Agro-climatic zonation of Maharashtra State using GIS

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Abstract

*Agroclimatic classification is essential for planning crop pattern and to bring
out agricultural potential of a region. Moreover, the classification needs to be
done on an objective and rational basis. Agroclimatic zonation of Maharashtra
State is attempted using an adaptation of Reddy's method (1983). Long period
weekly rainfall for 47 stations and estimated potential evapotranspiration were
used. The agroclimatic variables viz., length of growing season (G), coefficient
of variation (CV) of G, mean week of sowing rains (S), variability of dry spells
(CV), variability of wet spells (CV), aridity index (%) were derived using Reddy's
method. The variables were interpolated using geo-statistical approach of kriging
to generate variable maps. The region was classified into relevant agroclimatically
homogeneous zones by integrating the variable maps in raster modeling
environment in GIS. The combination of mean of length of growing season, wet
spells and dry spells with other variables as suggested by Reddy, resulted in
inaccurate zonation. However, satisfactory results were obtained when variability
(CV) of length of growing season, wet spells and dry spells were considered. The
agroclimatic zonation resulted in delineation of 6 zones viz., arid, semiarid, dry
sub humid, sub humid, humid and per humid.*

Key words : *agroclimatic zonation, semi arid tropics, GIS, kriging*

Introduction

Quantitative understanding of the climate
of a region is essential for developing
efficient farming systems and crop
improvement research programmes, and
for establishing principles for improved
resource management. A logical step in
this direction is to classify the climate into
relevant agroclimatically homogeneous
zones that aids the transfer of location-
specific dryland technology to other
regions, mainly by identifying limitations
for different zones. In India, every year
there is considerable agricultural damage
by floods in one part of the country and
severe drought conditions causing famines
in another part. Several scientists have
used numerical techniques for grouping
locations according to agricultural climate
using average of annual, monthly or weekly
climatic data. Some of these studies show
anomalous groupings when compared with
observed agricultural production patterns.
Reddy (1983) presented a modified method

after Cocheme and Franquin (1967) and Hargreaves (1975) for estimating agroclimatic variables that could be used to classify the climate of semi arid tropics (SAT) into relevant agroclimatically homogeneous zones.

The potential of geographical information system (GIS) to analyze and model spatial meteorological databases can be effectively utilized for agroclimatic classification. Batjes (1994) demonstrated agroclimatic module of Physical Land Evaluation System for Jamaica (JAMPLES) by computing ratio of dependable monthly rainfall and potential evapotranspiration (PET) at 141 meteorological stations to delineate four 'moisture availability' zones using GIS. Geerts et al. (2006) developed agroclimatic suitability library for crop production by using agroclimatic indicators (PET, length of growing season, severity of intra-seasonal dry spells and monthly frost risk) for 41 meteorological stations in Bolivia. Geographical coverage of the variables was obtained by interpolating the point data in GIS environment. They delimited zones where irrigation can be useful to stretch the length of growing season beyond the limits of rainy season and/or to mitigate intra-seasonal dry spells. This paper presents an attempt of agroclimatic classification of Maharashtra State based on agroclimatic variables derived by Reddy's method using raster modeling environment in GIS.

Study Area

Maharashtra is the second most populous and third largest state with respect to geographical area in India (Census, 2001).

It is one of the eight major littoral states of the country with a coastline of 720 km. The Sahyadrian range is the most important landmark of the State, running parallel to the Arabian sea coast, dividing the State into two distinct units, the Konkan coastal lowland and Maharahtra plateau. An alternate arrangement of plateaus and valleys, with a northwest-southeast disposition marked by the Satpuda, Ajanta, Balaghat and Harishchandra ranges confine agriculture largely to the fertile land in the valleys. Agriculture is the main landuse in the State with 60% of its geographical area under cultivation as against 47% for the whole country (Dikshit, 1986).

