Agroclimatic classification on the basis of moisture availability index and its application to the dry farming tract of Gujarat

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Abstract. Weekly Moisture Availability Index (MAI) at different probability levels has been calculated at 81 stations in the dry farming tract of Gujarat. This tract has been divided into four agroclimatic zones, i.e., D, E, F, and G on the basis of MAI at 50 per cent level. The zone D is the low crop potential area where rained crops are possible in 30-40 per cent of the years. A short duration crop may be grown from area E at 40-50 per cent of occasions. Area F has the potential to grow crops 50-55 per cent of years. Rained crops may be raised in 60 per cent of the years from area G. Moisture availability index at 40, 60 and 70 per cent levels have also been computed to find out agricultural potential at different risk levels. From this analysis, it is possible to identify the core of low crop potential area and time of life saving irrigation. Crop prospect of one station at each zone at various risk levels has been discussed, taking into account the water stress period, type and depth of soil.

1. Introduction

The basic requirement for a study of dryland farming is the rainfall pattern and water availability period. A certain amount of rainfall does not indicate that all that amount will be used up by the crop, because the same amount of water behaves differently depending on the atmospheric demand of the place, depth and slope of the land. So, it is required to account for not only assured rainfall but also atmospheric demand of a place and type and depth of the soil for any agroclimatic classification and to know crop potential of a place.

More than 80 per cent of the area of Gujarat comes under dry farming tract which is defined as an area where annual rainfall varies from 400 to 1000 mm and arid zone. Only eleven per cent of cultivatable land enjoys the benefit of irrigation.

There is scope of increasing irrigation, but estimates show that area under irrigation is not expected to be more than 40 per cent of total cropped area even in 2000 A.D. (Commission on Agriculture 1976). Therefore, it is necessary that a close study of the climatic resources of the State is made so that the information evolved may be made use of for increasing agricultural production.

Isolated attempts were made to study rainfall and in a few cases it was tried to correlate with yield. National commission on Agriculture (1976) tried to divide the State into different parts on the basis of monthly rainfall and average temperature. Gujarat State Government (1976) demarcated the State into different agroclimatic zones on the basis of monthly rainfall, average maximum and minimum temperatures. Khambete and Biswas
(1978) studied runs of wet and dry spells and computed weekly probabilistic rainfall of 15 stations taking one station in each district.

An attempt has been made in this paper to classify the dry-farming tract of Gujarat into various agroclimatic zones by using moisture availability index so that the agricultural scientists and progressive farmers may get reliable guidance of crop potential of a place at different risk levels.

Review of literature

The earlier attempts to classify climate mainly centred round the identification of average annual, seasonal or monthly rainfall and/or temperature regimes that naturally produced some typical types of vegetation or crops in abundance [Koppen (1936), Prescott (1938), Trewartha (1954), Burgos (1958) and others]. Thornthwaite (1948) developed the concept of potential evapotranspiration (PE). He adopted the water balance technique by using monthly PE and average monthly rainfall for the calculation of the various degrees of water surplus and water deficit and the classified climates with the help of these parameters. He & Mather (1955) further improved the work by incorporating realistic assumptions. Subrahmanyan (1956) made a classification of India’s climates following this method. For assessing agricultural potential of various countries Padakais (1961, 1975) used a very simple water balance technique along with average maximum and minimum temperatures. Although Thornthwaite & Mather and Padakais used some kind of comparison between the potential evapotranspiration and the water available from precipitation, the results obtained by them are not quite satisfactory as the respective empirical formula, used by them to compute evapotranspiration are not found suitable for universal application. Because wind speed and radiation which play a vital part for the loss of water, especially in the tropics, are not taken into account. Moreover, the period used by them is too long in comparison with the entire life cycle for a present agricultural crop. And as they used only monthly average rainfall, their methods do not help the users to assess the element of risk involved, if agriculture of a country is planned using their classifications.

Wallen et al. (1962) improved upon their methods by using Penman’s formula for calculating potential evapotranspiration for purpose of water balance and by providing a very rough and short range answer to a risk factor by coupling the water balance with inter-annual variability of annual rainfall. Cocheme and Franquin (1967) used monthly precipitation and potential evaporation to find out the crop growing period and suggested tackling of the risk factor from probability of rainfall determined by semi-logarithmic distribution. Hargreaves (1971) used the ratio of monthly assured rainfall at 75 per cent probability level and average monthly potential evapotranspiration calculated by Penman’s method to classify agroclimate of northeast Brazil.

