell the number of wet weeks are often alternated by dry weeks. If the dry period extends to more than three weeks it hampers crop growth. Therefore, above classes are sub-divided according to the probability of occurrence of dry period of more than three weeks.

Kharif season corresponding to the period 23rd to 35th standard weeks (4 Jun to 2 Sep) is the active monsoon period of the State. The probability of dry spells is computed only for this period and used in the classification.

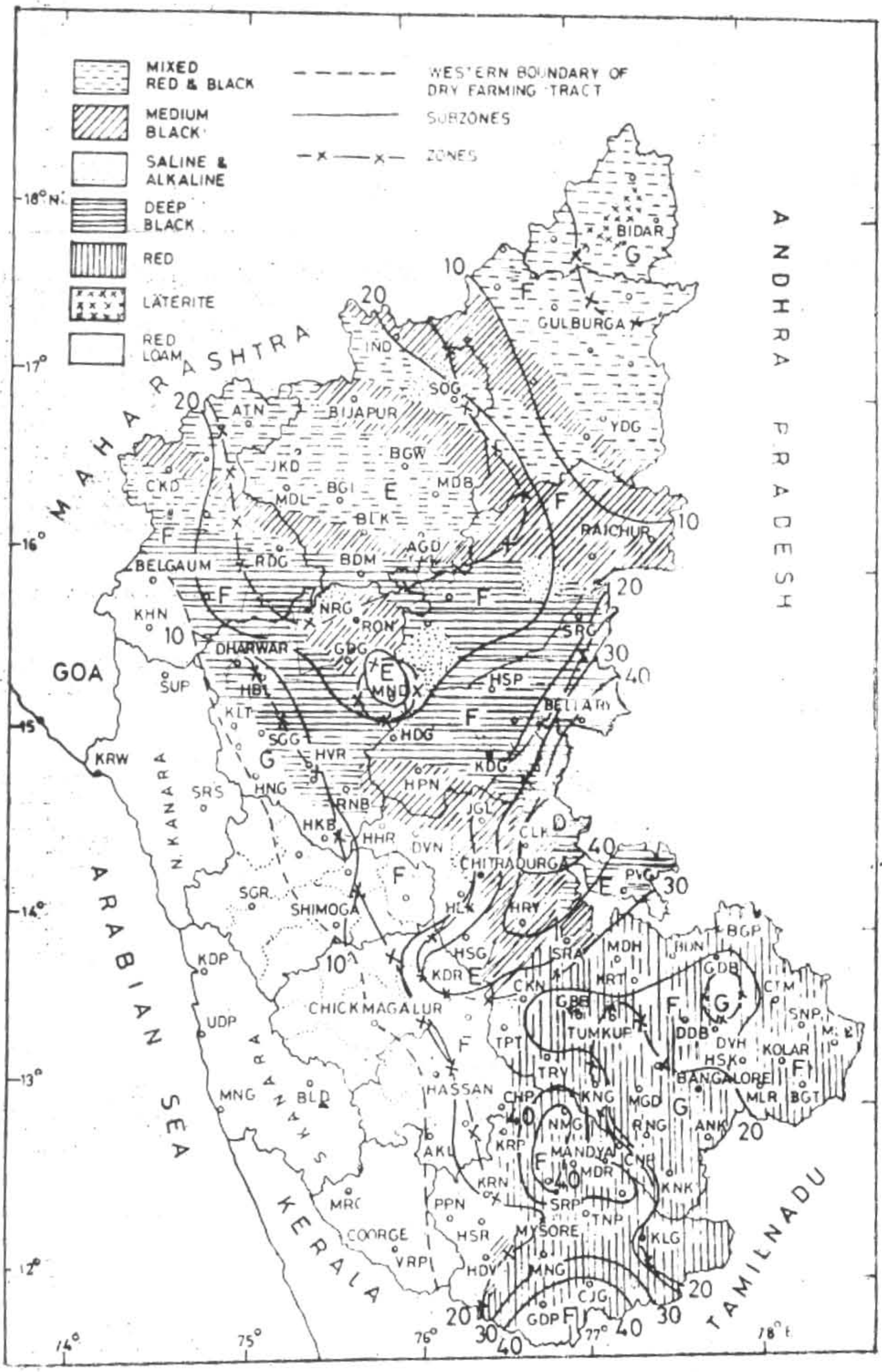
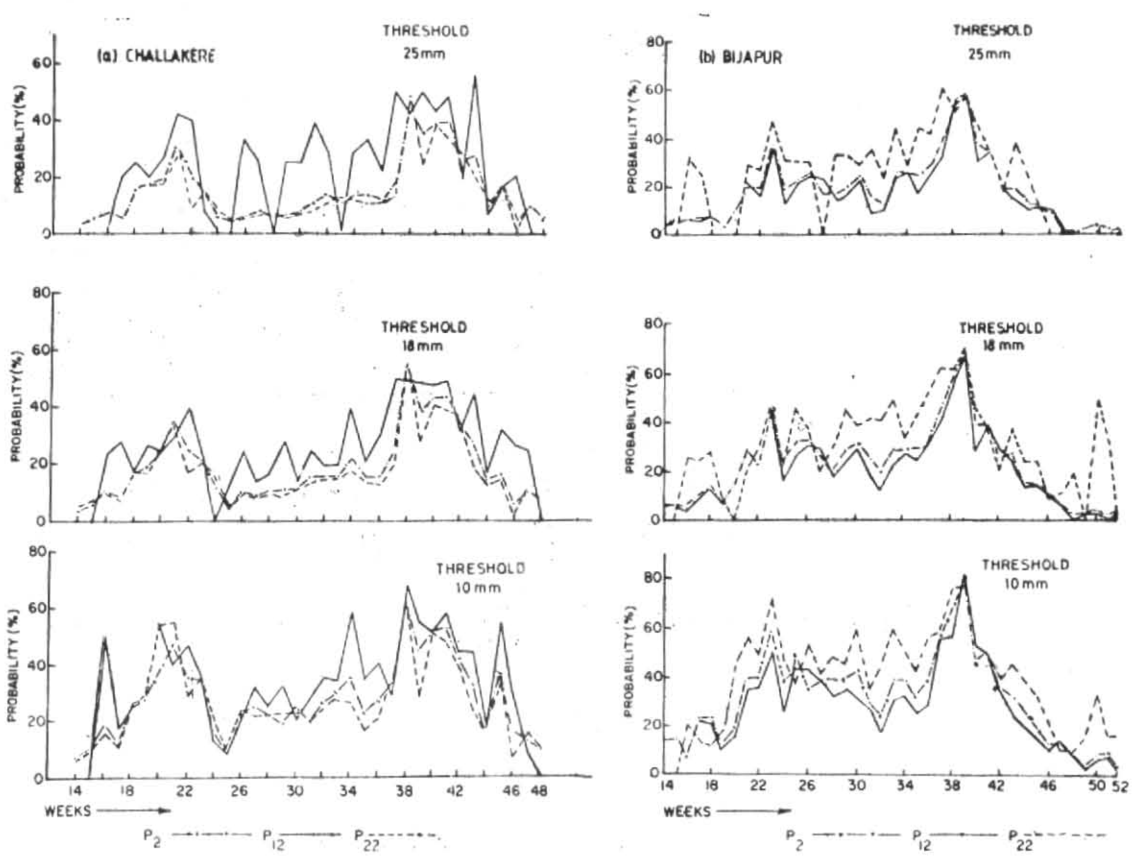


