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Usefulness of monthly rainfall normals in agroclimatic mapping

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ABSTRACT. Rainfall has the most dominating influence on Indian agriculture. It is, however, commonly argued that monthly rainfall data are not adequate for agricultural planning, for which intervals of 10 days, week or shorter would be appropriate. The paper reviews some of the attempts made in this direction, particularly for the state of Maharashtra in Peninsular India. It then explains how the results of such studies can be derived by a simpler method of mapping which involves only monthly normals of rainfall and number of rainy days.

1. Introduction

Among all the climatic elements which influence Indian agriculture, rainfall is of outstanding importance. Its effect is so decisive that the entire economy of the country has become associated with the behaviour of the monsoon. At the same time, rainfall has been measured much more extensively than any other meteorological parameter. Presently, there are 4400 raingauges in India, whose data are processed and archived by the India Meteorological Department (IMD), besides 500 raingauges which form part of the IMD observatory network. In addition to these, about 3600 raingauges are maintained privately by other agencies like the railways. At many stations, rainfall records have been maintained without a break for more than a century, the longest series being that of 160 years for Madras.

In many developing countries, paucity of agroclimatic information is a major constraint in agricultural planning. This is not so in the case of India. Our main problem is to evolve powerful techniques to process the wealth of rainfall data in order to meet the requirements of agricultural scientists and planners.

Rain, in itself, is not a prerequisite to crop growth. Its action lies in the replenishment of soil moisture consumed by the crop. Traditionally, in India, crops are grown during the June-September rainy season (kharif) or they are raised on the moisture reserve built up during the monsoon (rabi). Therefore, assuming that temperature and other conditions are non-limiting more than a single crop can be grown in a year if water supply can be provided. In some parts of the country, the effective rainy season itself extends long enough to afford scope for double cropping. Elsewhere, irrigation resources can be so developed as to make good the deficiencies in rainfall. Even under irrigated conditions, maximum utilisation of rain water can lead to substantial savings in irrigation water. In areas where only rainfed agriculture is possible, the choice of crops should be compatible with the rainfall pattern. While planning all such efforts, analysis of past rainfall data becomes a primary and practical necessity.

The supply of climatological information for agricultural applications is, in general, a difficult task. Perhaps, the inquirer may be unaware of the type of data, either raw or processed, which are readily available. Sometimes, the material which the climatologists possess may not be easily convertible into the form most desired by the user. Therefore, cartographic representation of basic rainfall data and related parameters is able to satisfy a wider range of user needs. Compared to tables, maps are easier to understand and interpret, and they permit the user to exercise a fair degree of interpolation or extrapolation in his area of interest. For examining spatial distributions, for identifying homogeneity, etc, maps are very convenient and often indispensable.

Maps of India showing distributions of annual, seasonal and monthly rainfall are available in atlases (Anonymous 1971. 1978). The rainfall climatology of India has been exhaustively treated in books (*e.g.*, Das 1968) and also subjected to statistical scrutiny in a variety of ways (*e.g.*, Jagannathan and Bhalme 1973). It is, however,

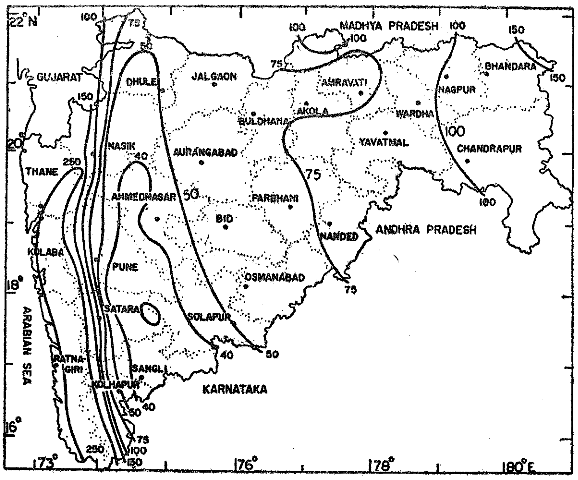

Fig. 1. Maharashtra : Normal Rainfall (cm) in monsoon season, June to September
(*Source*—Rainfall Atlas of India)