Short period rainfall distribution is skew, the skewness being more when the period is short (monthly, bi-weekly, weekly). Under this condition the use of incomplete gamma distribution gives a better fit (Mooley 1970, 1973 and Sarker et al. 1981). Hence use of the probability of rainfall obtained from such a distribution should be more appropriate in handling the risk factor.

2. Method

Several factors have to be considered to assess the agricultural potential of a place. Among these, an accurate evaluation of the moisture available to plants during their various phases of growth at different probability levels of rainfall is the most important.

2.1. Choice of interval

As already mentioned, a month is too long a period compared to the entire crop-life. This is particularly so now a days because the plant breeders are constantly evolving new varieties of short duration to raise more number of crops per year for increasing production. Use of monthly rainfall suffers from another defect too. There are areas where even during the height of the wet season the daily rainfall varies immensely in amount, so that a month’s average rainfall may be realised only in a few days (say a week or even less) while the rest of the month may go dry. If this happens during the early part of the life of a crop, it may cause irreparable damage to it. In the tropics where the rainfall is generally of a showery type and highly erratic in intensity, amount and distribution (both in time and source), it is necessary to use the week as the unit of time at least for the early part of the crop-life and later not more than two weeks and a taluka or its equivalent as the unit of area.

2.2. Moisture availability index

An index called the Moisture Availability Index (MAI) has been defined as the ratio of assured rainfall (weekly, bi-weekly or monthly) to potential evapotranspiration of the corresponding period. This MAI has, however, been calculated for 30, 40, 50, 60 and 70 per cent probability levels, although the climatic classification has been done on the basis of the index at 50 per cent level. Considering the MAIs at all the probability levels, a suitable label can be selected for each zone depending upon the duration of adequacy of moisture.
2.2.1. Range of MAI

Water requirement of a plant growing under natural conditions mainly consists of three parts, namely (i) transpiration for maintenance of its life process, (ii) Evaporation from soil and (iii) the part that enters into its body-building. The first two together are known as evapotranspiration. The last one is small compared to the sum of the first two that it is neglected in agro-meteorological studies and actual evapotranspiration is taken as a good measure of the water requirement of crop plants.

It is very difficult to have data on actual evapotranspiration which varies with the growth of the plant and also perhaps, to some extent, from crop to crop. However, it is assumed in the all agrometeorological studies that potential evapotranspiration covers the maximum requirement of fully grown crop plants (the peak period of their moisture demand) covering the soil surface completely. It has been found that during its early stage of growth (first 3 to 4 weeks) actual evapotranspiration is about a quarter of the potential rate due to small and sparse foliage and that the maximum demand may even slightly exceed the potential rate if the size of the field is not too large and there is considerable advection of sensible heat into crop field (Replay 1966). But experiments have shown that due to its stomatal openings to restrict transpiration when there is moisture stress plants grow almost normally as long as the moisture supply does not fall below about three quarters of the potential rate (Arnon 1972). After completion of grain formation the water demand falls off rapidly becoming small at the ripening stage (Holmes 1963).

In view of above, the classification in the present study has been made on the basis that a crop will be nearly normal if it gets moisture varying from 0.3 to 0.7 of potential evapotranspiration commencing from germination to completion of grain formation stage. The varying degree to which this condition is satisfied using precipitation expected at different probability levels obtained from incomplete gamma distribution forms the basis of the present study.

2.2.2. Criteria for classification

Classification has been made using MAI mentioned above. Increasing MAI both in duration and magnitude has been denoted in alphabetical order of the English capital letters starting from D. Some letters at the beginning, i.e., A to C have been kept reserved for classification, by the author, of arid zone where annual rainfall is less than 400 mm.

Following is the classification in the present study:

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<tr>
<th>Classification</th>
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2.2.3. Sub-division to water stress period

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

2.3. End of growing season

Cessation of rainy season does not mean the end of crop season. Crop can thrive on stored moisture. It is, therefore, necessary to examine and find out the amount of moisture stored in the soil at the end of the season when MAI is just 0.3. This could be done by the water balance technique which is not within the scope of present study. However, the cumulative seasonal evapotranspiration for dry land crops like sorghum etc., even under relatively favourable moisture conditions, may be only 65 per cent of PE (Jenson 1968). Replay (1966) observed that in many farm crops seasonal water use may range from 55 to 75 per cent of PE.

India Meteorological Department installed about 35 lysimeters in various soils and climatic zones of the country to find out the water requirement of different crops. Venkataraman et al. (1976) found that cumulative seasonal ET is about 70 per cent of the PE. It has, therefore, been taken for this study that difference between seasonal total assured rainfall and two-third of PE of the corresponding period will go into stored soil moisture and the plant can use it even after the end of rainy season.