A part of tropical monsoonal land, the region displays significant regional variations not only in thermal conditions but also in the duration, amount and intensity of rainfall. Temperature maxima occur on the Konkan coast in March (33° C), in upland Maharashtra in April, and in the Vidarbha (>40° C) region in May. Mean minimum temperature of the coldest month on the coast varies between 16° and 20°C, 11° and 15°C on the plateau and is relatively low in the eastern part ~12° C. Rainfall in the State varies from 450 mm in the driest part to over 6000 mm in the hilly areas of Western Ghats. Distribution of rainfall across the State exhibits large variation as compared to temperature. The coastal area receives 2000 to 3000 mm, western part of the plateau 700 to 800 mm, the dry core 400 to 500 mm, the eastern part of the plateau 700 to 800 mm and the eastern margin of the State receives 1200 to 1500 mm of rainfall. The zone of heaviest rainfall coincides with the west Sahyadrian mountainous zone and creates

a rain shadow area on its eastern side. From west to east, the western ghats comprise the heavy rainfall zone trailed immediately by a rain shadow zone and its degeneration into a semi-arid tract, followed by a gradual rise in Vidarbha region where it is steady till one reaches the extreme eastern part of the State with moderately high rainfall.

Materials and Methods

Long period weekly rainfall (R) and weekly estimated potential evapotranspiration for 47 stations in Maharashtra State were used. Rainfall data used in the study are weekly totals derived from daily data sets. PET was calculated using the Modified Penman Method given by Doorenboss and Pruitt (1977). Characterization of growing season is considered as the rational basis for agroclimatic zonation. Growing season normally refers to the time taken by the plant to complete its development from germination to ripening and harvest without any adverse conditions of serious intensity that will lower the yield of harvestable product below reasonable limit (Kakde, 1985). Reddy's (1983) method was used for deriving agroclimatic variables to classify the semi-arid tropics (SAT) into homogeneous zones based on R and PET. The following agroclimatic variables were derived:

$\hat{G}$ The mean available effective rainy period (weeks)

CV The coefficient of variation of G (%)

$\hat{S}$ The mean week of commencement time of sowing rains (week no.)

$\hat{W}$ The mean wet weeks within the available effective rainy period (weeks)

$\hat{D}$ The mean dry weeks within the available effective rainy period (weeks)

A The percentage crop failure years (drought risk or aridity index).