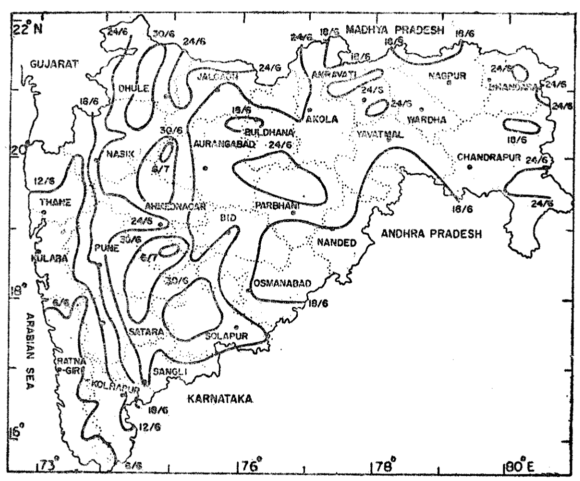

Fig. 2. Date of commencement of sowing rains. Figures represent date/month
(*Source*—Raman 1974)

commonly argued that a month is too long an interval for agricultural applications for which rainfall data should be analysed for periods such as 10 days, week or shorter.

The aim of the present paper is (*i*) to review some of the attempts made in this direction and (*ii*) to examine whether the results of such studies can be derived in a simpler manner involving only monthly normals. Again, the emphasis of the paper is on *mapping* of rainfall for agricultural planning. Studies for individual stations or small areas would require a different approach.

2. The 'Sowing Rains' Concept

Heavy rainfall is known to be harmful at the time the seeds begin to germinate. On the other hand, if a long dry spell sets in soon after germination, the seedlings may wither. The decision on the time of sowing is, therefore, a critical one. "The Indian farmer looks forward with great anxiety to the onset of the monsoon and prays for timely and suitable distribution of rainfall during the season" (Ramdas 1960). The normal dates of onset and withdrawal of the monsoon in different parts of the country have been mapped long ago (Anonymous 1943). For the preparation of the onset map, an abrupt rise in the curve of 5-day accumulated rainfall was used as an indicator of the onset. This is only one of the many ways in which the onset of the monsoon has been defined, there being a wide divergence of views in this regard (Raman 1964, Pant 1964) and it has limitations from the agricultural angle. Raman (1974) pointed out that it was desirable to have a map which showed the dates of commencement of sowing rains. This he defined as a spell of at least 25 mm of rain in a period of 7 days with 1 mm or more on any 5 of these 7 days. The 7-day criterion enables to differentiate the early monsoonal rains from the pre-monsoon thundershowers, and the rainfall amount is so chosen as to ensure adequate moisture storage after accounting for evaporative losses.

Raman's analysis is confined to Maharashtra State, situated in Peninsular India. The Western Ghats, known also as the Sahyadri range of mountains, run north-south, separating the west coastal belt (Thane, Kulaba and Ratnagiri districts, comprising Konkan) from the plateau area to their east. As the ridge comes in the way of the monsoon stream, it forms an important climatic divide. The western slopes and Konkan get very heavy monsoon rainfall, while leeward regions receive as little as a tenth of it (Fig. 1). In the central parts of the State, called Madhya Maharashtra, rainfall is the lowest. Rainfall picks up again as one goes eastwards to the Marathwada area (Aurangabad, Bid, Osmanabad, Parbhani and Nanded districts) and Vidarbha (districts further east). Konkan receives 94 per cent and Vidarbha 87 per cent of the annual rainfall during the monsoon season, June to September, whereas Madhya Maharashtra and Marathwada receive 83 per cent (Anonymous 1974). The area under irrigation is about 10 per cent.

Raman applied his sowing rains definition to *daily* rainfall data of 70 years at 231 stations in Maharashtra and fixed the date of Commencement of Sowing Rains (CSR) for every year, stationwise. The dates were then averaged over the years and the mean CSR dates were plotted and analysed on a map of Maharashtra, a simplified version of which is given in Fig. 2. He also prepared maps showing distributions of the median CSR dates, dispersion about the mean and median, and of the interspell duration, *i.e.*, the average interval between the CSR and the next wet spell. The maps show that wherever the rainfall is meagre, mean CSR occurs late, standard deviation of CSR is high, the length of the growing season is short, the inter-spell duration is long and the necessity of a second sowing is high.