It may be noted that the use of potential evapotranspiration in this classification takes account of an integrated picture of air temperature, radiation (sunshine duration), relative humidity and aeration (wind speed), the meteorological factors known to influence the health and growth of a plant. Temperature has, therefore, not been considered separately in classifying agroclimatic zones specially in the area under consideration, where variation of maximum and minimum temperatures is not much during the monsoon season.
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2.4. Rational approach to dependability

Table 1 gives the MAIs of weekly and bi-weekly assured rainfall at different probability levels for selected stations. It is seen that classification based on weekly MAIs at 50 per cent probability level remains practically same as that of bi-weekly at 60 per cent level. In other words for the purpose of classification, use of weekly MAIs at 50 per cent probability level is equivalent to using the bi-weekly MAI at 60 per cent level during the period when MAI is more than 0.3. An examination of MAIs and assured accumulated rainfall at various levels leads to a conclusion that, in general dependability increases by 10 per cent if one switches over from weekly to bi-weekly analysis. But as mentioned earlier, it should be kept in mind though the minimum water requirement for the crop in its early stage is low, it is very susceptible to moderately prolonged moisture deficiency. Hence, choice of a bi-weekly assured rainfall is not desirable for the early growth stage, particularly in areas where time variability of rainfall is high. Secondly, each week is not carried over to the successive weeks. But in reality the crops do not suffer such water stress for two or three weeks after a heavy rainy week. This situation occurs on many occasions during the monsoon period in the tropics where most of the rainfall occurs in association with synoptic disturbances. Thirdly, due to the adoption of drought resistant crops, the yield may be more or less good even under partial drought condition. In view of the above, the dependability may be 10-15 %, more than what has been brought out by this classification.

3. Data

Application of the classification — The classification developed has been applied to the dry farming tract of Gujarat (Fig. 1). The following data have been used for this purpose. Weekly assured rainfall at different risk levels of 76 stations computed by Biswas and Basarkar (1981) has been used in this study. Weekly potential evapotranspiration has been obtained by interpolation both in time and space from monthly PE calculated by Rao et al. (1971). Soil characteristics have been extracted from Technical Bulletin No. 36 published by Government of Gujarat. There are 184 talukas in the Gujarat State. Of these about 120 talukas come under dry farming tract. It would have been ideal to have had one station in each taluka, but it was not possible due to paucity of data. Five stations in arid zone have been used for the sake of comparison.
## Table 2

**MAI, PE and Accumulated Assured Rainfall (AAR)**

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AGROCLIMATIC CLASSIFICATION OF DRY FARMING TRACT OF GUJARAT

4. Discussion

Dry farming tract of Gujarat has been divided into four broad climatic zones following the present classification based on MAI. It is already mentioned that type, depth and quality of soil play a vital role for crop production. Even the same climatic of two different places will give different yields due to variation of soil. When the climatic information is superimposed over that of soil, it will give various agroclimatic zones. Fig. 2 gives such an agroclimatic classification of Gujarat. Figs. 3 and 4 give the accumulated assured rainfall (AAR) during the period when MAI is more than 0.3 at 30 and 50 per cent levels respectively. Table 2 gives the MAI at 40 and 50 per cent levels along with the agroclimatic classification whereas Table 3 depicts the MAI of 60 and 70 per cent levels. These tables reveal the gradual reduction of moisture adequacy period with increasing probability level. Appendix I gives the dates of standard weeks.

In the same climatic zone variation of depth-texture, field capacity and wilting point of the soil are so much that cropping pattern of each zone has not been suggested as all this information is not available. Moisture adequacy at various levels has been discussed. Cropping pattern has been left to the agricultural scientists or progressive farmers of the region. These zones are discussed below:

4.1. Area D

This area comprises of Jamnagar and Surendranagar districts, parts of Junagad, Rajkot and Banaskantha districts. Three types of soils are found over this area namely, coastal alluvial, medium black and sandy soil.

Coastal alluvial soils are found in Porbandar and adjacent coastal area. As this soil is formed from a mixture of black clay material and old marine salt deposit, it has good water holding capacity. Soil of this area is about 60 cm deep.

Medium black soil is observed in the whole area of Saurashtra except in the coastal region. Depth of the soil varies from a few centimetres to 60 cm. At many places colour of the soil in the surface layer is dark grey to light grey and the texture is clayey. A layer of murum is generally found at 40-60 cm depth. Field capacity of this soil varies from 21 to 27 per cent by weight.