The method takes into account the variability of weather from year to year with respect to effective rainy period (G), commencement of sowing rains (S) and dry (D) and wet (W) spells. The first two parameters are used to assess dependability of the cropping system and dry seeding feasibility while the latter two for drought and water-logging hazards respectively. G is the number of consecutive weeks in which the 15-week moving average of R/PET is 0.75, but for the initial week (S) the value of R/PET is 0.50. The deviations in the onset and cessation times of the monsoon rains modify the duration of G which is denoted by coefficient of variation (CV). The week (S) at the beginning of G is taken as the sowing week. Mean week of commencement of sowing rains $\hat{S}$ is an important parameter to determine the appropriate sowing time for optimum utilization of available soil water. This method also considers estimation of wet (W) and dry (D) spells during the available effective rainy period and an estimate of the percentage of crop failure years. Wet (W) and dry (D) weeks in the available effective rainy period are those that have a R/PET ratio of 1.5 and 0.50 respectively. Crop failure years are those for which G < 5 weeks as this is the minimum critical
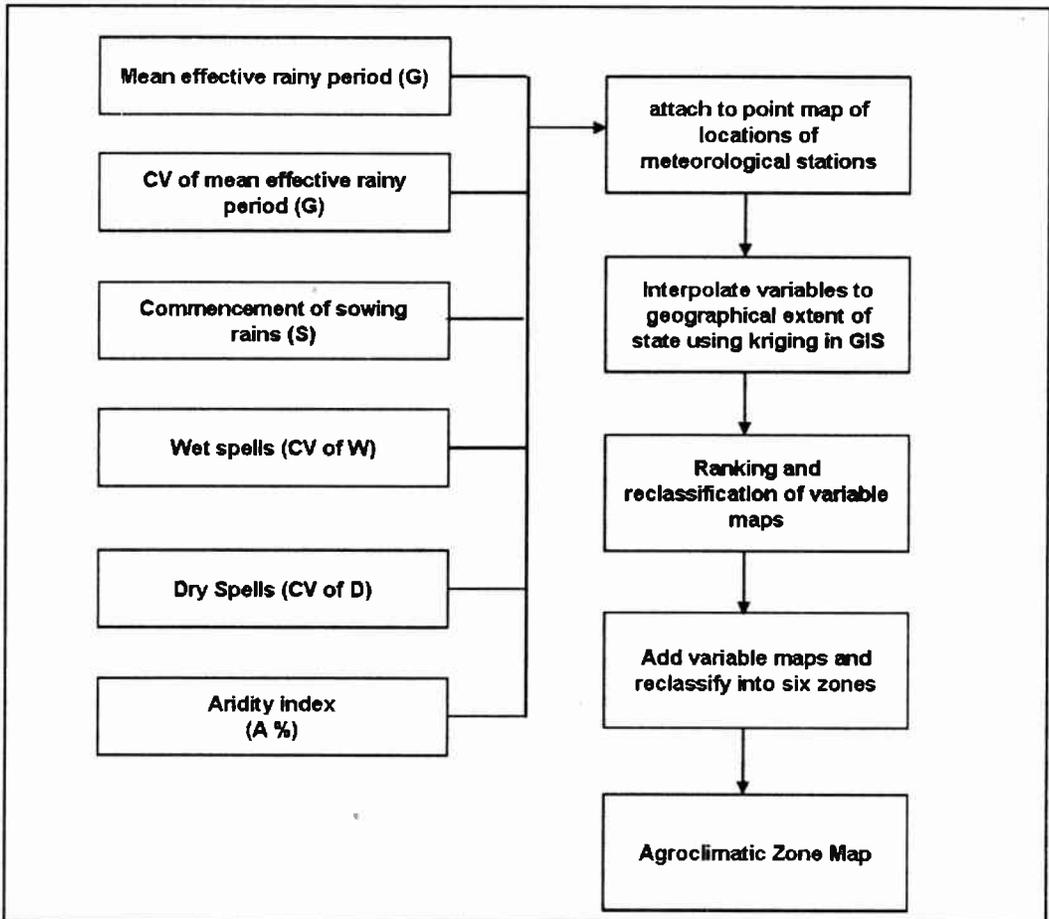
Fig. 1: Overview of methodology

Table 1: Criteria for agroclimatic zonation

Variables → Zones ↓	G	CV G (%)	S	CV W (%)	CV D (%)	A (%)
Arid	<5	>100	>30*	>70	>50	>50
Semi arid	5-10	60-100	26-30	50-70	40-50	20-50
Dry subhumid	10-15	30-60	25-26	50-60	30-45	5-20
Sub humid	15-20	15-30	20-25	20-50	20-30	1-5
Humid	20-25	10-15	<20*	18-20	18-20	0
Per humid	>25	<10	<20	<18	<18	0

* later than 30th week   ** before 20th week

(reproductive) period with good moisture conditions for successful harvesting of a 15-week crop; it is taken as an index of aridity (A).

Mean and standard deviation (SD) of G are calculated by considering the entire period of data while those of S, D and W are based on that period of data when the number of weeks in G in that year is 5. Coefficient of variation (CV%) is obtained to indicate annual variability in the descriptors. A preliminary investigation revealed that coefficient of variation was a more reliable estimate of climatic condition of the region than the direct use of $\overset{\scriptscriptstyle\wedge}{G}$, $\overset{\scriptscriptstyle\wedge}{W}$ and $\overset{\scriptscriptstyle\wedge}{D}$ Hence, the CV of G, W and D were used in the present study. A broad overview of methodology is illustrated in Fig. 1.

A point map was generated in GIS using geo-coordinates of the meteorological stations. The data of derived agroclimatic variables were attached to each station location. Each variable was interpolated to the geographical extent of the State using ordinary Kriging. Kriging is a geostatistical method of interpolation deriving from regionalized variable theory. It depends on expressing spatial variation of the variable in terms of the variogram, and it minimizes the prediction errors which are themselves estimated. It is an optimal interpolator in the sense that the estimates are unbiased and have known minimum variances (Oliver and Webster, 1990). The six interpolated variable maps in thus obtained in raster form were reclassified into 6 classes by ranking on scale of 1 to 6 using criteria compiled by authors from various literature (Table1). The reclassified variable maps thus consisted of raster cell values ranging

from 1 to 6. They were further combined using addition operation of map algebra in raster modeling environment in GIS. The output result was generated with raster cell values ranging from 1 to 36 as a result of addition of six variable maps. This output was further reclassified into 6 zones to generate the final agroclimatic zone map.