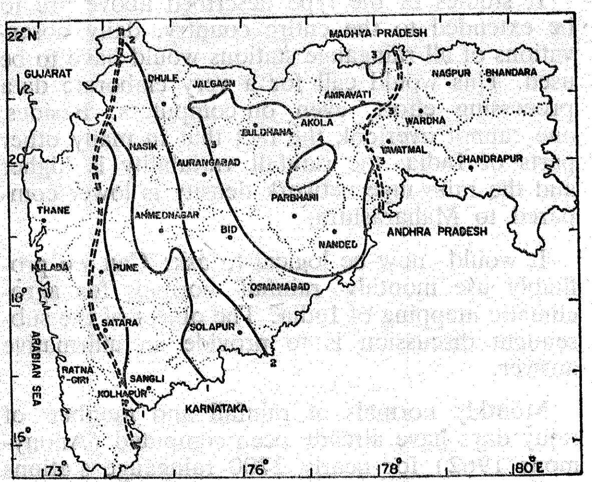

Fig. 3. Assured rainfall (cm) at 50 per cent probability level in the week 18-24 June

[*Source:* Biswas *et al.* 1978]

CSR is earliest, 2 June, over extreme south Konkan and over Western Ghats. Later dates are observed as one goes northwards or eastwards. In the rain-shadow area, CSR isopleths run north-south and the CSR is progressively delayed to the east. CSR is as late as 4-6 July in west Aurangabad, south Ahmednagar, east Pune and west Solapur districts. Over Marathwada and Vidarbha the dates range between 18 and 28 June.

The regions where CSR falls in July are also regions having standard deviation of 26-30 days of mean CSR, and having inter-spell duration of the same order. It is concluded that only short-duration, drought-resistant crops have a chance for survival in these areas.

3. Probability analysis

The onset of the monsoon is a significant event in agriculture because prior to it, the soil is too dry for crops to grow. Nevertheless, other features of the monsoon also pose serious problems at times, *e.g.*, dry spells following normal onset, break in the monsoon, early or delayed withdrawal, etc. These are studied by analysing the rainfall probability, also termed reliability, over short periods of 5 to 10 days. It usually entails a fitting of the incomplete Gamma function to the rainfall distribution, which cannot be considered to be normal in this time scale.

Results of rainfall probability analysis are, by themselves, useful chiefly in connection with the timing of operations. When coupled with data on edaphic and other agroclimatic factors, however, they can help in computing the length of the growing season, identifying periods of water stress, choosing varieties which can withstand the water stress, and determining the moisture available in the soil at the end of the rainy season (Rijks 1973).

Biswas and Khambete (1978) have followed a similar methodology to compute minimum assured rainfall amounts at different probability levels for 82 stations in Maharashtra, adopting a *week* as the interval. The station network is restricted to the areas where dry land farming is practised in the State, bounded between the annual isohyets of 40 and 100 cm. Daily rainfall data of 60 to 70 years have been used in this study. The assured rainfall amounts at selected probability levels have been analysed on maps separately for every week in the monsoon season. The map for the week 18-24 June showing the distributions of assured rainfall at the 50 per cent probability level is reproduced in Fig. 3 as a typical example.

Biswas *et al.* were able to identify three areas with characteristic features: (A) Solapur, Sangli, Satara, east Pune, south Ahmednagar, west Osmanabad and west Bid: Here the assured weekly rainfall is highest in mid-September (20-30 mm) and low (10-20 mm) throughout July and August. It is recommended that rabi crops should be sown early in September in this Area. (B) west Pune, north Ahmednagar, east Osmanabad, east Bid, south Parbhani, south Aurangabad and south Nasik: Here the assured weekly rainfall is high (20-30 mm) both in mid-September and at the end of June, with a lull in between. There are good prospects of rabi crop in this area. Even a kharif crop can be taken if irrigation can be given in August. (C) Remaining area in the north: Assured weekly rainfall is mostly greater than 20 mm, with maximum amounts (40 mm) in mid-July. Prospects of kharif crops are good. Long-duration crops and double cropping can be tried. The core of area A with lowest assured rainfall is delineated as the drought-prone area.

