Chapter V
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In the recent years the main emphasis of national efforts has been towards stabilisation and augmentation of agricultural production in dry farming areas because 70% of Indian agriculture is devoted to dry farming. The dryland farming is exposed to large variation to rainfall from year to year. The evaporation losses are higher due to arid climates. Irrigation is minimal. Therefore, for developing dryland farming systems on firm scientific basis, it is necessary to build up adequate scientific knowledge on rainfall climatology. The main focus of this thesis has been to quantify the environmental conditions particularly rainfall related variables and their interaction with crops and soils. This has been achieved through a detailed examination of the following features:

1 - Monthly and weekly rainfall analysis applying Markov Chain and Incomplete Gamma Distribution analytic techniques.

2 - Agroclimatic classification by Moisture Availability Index (MAI).

3 - Estimation of weekly soil moisture storage by water balance techniques and the determination of growing period on the basis of Moisture Availability Index (MAI) and AE/PE ratios.
Fitting water requirements of long, medium and short duration crops to the probabilities of moisture availability.

On the basis of analyses described above, following conclusions can be highlighted.

The rainfall, which is variable in both the temporal and spatial dimensions is characterised by a characteristic seasonal pattern which occurs mainly during the period of SW monsoon. Rainfall is low (550 mm) at Vijapur in Western part of Marathwada and increases to 1200 mm at Kinwat on the Eastern part of Nanded district. The average annual rainfall for the region is 800mm. The variation in the amount of rainfall is mainly because of the presence of transverse ranges of Western Ghats which give a ground contour in the vicinity of study area. The degree of reliability of the rainfall also shows a general regional variation which is lower in the Eastern part compared to the central region. The highest annual rainfall in the region was observed at Kinwat (2049 mm) in the year 1955 while the lowest was recorded at Ashti (162 mm) in the year 1972. An analysis of the rainfall data showed that the years 1920 and 1972 were exceedingly poor monsoon years almost over the entire region. The monsoon rainfall was above normal for most of the stations studied during the period 1930 to 1958. The rainfall series filtered with a ten year window shows a gradual decrease in the average rainfall amount since 1958 for all the stations except Nanded and Farbhani.
Vijapur and Ashti talukas belonging to the Western part of Aurangabad and Beed districts can be identified as less Assured Dependable Rainfall area (260 mm); while area of high assured dependable rainfall is seen in Nanded district where it varies between 540 mm to 640 mm.

On the basis of peak in Assured Rainfall pattern Marathwada can be divided into 3 homogeneous zones (A, B, C). Fig. 3.9.

Region A; is characterised by a single peak of Assured Rainfall in July. It covers central Northern and Eastern part of the study region. The average Assured Rainfall is 433 mm and 674 mm at 75% and 50% probability levels respectively. The dependable rainfall increases from North-West to East.

Region B, in this region peak in Assured Rainfall is experienced in August. The average dependable rainfall is 540 mm which varies between 451 mm and 649 mm. At 50% probability level the average Assured Rainfall is 843 mm; its range is 709 mm and 993 mm. The Eastern part of the study region comprising of Kinwat, Kallamnuri, Bhokar and Hadgoen is included in this region. This region has the greatest agricultural potential as per to the assured rainfall analysis.

Region C, Assured Rainfall is high in September followed by July, more than half of the study area is included in this region. The average Assured Rainfall is
379mm and 580mm at 75% and 50% probabilities respectively. Region C has a bimodal rainfall distribution, therefore farmers can raise short duration crop in rainy season as well as a crop in the post-rainy cropping season in order to obtain maximum benefit.

Probability of constant weekly rainfall totals reveals that Initial Probabilities of receiving small amounts of rainfall (≥ 5, or ≥ 10 mm/week) are higher in most of the region. However for the larger amounts of rainfall (≥ 20, or ≥ 30 mm/week) higher probabilities are noted only for a few weeks and that too in Nanded district only. The probability of receiving ≥10 mm is 100% for MW 31 and MW 32 for Kinwat which indicates assured rainfall during this period. This period (MW 31, 32) could be utilized for adjusting a sensitive growth stage of the crop or for the application of fertilizer as a top dressing.