Results and Discussion

Spatial distribution of agroclimatic variables derived from long series climatic data using Reddy's (1983) method are presented in the following section.

G - Mean available effective rainy period

It defines the available growing period excluding the period that is available from the soil moisture reserve, which varies according to soil type. This variable correlates with type of cropping pattern, but is modified by the variation in onset and cessation times of sowing rain. The spatial variation of G in the State (Fig. 2A) suggests that the longest period of >25 weeks is in the Konkan coastal region where mean annual rainfall is about 4000 mm. It is decreasing eastward from Sahyadris following its rainshadow properties and the shortest period of <5 weeks is recorded in parts of Ahmadnagar, Pune, Satara, Sangli and Solapur districts where annual rainfall is between 500 and 550 mm, in north-south orientation parallel to the Sahyadris. Further eastward, the duration of mean growing season is progressively increasing in Marathwada (10 to 15 weeks with rainfall between 800 and 1000 mm) and Vidarbha (15 to 20 weeks with mean annual rainfall 1200 to 1600 mm) region. There is close

A

Legend
**Mean effective
rainy period - G (weeks)**

< 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25

B

Legend
CV of G (%)

< 10
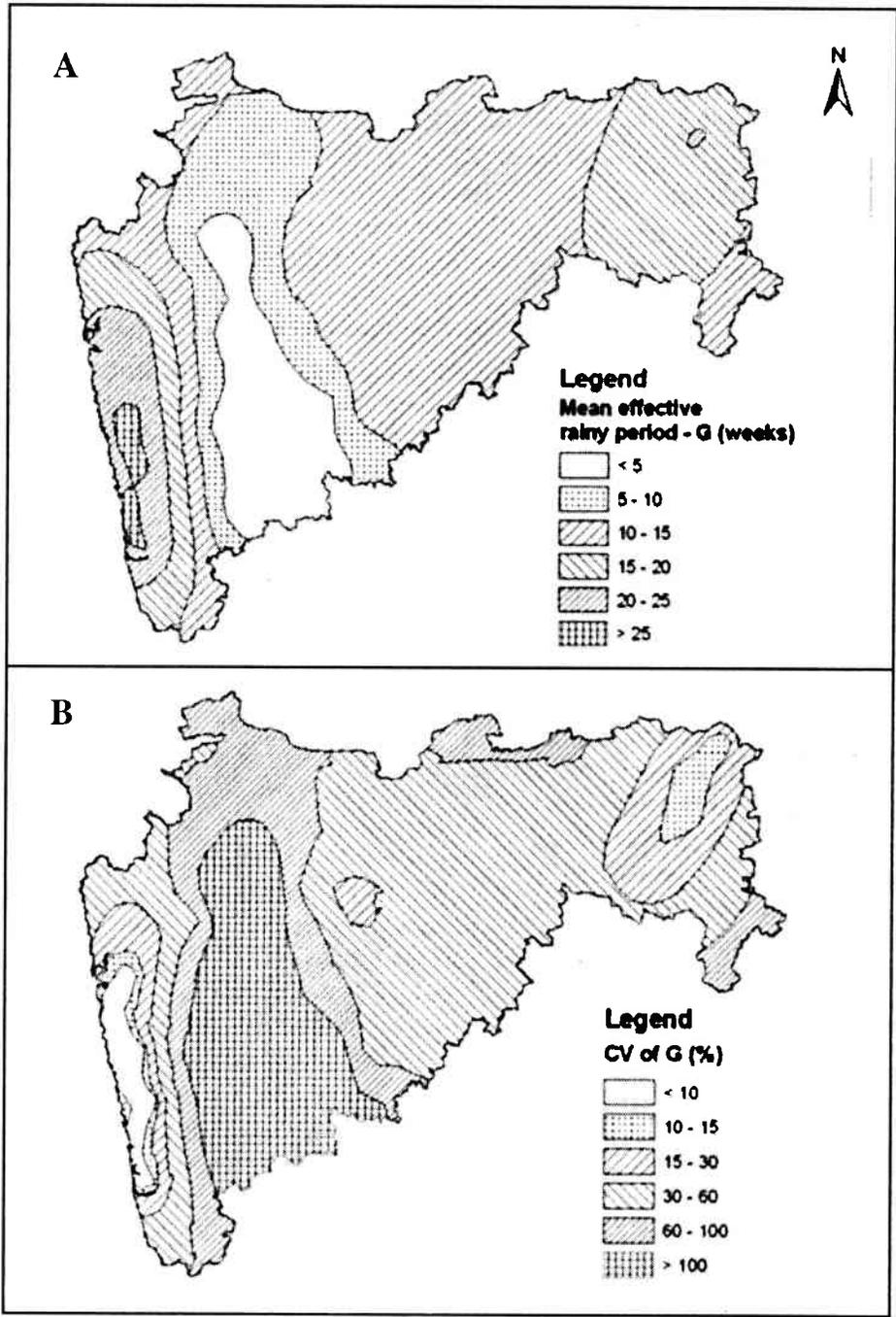10 - 15
15 - 30
30 - 60
60 - 100
> 100