4. Variability of rainfall

The annual rainfall over India as a whole is quite a stable parameter. For example in 1899, a year of widespread famines, the annual total rainfall was only 26 per cent below normal. On the contrary in 1917, when three were extensive floods, it was just 29 per cent above normal. However, the departure from normal increases sharply as we consider smaller areas and shorter periods. In general, it can be said that when or where the average amount of rainfall is low, the associated variability is high.

The coefficient of variation (standard deviation/mean) of annual and monsoon rainfall is about 40 per cent for individual stations in Madhya Maharashtra and 20-30 per cent in other parts of the State. However, in the month of July, it is 80-100 per cent over south Madhya

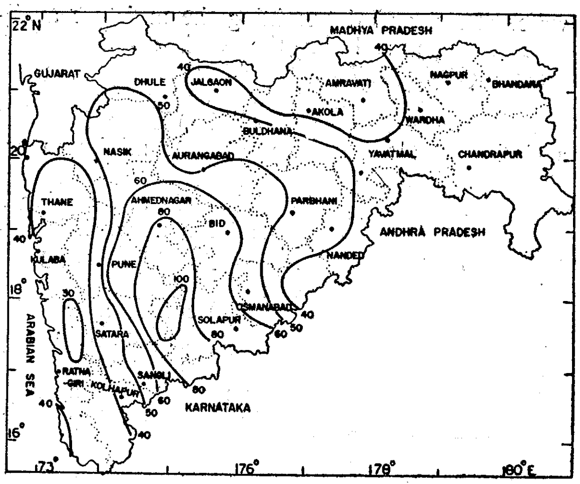

Fig. 4. Coefficient of variation (per cent) of rainfall in July
(*Source* — Rainfall Atlas of India)

Maharashtra (Fig. 4.). If we take weekly or daily averages, the coefficient of variation would assume an excessively high value. This is a serious constraint in rainfall mapping for agricultural applications which demand detailed analysis on both time and space scales.

In essence, it amounts to linking stations having the same mean value but with extremely large associated variability. The pattern of isopleth analysis in any given year would have little resemblance to the mean pattern. This applies equally to basic rainfall data or parameters derived from them. For example, the mean CSR for Ahmednagar (station) is 22 June, but the probability of its occurring anytime from 4 to 29 June is the same, *viz.*, 10 per cent. For Solapur likewise, the mean CSR is 26 June but there is a 5-10 per cent chance of the CSR being anytime between 30 May and 29 July. The CSR isopleths would, therefore, have little stability over the years.

Details on the space scale brought out by isopleth analysis are also dependent on the station network. In the absence of adequate number of stations, a pattern which appears flat and without gradient may not be truly so. Where the network is dense, odd values of a single station may lead to overcrowding of isopleths and the creation of "pockets" which may be unrealistic. The authenticity of rainfall data of some stations may also be questionable.

A comparison of Figs. 2 and 3 brings not these uncertainties. The weekly assured rainfall over Madhya Maharashtra in 18-24 June does not satisfy the sowing rains criterion of 25 mm in 7 days, even once in two years. But CSR isopleths of 18 June and 24 June run through this area. It may be recalled that the data base is the same in both cases.

If studies of the type described above are to be extended to the entire country, daily observations of all raingauge stations would have to be used. This would call for a very elaborate data processing effort, even on computers. Besides, one cannot overlook the fact that in many other parts of India, the rainfall variability is higher and the raingauge network density is lower compared to Maharashtra.

It would now be logical to ask: Can we profitably use monthly rainfall normals for agroclimatic mapping of India? The object of the subsequent discussion is to provide an affirmative answer.

Monthly normals of rainfall and number of rainy days have already been computed (Anonymous 1962) for nearly 2700 raingauge stations in India, which were in existence for more than 5 years before the end of 1950, using all available data for the period 1901-1950. A rainy day is defined as a day which had 2.5 mm or more of rain. Normals of hill stations (elevation exceeding 1067 m a.s.l.) are excluded from the evaluation of area normals. Monthly normals of selected stations are available for the 1931-1960 period (Anonymous 1967).