For most of the locations except Western parts of Aurangabad, Beed and Osmanabad districts the probability of getting sowing rains is ≥ 75% in MW 26 (25 Jun. - Jul.). This indicates a good time for the sowing of rainy season crops.

The conditional probabilities of wet week followed by wet week (w/w) indicate that the probability of continuous rain from MW 18 to MW 21 is low (25% - 35%) for the entire region. Such results indicate that planting in early June would appear particularly hazardous when April/May rainfall had been low, the moisture - storage in the top soil would be
minimal due to high evaporation. The traditional farming practice has been to sow crops with first rain, while, from the analysis of these data it would appear advisable to delay planting till late June (MW 25) when the probability of rainfall is high (75%) and continuity is more assured (W/W probability is high).

By late July, rainfall probabilities show appreciable increase in all of the region, which shows a good promise for arable agriculture.

By late August (MW 35-36), the highest probability of rainfall is observed for most of the region. It indicates that the monsoon is very active during this period. The crops are most sensitive to soil moisture stress at this stage due to their high water requirements at flowering stage. MW 35, 36 is the period which generally coincides with flowering stage. Therefore sowing of rainy season crops should be adjusted so that flowering period coincides with MW 35 to 36 in the region.

The weekly rainfall probability analysis is an index of rainfall availability period and the likelihood of its continuation week by week over the growing season. Based on the continuity of receiving ≥ 10 mm weekly dependable rainfall, the region has been divided into three zones (1, 2, 3). Fig. 3.12.

The Western region (zone I). It comprises of Beed, Vijapur and Ashti talukas. It has less than 5 continuous
weeks of dependable precipitation. The probabilities of rainfall during the growing period are low (60%).

In the Eastern region (zone III) which is represented by Kinwat, Kalamnuri and Bhokar talukas, the continuous length of assured rainfall exceeds 10 weeks (MW 25 to MW 36). In the remaining areas (Zone II) the length of the continuous dependable rainfall exceeding ≥ 10 mm per week ranges between 5 and 10 weeks.

An analysis of the potential evapotranspiration trend reveals that higher values of PE are observed in the Southern region (Osmanabad). The PE values decrease towards West (Beed) and the Northeastern side (Nanded). During the rainy season, the PE values are lower than in the other seasons of the year.

On the basis of Moisture Available Index (MAI) the study region can be divided into 6 different agroclimatic zones (A, B ... to F).

As per this classification, region A has at East two continuous months with Excessive Moisture (EM). It is a high rainfall zone of the study area which provides favourable conditions for cultivation of medium and long duration crops like cotton such crops can be grow with minimum risk in this zone.

The agroclimatic region B has two consecutive months of Adequate Moisture condition (AM) (July, August). In this
region the amounts of dependable precipitation are adequate during most of the season, as such the crop would not be exposed to water stress. The farmers can therefore easily go in for medium and long duration crops. Introduction of suitable crops cultivars and efficient management methods of farming can increase the production of this region to a high level.

Region C. It is characterized by 3 continuous months having Somewhat Deficit Moisture condition (SD). It has an Assured Dependable Rainfall between 379mm and 449 mm. In this region the farmers can grow short to medium duration crops.

Region D. In this region there are two months of Somewhat Deficit (SD) and two months of Moderately Deficit (MD) moisture. Assured Dependable rainfall is between 300 mm and 450 mm. In this region medium duration crops can be raised in deep soils. Osmanabad is located in this zone. The soils are mainly medium deep black. The Assured Dependable Rainfall is 396 mm.

Region E. In this region the months of June, July and August are Moderately Deficit (MD) and September is Somewhat Deficit (SD). The Assured Dependable Rainfall is between 260 mm and 353 mm. Short duration crops can be easily grown. This region is more suitable for post-rainy crops e.g. Post-rainy season sorghum, Safflower.