Fig. 2: A) Mean effective rainy period - G,   B) CV of G,

positive relationship between the amount of mean annual rainfall and the duration of available effective rainy period.

CV (%) of G – Variability in available effective rainy period

The variability is defined by the SD of duration of effective rainy period (G). When SD is large the dependability of that cropping system is very low, therefore, careful planning is necessary before any system is adopted. Year-to-year variability in mean growing period is very less in the coastal region; in other words, the growing season is highly dependable with CV< 10% (Fig. 2B) followed by Marathwada (30 to 60%) and Vidarbha (10 to 30%). The rain shadow region is marked by highly undependable (CV>100%) growing season.

$\hat{S}$ (week) – The mean week of commencement of sowing rains

Determination of appropriate sowing time is important for optimum utilization of available soil water. Fig. 2C illustrates region wise characteristics of commencement of sowing rains in the State. Early commencement in meteorological week (MW) 20 – third week of May – is observed in the coastal region, eastward approaching towards the Western Ghats, the growing season commences between MW 20 and 25. In the rainshadow region of Sahyadri, it is delayed after MW 30 (end of July). Further eastward the sowing week progressively advances to MW 26 (end of June) in Marathwada and MW 20 to 25 (whole of June) in Vidarbha region. Amount of mean annual rainfall is closely related to week of commencement of sowing rains in Maharashtra.

CV (%) of W – Variability of wet spells

Occurrence of wet spells has significance in two ways; if wet weeks are many, a humid crop like rice may be planned and if wet weeks are less then intermediate crop like groundnut, sorghum and maize may be suggested. Some crops are sensitive to waterlogging; in that case the information of CV of wet weeks during the growing season would help water management in the field. Fig. 2D illustrates the variability of wet spells is less in Raigad and Ratnagiri districts (CV < 20 %). It is increasing eastward and again rainshadow region has emerged as high CV of wet spells (>70%) due to less numbers of wet weeks reported. Further eastward, through Marathwada (CV 50 to 60%) and Vidarbha (20 to 50%) wet spells are frequent and less variable.