Fig. 1. Agroclimatic classification by Water Availability Index (WAI)



Figs. 2(a-b). Initial (P_2) and conditional probability (P_{12}, P_{22}) (a) Challakere and (b) Bijapur

In the analysis, no situation is observed in which the probability of continuous dry spells of more than 3 weeks during 23-35th week (4 Jun-2 Sep) period exceed 50%. Criteria adopted for the purpose of sub-classification on the basis of dry spells is given below.

Suffix 'O' is used to the letter of main classification, if $(1-P_{12})^3$ is less than 10 per cent. Suffices 1 to 4 are used when $(1-P_{12})^3$ is 10-20, 20-30, 30-40 and 40-50% respectively. For purpose of delineating the agro-climatic zones the category to which each station belongs, *viz.*, D, E, F and G are plotted alongwith the sub-class to which each station belongs on the basis of the analysis of dry sequences.

4. Results and discussion

When the WAI are computed for the three categories, in none of the locations $W_{10} \geq 20$, $W_{18} \geq 17$ and $W_{25} \geq 13$ are observed. This is not surprising. Any area satisfying criteria greater than that categorised by G would have atleast 4½ months with rainfall satisfying 0.3 PET, 4 months with 0.5 PET and minimum of 3 months with 0.7 PET. In such an area, crop requiring continuous moist situation like paddy can be grown under natural conditions. We know in dry farming tract, paddy cannot be raised unless sufficient supplementary irrigation facilities are available. Thus, it appears that the classification made on the basis of WAI is more realistic. The different zones and sub-zones are illustrated in Fig. 1.

Fig. 2 gives the initial (P_2) and conditional probabilities of wet preceded by wet (P_{22}) and wet preceded by dry (P_{12}) weeks for all the thresholds for one representative station in each zone.

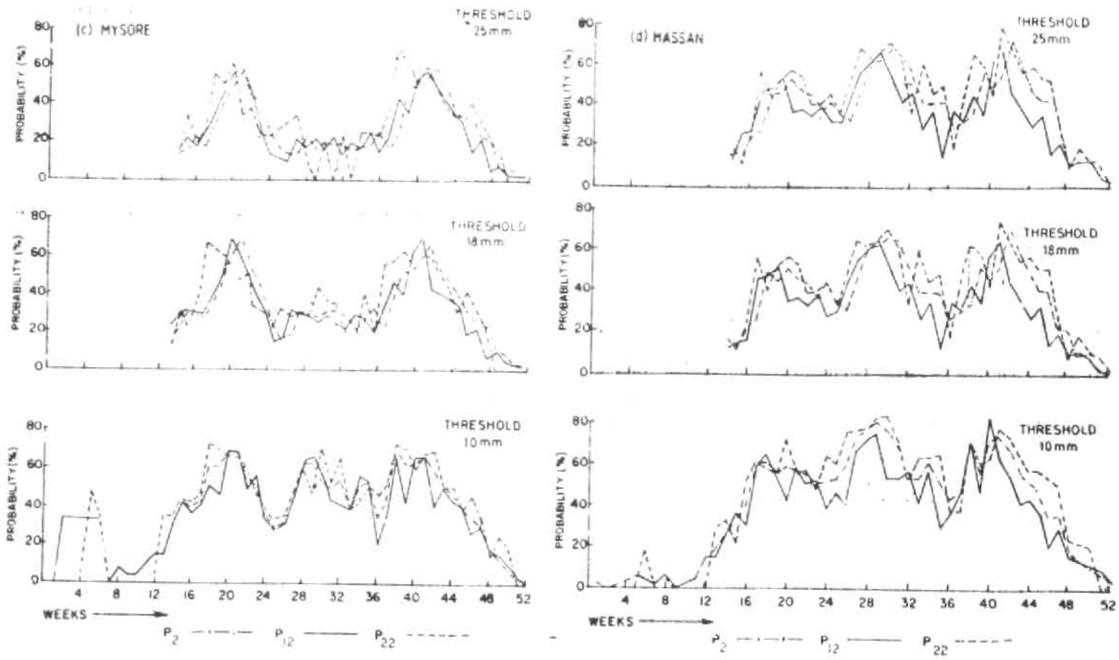
This rainfall probability pattern gives an idea of rainfall availability period and its likelihood of continuation week by week over the annual march of time.

The growing periods of crops depend not only on the rainfall amount and distribution but also on the type of soils which holds and supply water to the crops. Therefore, with all the above information and that on the soil type, an agronomist can evolve a suitable cropping pattern for the zone. Therefore, broad soil zones are also shown in Fig. 1.