5. The NCA approach

The National Commission on Agriculture undertook an extensive survey of the prevailing cropping patterns *vis-a-vis* rainfall patterns (Anonymous 1976) aimed at determining the nature of changes required in the former which have evolved traditionally. The chief features of this study were: (*i*) use of *taluk* (the primary administrative unit) as the basic unit of area, (*ii*) expression of the pattern of distribution of monthly rainfall at a place in terms of a simple alphanumeric code, (*iii*) description of the cropping pattern and livestock population in a similar coded manner and (*iv*) consideration of orography, soils, temperature, evapotranspiration, irrigation facilities, land use, etc.

The NCA study was carried out on a national scale, for which *monthly* rainfall normals were found to be more dependable and convenient to handle. Considering that a majority of crops have a maturity period of about 90 days, the NCA stipulated the following criteria :

Monthly rainfall (cm) in 3 consecutive months	*Compatible crops*	*Examples*
>30	Crops having high water need	Paddy
20-30	Crops whose water need is high but not as high as paddy	Black gram, maize
10-20	Crops having moderate water need	Bajra, small millets
5-10	Crops having low water need	Ephemeral grasses
<5	Not of agricultural significance	—

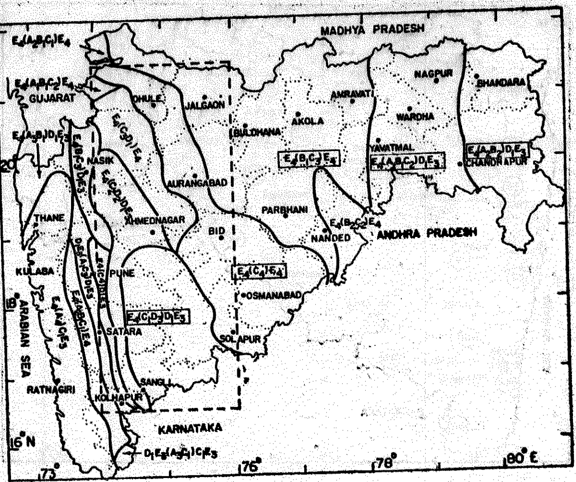

Fig. 5. Rainfall distribution pattern based on monthly normals. Symbols explained in text

(*Source* — Rep. National Commission on Agric.)

Related to this, the monthwise rainfall was represented symbolically as: A(>30 cm), B (20-30), C (10-20), D (5-10) and E(<5). A subscript was used to denote the number of months falling under the particular category. The complete code gave information groups pertaining to February-May, June-September and October-January.

For example, D_1E_3 (A_2B_2) C_1D_3 would be interpreted as: (*i*) during February-May, one month's normal rainfall is in the 5-10 cm range and that of the other months is in the 0-5 cm range, (*ii*) in the monsoon season, two months receive more than 30 cm and two between 20-30 cm, (*iii*) in the months October-January, one month is of the C category and three of the D category.

A distribution of the type E_4 (A_4) E_4 would mean copious rainfall in the monsoon season making up for most of the annual rainfall.

The NCA has produced Statewise maps on the 1:1 million scale showing isolines which join stations having identical formulations. Usually, the isolines are drawn along taluk boundaries except where variations within a taluk are significant. The NCA map for the State of Maharashtra is of the type shown in Fig. 5. The original maps are larger in scale than any rainfall maps published so far, making it easier to interpolate the information. With certain simplifications, 62 rainfall patterns have been recognised in the whole of India and the zones in which they exist have been delineated. Similar types of maps have been prepared to show the prevailing cropping patterns and livestock population which is of great significance to Indian agriculture. In addition, other relevant factors like orography, human population density, soils, agroclimatic conditions other than rainfall, food habits of people, economic conditions, have been given due weightage while framing recommendations for new cropping patterns.

The NCA approach to rainfall mapping, in effect, condenses in a single map quite the same information that one may derive by referring to 12 separate monthly maps. This makes the data highly manageable, especially for large-scale planning purposes.