CV (%) of D – Variability of dry spells

Monsoon rainfall is characterized by dry and wet spells. During the growing season large number of dry weeks cause early/mid/late-season agricultural droughts which reduce crop yield significantly. Number of dry weeks though small, causes problem, if they are associated with short growing season. Hence number of dry weeks was not considered as an appropriate measure for assessing favorability of a season for a given crop cultivation. Variability of dry spell was found a reasonable measure of dryness during the growing season. Spatial trend in mean and CV of dry spell (Fig. 2E) is similar to that of mean growing season G (Fig. 2B).
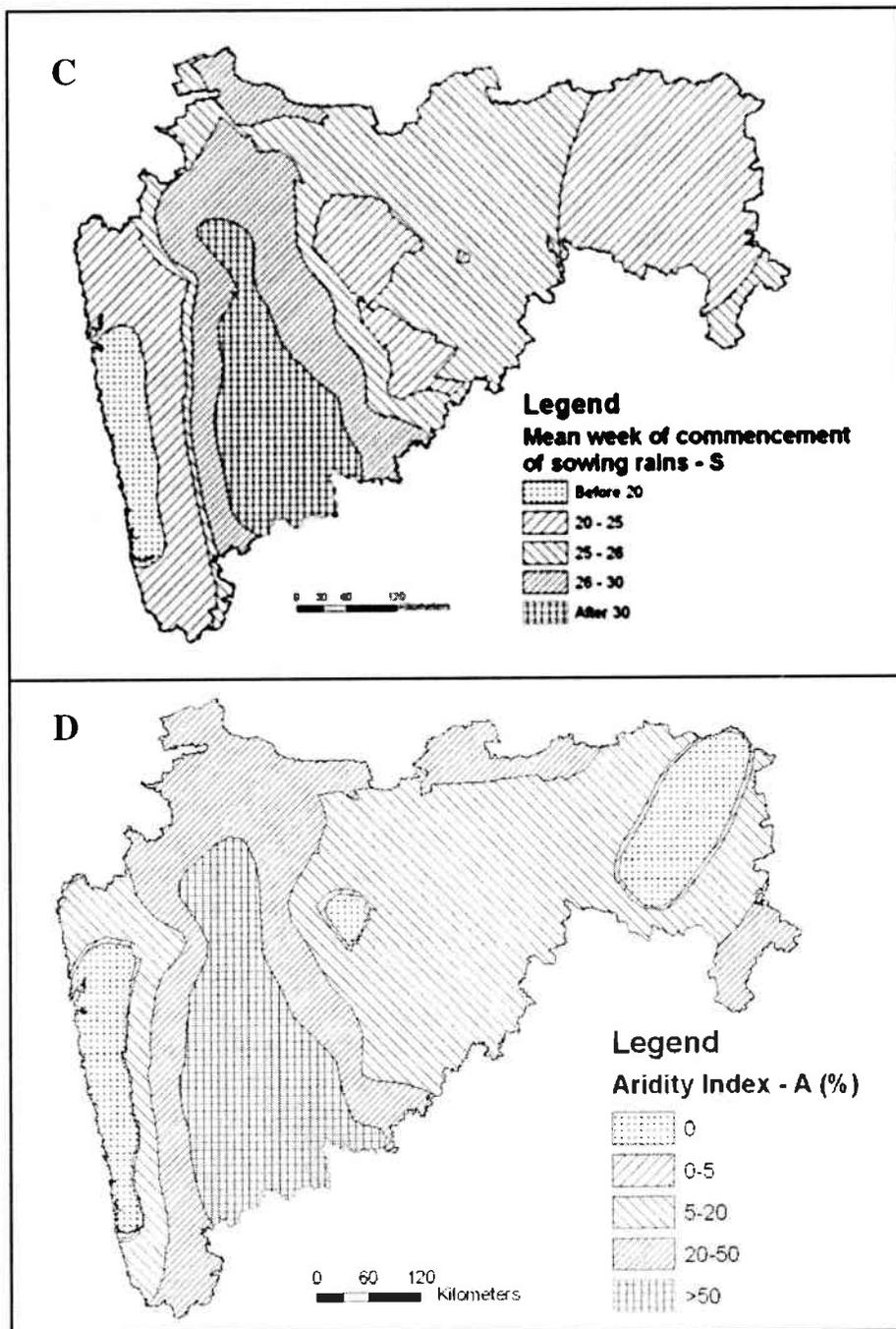
Fig. 2: C) Mean week of commencement of sowing rains - S   D) Aridity index (A)

A (%) – The years of crop failure or Aridity Index

The aridity index (A) presents a measure of risk in terms of probable percentage of crop failure (Fig. 2F). In costal region and parts of Gondiya, Bhandara and Chandrapur districts mean growing season is highly sustainable as indicated by the absence of failure of growing season (i.e. less no of years with G < 5 weeks) during period under study. Rain shadow region is extremely prone to failure of growing season; every alternate year. In Marathwada, aridity index varies from 5 to 20%.