Region F has the lowest rainfall of the study region. It has Assured Dependable Rainfall between 259mm and 261 mm
with 4 Moderately Deficit (MD) months. The rainfall is dependable only for one week i.e. MW 39. Because of the limited availability of moisture this region may be suitable for growing millet or other drought hardy crops with some fair success.

Soil water balance studies discussed in Chapter IV enable evaluation of the soil moisture regime, length of the growing season, moisture available to crops during different periods of the crop growing season.

This study has established that in the medium and deep black soils of Marathwada except in the initial week of the commencement of sowing rains the soil reaches more than 75% of the available water holding capacity. This soil moisture is maintained for more than 10 weeks in Agroclimatic zones A and B. For Agroclimatic zone C also the soil moisture exceeds 75% of the available water holding capacity for 6 to 10 weeks. Agroclimatically therefore this zone also offer an equal potential for medium and long duration crops. A study of stations in Agroclimatic zone D shows that the soil moisture storage is at 50 to 60% of the available water holding capacity for 12-13 continuous weeks. In Agroclimatic Zone E the estimated soil moisture exceeds 50% of the available water holding capacity for 8 to 10 continuous weeks. Agroclimatic Zone F has been identified as the area where soil moisture storage is the lowest amongst all the zones. The soil moisture is 50% of the available water holding capacity only for one week i.e. MW 39 for medium
black soils. There is a marked decrease in the amount of available water in MW 33-34 (Aug. 13-26) to less than 30%. Data for PE demand reveals that during this period the atmospheric demand for evaporation exceeds 27 mm, therefore any break in the continuity of rains exceeding one week would be quite a hazard to crop production in this zone.

A determination of the commencement, termination and the total length of the crop growing season (LGS) is of great utility in crop planning and for selecting crop varieties. These data are also useful for drawing a calendar of agronomic practices.

The climatic analysis reported in this thesis reveals that for the Western parts of Marathwada belonging to Agroclimatic zone F, the growing season starts late and ends early. The growing period is therefore relatively short. For the Eastern region, on the other hand [Agroclimatic Zone A and B and Eastern part of Zone C] the growing season starts early and ends late, this long growing season of 140 to 200 days on deep soils permits raising of long duration crops like cotton, pigeonpea etc.

The analysis of weekly actual evaporation (AE) in relation to potential evapotranspiration (PE) gives an idea of the pattern of water availability period during the growing season. The study for Agroclimatic region F, has shown that excellent soil moisture condition (AE/PE ≥ 0.75) is available only for 4 to 5 weeks in 7 years out of every 10
years, while this period extends to 15 to 17 weeks for rest of the Marathwada region.

The relationship between the crop moisture demand and moisture availability have also been dealt with in Chapter IV. Some of the conclusions drawn from this study are:

1. For Agroclimatic zone F, excellent soil moisture condition (AE/PE > .75) is available only for 1-2 weeks MW 39-40, while mild water stress condition is observed during MW 29, 33, 35 and 41. In this zone therefore long duration rainfed crops will be exposed to intermittent water stress. The medium and short duration crops will be exposed to moisture stress at reproductive stage if planted in MW 28 (Jul. 9 to 15). Therefore the climatic analysis suggested that farmers should adopt the practice of late sowing. The sowing time may be adjusted in such a way that flowering stage would match with the second peak in rainfall in MW 31 and 32. However in this zone available moisture is not satisfactorily obtained throughout the season. For sustainable agriculture there is need for developing alternative water resources to increase crop production.

2. For the region belonging to Agroclimatic Zone E the rainfall distribution is bimodal. The peak of rainfall occurring during the period 3rd Sep. to 7th Oct.) maintains the soil moisture at substantially higher levels after the termination of the seasonal rains.
Farmers in this region can take two short duration crops in a sequence. The analysis of data also suggests that sowing of medium duration crop such as sorghum, sunflower is preferable in August (5-10). In case of deeper soils a long duration crop like pigeonpea intercropped with sorghum can be successful if planted in MW 25.