The NCA map for Maharashtra clearly brings out variations of agroclimate over the State with the entire coastal belt having an E_4 (A_4) C_1E_3 classification, a multiplicity of patterns on the leeward side of the Ghats, the bad rainfall zone of Madhya Maharashtra having C_4 to C_1D_3 type rainfall in the monsoon, and the good rainfall area of Vidarbha. The main crop in the coastal belt is paddy, the yield levels being on par with the national average. It has, therefore, been recommended that efforts should be made to increase the yields in view of the A_4 rainfall. Over the Ghats and adjoining area, it may be possible to raise some plantation crops. Tuber crops, economic tree crops and grasses for fodder could be considered for the heavy rainfall areas. Paddy is also being grown in Bhandara and Chandrapur districts, but yields are low because the A_2B_2 type rainfall cannot sustain the crop through later stages. Paddy could be replaced here by a less water requiring crop like maize. The NCA has recommended that changes in the cropping pattern are required in Madhya Maharashtra where rainfall is C_2D_2 or C_1D_3 during the monsoon.

6. Further use of monthly normals

The NCA map is a fine example of the use of monthly rainfall normals in agroclimatic mapping, which is capable of interpretation in practical terms. The author has chosen an area bounded by 74 deg. E and 76 deg. E longitudes, and 16 deg. 30 ′N and 21 deg. 30 ′N latitudes, for further examination on similar lines. This area (hereafter called "Problem area") encloses parts of Madhya Maharashtra and Marathwada having critical rainfall. The monsoon rainfall deteriorates eastward and southward in the problem area from C_4 to C_3D_1, C_2D_2 and C_1D_3.

In rainfed agriculture, different strategies have to be adopted in years of (*a*) normal monsoon, (*b*) normal onset of monsoon followed by long dry spells, (*c*) delayed onset, (*d*) early withdrawal of monsoon, or (*e*) late withdrawal (Krishnamoorthy 1977). While the NCA map

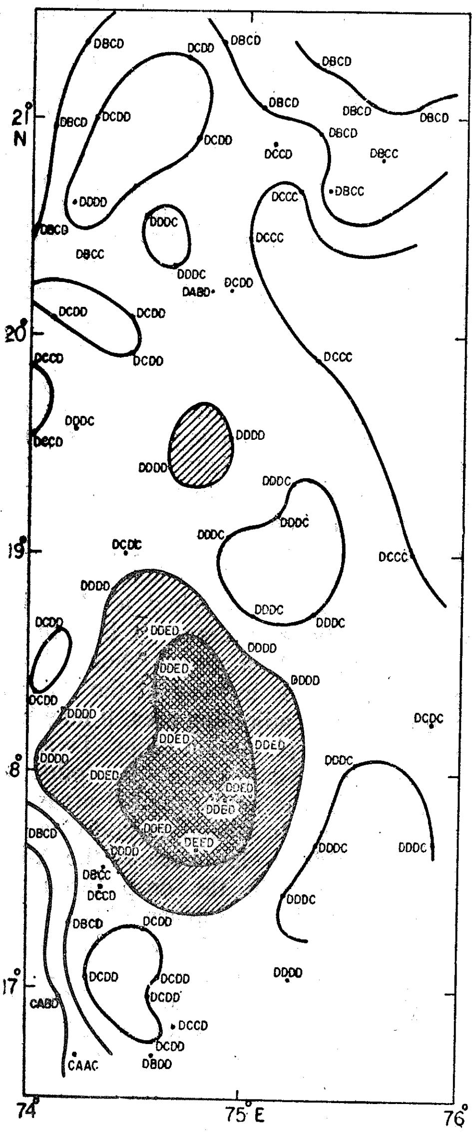

Fig. 6. Normal monthwise distribution of rainy days in the monsoon season. Symbols explained in text. Area corresponds to that demarcated by dashed line in Fig. 5

is useful for examining the extent of matching or mis-matching between rainfall and cropping patterns, a supplementary rainfall analysis is required, to plan agricultural strategies in the kharif and rabi seasons. Since in low rainfall areas, a heavy downpour on a single day may account for a large share of the month's rainfall, but which is actually lost as run-off, the author has considered the number of rainy days per month for this analysis instead of the monthly rainfall. The normal number of rainy days per month are categorised symbolically as A(>16), B(12-16), C (8-12), D (4-8) and E (<4). On this basis