Agroclimatic Zones

The integration of agroclimatic variables in GIS resulted in delineation of 6 zones viz., arid, semiarid, dry sub humid, sub humid, humid and per humid (Fig. 3).

Arid Zone

Arid zone is situated in the rainshadow area in the east of Sahyadri mountains where mean annual rainfall is 500 to 600 mm. Growing season is marked by delayed commencement (MW 30), mean duration of <5 weeks with very high variability >100%. Aridity index is high >50% with dry spell and wet spell duration of >50% and 70% respectively. Under such adverse agroclimatic conditions hardly any crop cultivation under rainfed management is carried out in this region.

Semi-arid zone

This region extends from Dhule in the north to the southern end and lies to the east of Western Ghats. Mean annual rainfall varies between 600 to 700 mm. Growing season of 5 to 10 weeks with high variability of 60 to 100%, 2 to 5 years out of 10 facing failure of growing season and delayed commencement of sowing rains any time in July are the limitations for sustainable agriculture in this region. Sorghum and pearl millet, short duration crops are cultivated with uncertainty of success.

Dry sub humid

This is the largest region covering Marathwada area. The region receives mean annual rainfall varying from 800 to 1000 mm and experience high growing season variability of 30 to 60%. One out of five is observed to have failure of growing season. The season commences in MW 25/26 (end of June). Dryness and wetness vary considerably as 30 to 45 % and 50 to 60 % respectively. Cotton and ground nut are the principal crops. Sorghum is the major crop where irrigation is not available post rainy season.

Sub humid

Sub humid agroclimatic region is observed in immediate east of Sahyadris and in Nagpur, Wardha and Gadchiroli in Vidarbha where mean annual rainfall is between 1000 and 1200mm. Mean growing season ranges from 15 to 20 weeks with moderate variability of 10 to 30%. Failure of growing season is 5 to 20%, variability of both dry and wet spells is reduced to 20 to 30% and 20 to 50% respectively. Growing season commences any time in the month of June. The bare slopes of the Sahyadris and the highly irregular terrain of Maval suffer from excessive leaching and erosion, making the land in the process unsuitable for cultivation.
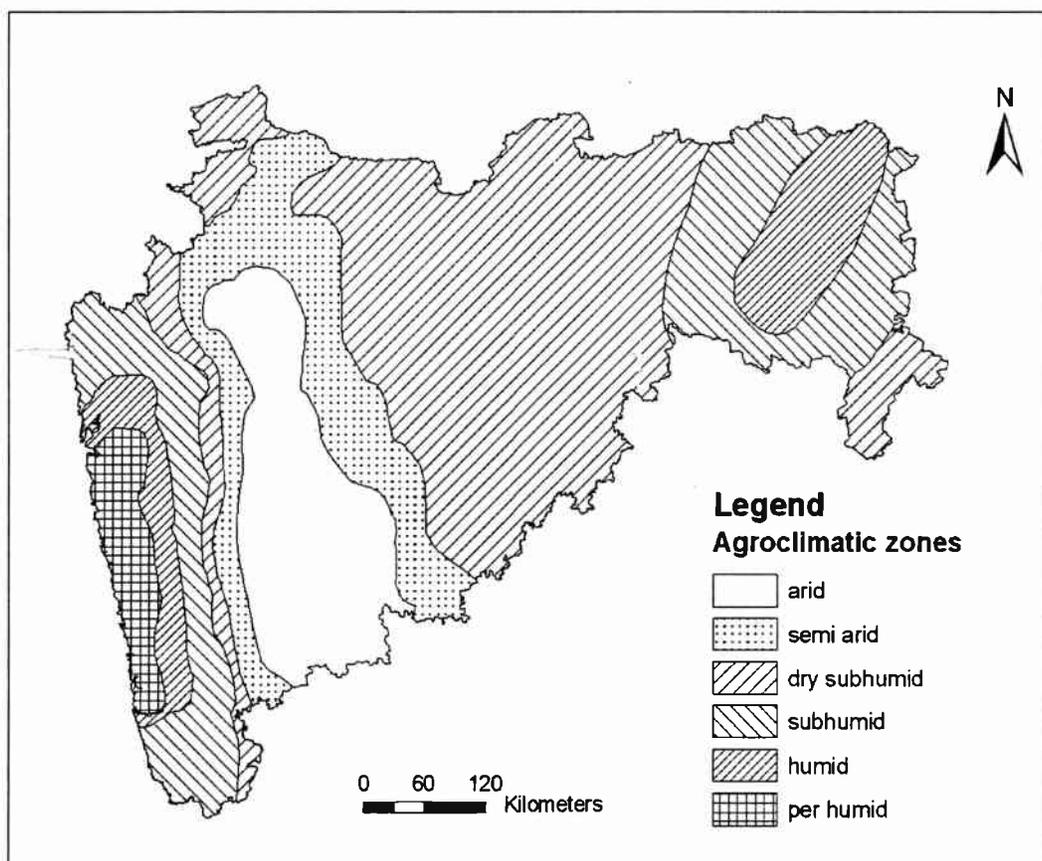
Fig. 3: Agroclimatic zone map of Maharashtra State