Sandy soil is found in Surendranagar district. This soil contains very low percentage of clay and has good drainage capacity. But irrigation facilities are low due to paucity of water resources. Moreover, the underground water being brackish is unsuitable for irrigation.

Prospect of dryland crop once in two years is speculative as MAI more than 0.7 varies from zero to 4 weeks. Even at 40 per cent probability level it is difficult to raise short duration crop from many stations. At 30% level most of the stations have the potential to raise a crop of 14-16 weeks duration as MAI is more than 0.3 for these weeks and accumulated assured rainfall varies from 559 to 353 mm.

4.2. Area E

This may be considered as a transitional zone. Parts of the districts of Junagad, Rajkot, Bhavnagar, Ahmedabad, Mehsana and Banaskantha come under this zone. In this area three types of soils can be identified. In the coastal zone, soils are alkaline in some places. Depth of soil varies from 40 to 70 cm. The major portion of the soil is medium black. Porosity of soil is good and the soil is rich in chemical nutrients. Sandy soils are found over Chanasma and Patan talukas of Mehsana district and Dhanera, Deesa and Barij talukas of Banaskantha district.

In this area MAI at 50 per cent level is more than 0.3 and 0.7 at least for ten and one weeks respectively. Most of the stations are not suitable for rainfed agriculture although in a few stations short duration crop may be raised. Table 2 (40
per cent probability level) shows that MAI more than 0.7 varies from 4 to 9 weeks. A medium duration (12-16 weeks) crop may be raised from this area. A mixed crop or a long duration crop may be grown at 30 per cent probability level as accumulated assured rainfall is about 600 mm in many stations.

4.3. Area F

Almost 50 per cent of area of dry farming tract of Gujarat is under this zone (Fig. 2). Proportion of sand is more and soil is fairly deep in most of the area. Clay loam or loamy clay soil is dominant in a major part of Ahmedabad, Mehsana, Sabarkantha and most of Kaira district. Medium black soil is found over Jumagadh, Amroli and Bhavnagar except in the coastal area. This soil is fairly deep and of good water holding capacity. Sandy soil is noticed in the northern part of the region and depth of this soil is about 70 cm. In the coastal area clay soils are dominant and in many places in this region soils are alkaline.

Duration of MAI at 50 per cent level more than 0.3 and 0.7 is at least 11 and 3 weeks respectively. Table 2 and Fig. 4 show that accumulated assured rainfall is more than 400 mm in many stations. From most of the area a short duration rainfed crop may be raised. Table 2 gives the total assured rainfall at 40 per cent level which is as high as 650 mm in many stations. Duration of MAI more than 0.3 is about 13 weeks of which for 7-8 weeks it exceeds 1.0 and the porosity of soil is more or less good. Hence a good amount of stored moisture may be available at the end of the rainy season. A medium duration (14-16 weeks) crop or a mixed crop can be raised from this region. Two short duration crops can be had from some of the stations, with proper adjustment of sowing time.

4.4. Area G

This region occupies a comparatively small area of Gujarat, but at the same time three types of soils are found in it, i.e., alluvial, sandy loam and loamy sand. Depth of the soils is about 60-70 cm and it is well drained. This area mostly comprises of parts of Broach, Baroda and Panchmahal districts. Medium black soil is observed in the northern parts of Baroda and deep black soil is predominant in the southern parts of Baroda and Broach districts.

In this zone, MAI will be more than 0.3 and 0.7 at least for 14 and 7 weeks respectively. Table 2 shows that accumulated assured rainfall varies from 667 to 386 mm and stored soil moisture available in many stations at the end of the rainy season could be used by the plants. Therefore, crop growing period may be extended even after cessation of the rainy season. A crop of 14-18 weeks duration could be raised from this area once in two years. Even at 60 per cent probability level (Table 3) a medium to short duration crop may be raised from some parts. Table 2 shows that crop prospect is very high at 40 per cent probability level as seasonal assured rainfall ranges from 960 to 590 mm. Most of the stations are having potential of two short duration crops or a mixed crop.

4.5. Crop prospect at a few representative stations

Crop potential at various probability levels of one station of each agroclimatic zone has been discussed taking into consideration the depth and type of soil. In this discussion socio-economic problems of this station have not been taken into account.

4.5.1. Jamnagar

This station is having medium black soil about 90 cm depth of good porosity. There is hardly any problem of drainage. Soil is fertile and there is much difference in chemical and physical properties of the soil at different layers.