Some salient features of each zone are stated below :

(a) *Zone D*

Challakere (Fig. 2a) represents zone D_4. This is an area of lowest rainfall in the whole of the dry farming tract of Karnataka. Probability of getting sowing rains (P_2) during July (27-31 weeks) and August (32-35 weeks) is quite low for threshold 25 mm. As such,



Figs. 2(c-d). Initial (P_2) and conditional probability (P_{12}, P_{22}) (c) Mysore and (d) Hassan

Kharif crop of 75 day's duration is possible only once in three years in deep black soil. Since the sowing rains are not dependable during the kharif season, the farmers may either adjust cropping pattern and agronomic practices taking into account the time of receipt of sowing rains or to be on the safer side, opt for a rabi crop since dependability of rainfall in 36-43rd week is high.

(b) *Zone E*

Bijapur (Fig. 2b) represents zone E_2. Initial probability for higher amount of rainfall is more than 50% during 38-40 weeks (17 Sep-4 Oct). This is the assured rainfall period which should coincide with the active growth period of the crop. Moreover, in 50th and 52nd week conditional probability P_{22} is high, therefore, the crop should be planned in such a way that the flowering period fall in 50-52nd week.

(c) *Zone F*

Mysore (Fig. 2c) represents zone F. It is sub-classified as F_1 as the probability of continuous dry weeks more than three is 10-20 %. At this place conditional probability is higher during 16-20 weeks (16 Apr-20 May) and 30-46th weeks (25 Jul-18 Nov). This period may be chosen as crop growing period.

(d) *Zone G*

Hassan (Fig. 2 d) represents zone G. It is sub-classified as G_1 as the continuous dry spell of more than 3 weeks is 10-20%. Except 32nd (6-12 Aug) and 36th week (3-9 Sep) conditional probability is always higher than initial probability. So, weeks 20-44 (14 May-4 Nov) may be the crop growing period of this place.

4.1. *Identification of drought prone areas*

Various methods have been suggested in meteorological literature to identify drought prone areas (Subramanyan and Subramaniam 1964, Koteswaram 1972, George and Kalyansundaram 1969, etc). WAI approach also furnished sufficient information for identification of such areas. Since prolonged dry spells hamper crop growth the pobability of such helps us in identifying drought prone areas (Fig. 3).

For Karnataka drought prone areas are identified as follows :

(*i*) When the total wet period (more than 0.3 PE) is of 12 to 14 weeks (or less) which is hampered by dry spells of more than 3 weeks in 20% of the years.

(*ii*) When the wet period is of 14 to 17 weeks which is hampered by dry spells of more than 3 weeks in more than 30% of the years.

Among the drought prone areas identified in this study the agroclimatic zone D stands out prominently. This is mainly confined to parts of Chitradurga district. Low quantum of rainfall coupled with frequent dry spells render agriculture to gamble in this area. The zone D, constitute the core of the drought prone area in Karnataka State.

Other climatic type which can also be classified as drought prone is E. Dry spells exceeding three weeks in the active monsoon period are more than 20%. Raising a crop in zone E remains a risky vocation though the degree of risk may be somewhat less compared to the zone D.