With very thin soil on the slopes some inferior millets like *nachni* is grown, which matures in less than 10 weeks. The valleys in Maval, carrying thick alluvial deposits are the favored sites for rice cultivation. Rice grows even in very shallow soils in the area due to heavy rainfall. In Vidarbha, cotton dominates followed by sorghum.

Humid

Humid agroclimatic region is located in the west between shoreline and the Ghat crest line and in the eastern Maharashtra covering districts of Gondiya, Bhandara and Chandrapur. Mean annual rainfall is between 2500 to 3000 mm in the west and above 1400mm in the east. In the west humid region, the duration of growing season is 20 to 25 weeks with high reliability (CV 10 to 15%) and almost absence of failure. Early commencement by the end of May ensures long growing season. Dry and wet spells vary negligibly with CV of 18 to 20% indicating stable agroclimatic characteristics from

year to year. Paddy is grown all over, though its scope is limited because of an overall low percentage of area under cultivation, either because of lateritic cover, as in Ratnagiri district or because of hilly terrain as in case of Thane and Raigad districts. The eastern humid region is characterized by growing period of 15 to 20 weeks commencing in June, long fairly dependable (CV of G 10 to 30%) growing season almost without fail. Dry and wet spells indicate 20 to 30% and 20 to 50% variability in their occurrence. Paddy is the predominant crop supported by tank irrigation.

Per humid

The region is spread over the coastal region of Ratnagiri and Raigad districts where mean annual rainfall is between 2500 to 3000mm. Longest growing season of >25 weeks extremely reliable (CV of G <10%) and sustainable (aridity index 0%). Season commences in mid-May and characterized by variability in dryness and wetness < 18%. Rice is a primary crop as a monoculture cultivated commonly twice or in some places even thrice a year.

Conclusion

Systematic appraisal of climatic condition for estimating potential of regional and local environmental factors is essential for recommending appropriate practices in agricultural production. Growing season characterization is considered to be the rational basis for agroclimatic zonation. Dates of commencement and end of the growing season and duration of intermittent dry and wet spells are essential for planning various agronomic operations. Therefore, assessment of characteristics of growing season assumes immense importance in crop planning for choice of crop variety and management practices. Zoning of agroclimatic conditions is necessary for crop planning and achieving sustainable crop productivity.

The present study attempts agroclimatic classification of Maharashtra State based on an adaptation of agroclimatic variables derived by Reddy's (1983) method. The agroclimatic variables were combined in raster modeling environment in GIS to derive 6 agroclimatically homogenous zones viz., arid, semi arid, dry sub humid, sub humid, humid and per humid. GIS is a powerful tool used for the classification which is uniquely suited for providing a framework in which data of multiple themes can be spatially displayed, analyzed and interpreted.

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