The station comes under D zone. MAI is more than 0.3 for 5 weeks only at 50 per cent level but all these weeks it is less than 0.7 (Fig. 5). No rainfed crop is possible once in two years. MAIs are
### TABLE 3

**MAI, PE and Accumulated Assured Rainfall (AAR)**

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4.5.2. Deesa

It represents the sandy loam soil of zone E. Depth of the soil is about 60 cm with good porosity. Field capacity of the soil is 12-14 per cent by weight. Salinity is one of the major problems which is further increased due to deposition of desert sand containing salt.

Fig. 6 depicts MAIs at different probability levels. The number of weeks with MAI more than 0.3 and 0.7 is 10 and 3 weeks respectively once in two years. A short duration cereal like groundnut and pulses may be raised with one/two irrigations. Crop prospect at 40 per cent level is good as MAI is more than 0.7 for 10 weeks. Plants can thrive on stored moisture after cessation of rainy season as total assured rainfall there will be more than PE by 150 mm at 30 per cent level. A crop (jowar, millet) of 14-16 weeks duration may be raised in rainfed condition.

4.5.3. Palitana

It represents medium black soil of climatic zone F. Depth of the soil is about 60 cm. Colour of the soil is dark grey to light grey. It has medium porosity and hardly any problem of drainage.

MAI at 50 per cent probability level is more than 0.3 for 13 weeks from 25th to 38th except 34th week (Fig. 7). A crop of 12-14 weeks duration (jowar, millet, pulses) may be possible to be raised. Rainfed crop at 60 per cent probability level is not possible to be grown. Crop prospect at 40 per cent level is very good as MAI is more than 0.7 for 9 weeks and total assured rainfall is about 420 mm. Short duration cotton, jowar and ground-nut may be suitable in this land. Two short duration (kharif followed by rabi crop) crops or a mixed crop may be raised once in three years because crop may use stored moisture at the end of rainy season as total assured rainfall is more than PE by 115 mm.

4.5.4. Baroda

Baroda comes under zone G having alluvial sandy loam soil. Depth of soil varies from a few centimetre to more than a metre. There is hardly any difference observed in respect of soil properties at different layers. Drainage problem is not much as the soil is having good porosity.

As MAI is more than 0.7 for 11 weeks and total assured rainfall is more than PE (Table 2), a crop of 14-16 weeks duration (short duration cotton, paddy and millet) may be planned for this station at 50% level. Fig. 8 and Table 3 show that 11-13 week duration crop is possible to be raised in rainfed condition at 60 per cent probability level. A short duration crop (ground-nut, pulses) may be grown with one or two irrigation even in 70 per cent level. A mixed crop or two short duration crops may be raised at 40 per cent probability level. Crop prospect at 30 per cent level is very high as crop can thrive about 4 weeks after cessation of rainfall.

5. Conclusions

The present analysis enables one to demarcate the dry farming tract of Gujarat into four zones. The zone D is the low crop potential area; rainfed crops are possible to be raised in about 30-40 per cent of the years. A short duration crop may be grown from area E at 40-45 per cent probability level. Area F has the potential to raise a crop in 50-55 per cent of the years. Rainfed crops may be raised more than 60 per cent of the years from area G.
Duration of stress period at different probability levels and time of life saving irrigation at various levels could be identified from this study.

Soil moisture storage at the end of rainy season at different risk levels could be roughly identified so as to find out where the crop could thrive on stored moisture after cessation of rain.

The core of low crop potential area is located around western part of dry farming tract and an area comprising of Ranpur, Danduka and Dholera, where accumulated assured rainfall is only about 100 mm at 50 per cent probability level but at 40 per cent level it exceeds 400 mm.

Acknowledgements

The author wishes to express his sincere thanks to Dr. R.P. Sarker, Deputy Director General of Meteorology (C & G), for his guidance and encouragement. The author also thanks Dr. A.K. Mukherjee, Deputy Director General of Meteorology (WF), Shri S. Venkataraman, Retired Director, Shri P.E. Morey, Smt. N.N. Kambete and Shri P.S. Nayyar for their constructive criticism. Thanks are also due to the staff of DFR unit and drawing branch and Shri S.R. Das for typing the paper.

References


Subrahmanyan, V. P., 1956, "Climatic types of India according to rational classification of Thornthwaite, Indian J. Met. Geophys., 7 (3).


Appendix 1

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*In leap year the week No. 9 will be 26 February to 4 March, i.e., 8 days instead of 7.

**Last week will have 8 days from 24 to 31 December.