3. Agroclimatic zone D shows a relatively better rainfall environment for crop production in rainy season. The length of the growing season varies between 17 to 20 weeks. In particular, the period between MW 26-27 to MW 40-42 (Jun. 25 - Oct 14) has excellent moisture conditions. In this zone short and medium duration crops such as mung beans, sorghum and other pulses are likely to be well supplied with available soil moisture. The chances for successful adaptation of long duration crops are low in shallow and medium deep soils. However, in deep black soils long duration crops can be adopted. Crops like sorghum, pigeonpea, cotton can be grown in inter-cropping systems. Base crops suggested are cotton and soyabean. These crops are suggested because they give significantly higher monetary returns.

The Southern part of this zone is represented by Osmanabad district. Here rainfall distribution is also bimodel. A prominent peak in rainfall is seen in July followed by another peak in September. If sowing of
crops is done as per the schedule in MW 26 then crops are likely to be exposed to mild seasonal water stress situation in 60% of the years during their reproductive stage, and 20% of the years at the maturity stage. Therefore for the Southern portion of this region it is suggested that planting of a short or medium duration crops in MW 30-31 (23 Jul.- 5 Aug.) would be a suitable practice. Long duration crops should be planted only in deep soils. The planting should be done as early as possible in MW 24 (Jun. 11-17) if soil moisture permits.

4. The Agroclimatic zone C, is suitable for the short and medium duration crops. In this zone the crops are likely to be well supplied with moisture in all the three types of soils. The long duration crops in shallow soils may face moderate moisture stress at their reproductive stage. The data on probability analysis of moisture adequacy (AE/PE) indicates that a twenty weeks crop will have 50%, 72%, and 80% chances of successful maturity in shallow, medium and deep soils respectively. Therefore for this region a successful cultivation of short and medium duration crop like sorghum, mung bean, pulses appears feasible. The farmers can go in for inter-cropping systems like sorghum and pigeonpea or cotton and black gram in the case of deep soils. Since sufficient moisture is left in the deep black soil even after the withdrawal of
rains; it is suggested that on medium and deep soils farmers should go in for double cropping of sunflower or chickpea during the post-rainy season.

5. The agroclimatic zones A and B of Marathwada which are located in the high rainfall region of the study area, the soil moisture analysis reveals a definite promise for different crops because of the high amount of soil moisture stored in the upper layers of the soil during the rainy cropping season and also after the recession of rains. There is enough soil moisture stored in the upper layer of the profile. It ensures success of crops in the post-rainy cropping season.

The water balance analysis gives an integrated index of the precipitation (R), evapotranspiration (PE) and soil. It quantifies the crop growing period and its characteristics in terms of water stress and soil moisture sufficiency periods. The water balance analysis therefore helps in the process of selection of crops with the required phenological characteristics. With substantial refinements, the methodology could be applied to any region. It also allows for the identification of ecological iso-climes with similar moisture regimes for the transfer of appropriate rainfed farming technologies. There is a great diversity in agricultural systems which is imposed by variation in the physical environment. The plant breeding efforts for developing suitable and high yielding crop cultivars will have to be integrated with appropriate farming system. It is
generally believed that a systematic approach to agriculture will help in planning and optimising land use for the present and for the posterity. It would also help in preserving the natural resources. The main objective of this thesis has been to establish through an inter disciplinary research involving the sciences of geography, climatology, agricultural disciplines and with appropriate statistical analysis an understanding of the agroecology of a dryland zone of India for sustainable agricultural planning. It has been demonstrated that the sum total of the knowledge base generated by interdisciplinary research is far in excess of the results obtained from individual scientific disciplinary analysis.

The thesis also exposes the subject of spatial variability within the Marathwada. Several agroclimatic zones have been established. These have different risk levels for sustainable agriculture. The results of the study could be also be linked to economic geography. The research presented in this thesis will assist in a better planning of agricultural land use for the Marathwada region of the Maharashtra state.