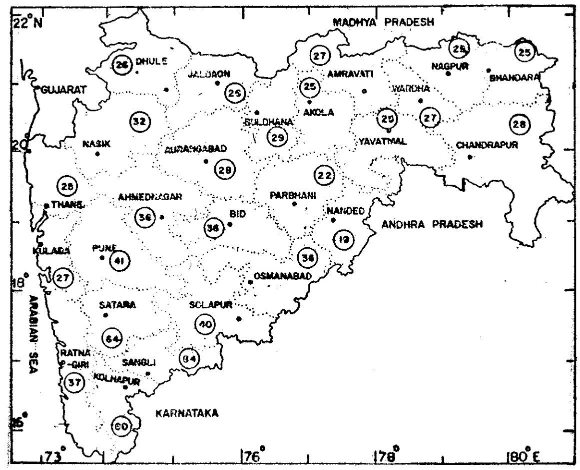

Fig. 7. Normal rainfall in October expressed as percentage of that in September. Values are representative of districts

the monthwise distribution of rainy days during the monsoon is represented by a 4-letter word. For example, DBCD would mean 4 to 8 rainy days in June, 12 to 16 in July, 8 to 12 in August and again 4 to 8 in September. The patterns of rainy days for all the stations in the problem area are plotted in Fig. 6 and stations having identical codes are joined by isolines.

Fig. 7 shows the percentage of October rainfall to September rainfall as obtained from district normals. Since the monsoon withdraws normally from Maharashtra by 1 October, this map gives additional information about the length of the rainy season.

Figs. 6 and 7, in spite of their apparent simplicity, can throw light on many important questions. Stations in the DBCD, DCCC and DCDD category are mostly in the northern part of the problem area and also in its southwest corner. Here the number of rainy days in July is normally much greater than that in June. This suggests that the optimum time of kharif sowings would be late June or early July, which is also confirmed by the CSR dates (Fig. 2). These places have also good scope for collection of surface run-off in farm ponds from the earlier spells for giving protective irrigation later in the season. It is noticed that at places in the north of the problem area, monsoon is likely to withdraw earlier since the October rainfall is only one-fourth of that in September. Early-maturing varieties are recommended here. However, stations in the same category but in the southwest corner of the problem area, have an extended rainy season, rainfall in October being 60-84 per cent of the September amount, Stations in the DDDC category are chiefly in the southeast sector of the problem area. The possibility of dry spells would be high and equally so in the months of June, July and August, rendering the identification of sowing rains impracticable. The situation in September-October is, however, hopeful and should be considered for the early sowing of rabi crops. Kharif cropping is risky and would demand hardier crops. Intercropping has to be resorted to for reducing risk of total failure in bad years.

The hatched area DDED enclosed within another area DDDD, is the worst on all counts. It is interesting to see that it corresponds to the drought-prone area indentified by CSR mapping or through weekly prohability analysis. It would, however, again be impracticable to fix mean CSR dates. Kharif crops would be liable to suffer extreme moisture stress, with less than 4 rainy days in August in the DDED zone and would require life-saving irrigation. It would also be necessary to undertake all possible water conservation measures. Otherwise, kharif agriculture in this area would entail a risk of the highest order, leaving hope only for the rabi season. Here again, early rabi sowings can be recommended.

7. Conclusion

(*i*) The ideal process of agroclimatic mapping might be to start with a crop, determine its climatic requirements, and then map out the areas where it can be grown. In practice, this is far from possible. We know very little about crop-weather relationship in the widest sense of the term. Efforts in this direction lag far behind the rate at which new varieties are being released everywhere.

(*ii*) Although water is the most limiting factor in Indian agriculture, rainfall is only a part of the picture. We need to pay due attention to water loss by evapotranspiration, the capacity of the soil to retain moisture, run-off from heavy showers, and other items of the water budget. Unfortunately, the data about them are too scanty to enable preparation of maps.

(*iii*) Under the present circumstances, there is a vital need to put to use the available rainfall data for broad-based agricultural planning. An attempt has been made in this paper to show that agroclimatic maps based on a manipulation of monthly rainfall normals already available, can be as meaningful as those derived from sophisticated exercises using daily data.

(*iv*) Maharashtra was used as an illustration because the many studies already carried out for this State provided a base for comparison. The approach suggested in this paper can easily be extended to other parts of India with only slight modification to conform to regional peculiarities.

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