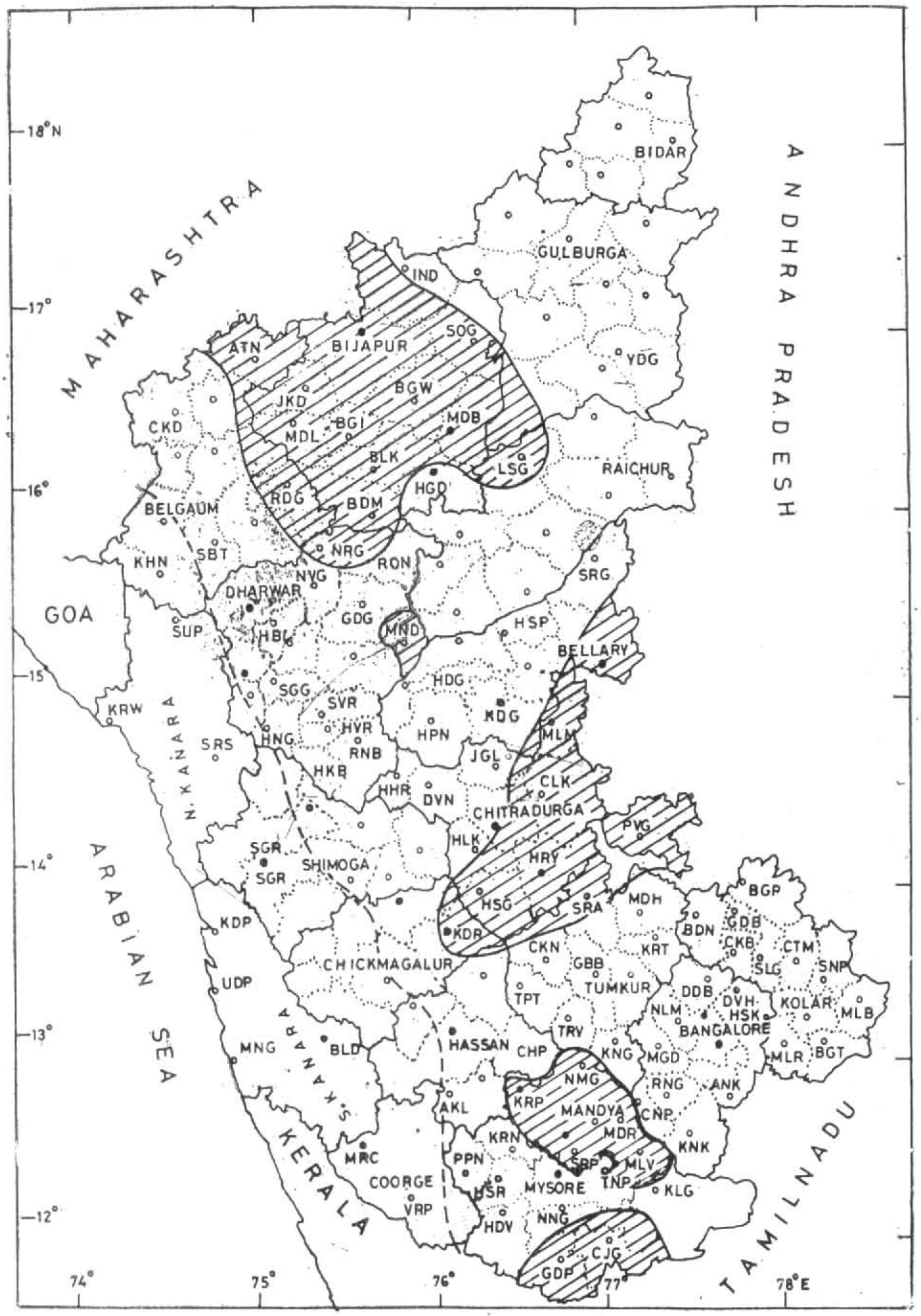


Fig. 3. Drought prone areas of Karnataka State

Zones F_3 and F_4 receive slightly higher amount of rainfall. But the intervening prolonged dry spells make these areas drought affected and hence of poor crop potential.

The identification of these types as the drought prone areas is in broad agreement with the studies on the subject (Chowdhury and Abhyankar 1984, Krishnan 1984 etc).

5. Summary

This study reveals that :

(*i*) Dry farming tract of Karnataka can broadly be divided into four agroclimatic zones.

(*ii*) The wettest zone does not experience intervening dry spells during the crop growth phase and has the greatest agricultural potential.

(*iii*) In the driest zone rainfed agriculture appears a gamble.

(*iv*) The most extensive agroclimatic zone in the state experiences different probabilities of longer dry spells.

(*v*) The drought prone area could be identified by the index developed in the study.

Acknowledgements

The author is gratefully indebted to Dr. R.P. Sarker. Director General of Meteorology, IMD for his guidance, constructive criticism and encouragement during the course of this work. She is extremely indebted to Dr. A. Chowdhury, Deputy Director General of Meteorology (Agrimet) for his constructive criticism and constant help in the preparation of this paper. She is also thankful to Dr. B.C. Biswas, Director (Agrimet) for interest and encouragement and to members of D.F.R. Unit and Miss Geeta Ramachandran for typing the manuscript.

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