AN AGROCLIMATIC ASSESSMENT OF THE CROP GROWTH POTENTIAL OF SOUTH INDIA

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METEOROLOGY

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D E C L A R A T I O N

I hereby declare that this thesis entitled **An Agroclimatic Assessment of the Crop Growth Potential of South India** is a genuine research work carried out by me during the period 1985 to 1992, and that no part of this thesis has been submitted to any University or Institution for the award of any degree or diploma.

Kochi - 16,
May, 1992.

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C E R T I F I C A T E

I hereby certify that this thesis entitled **An Agroclimatic Assessment of the Crop Growth Potential of South India** is an authentic record of genuine and bonafide work carried out by **Smt. P.V. Lekha** during the period 1985 to 1992, under my supervision and guidance at the Physical Oceanography and Meteorology Division, School of Marine Sciences, Cochin University of Science and Technology, and that no part of this thesis has been previously submitted to any University or Institution for the award of any degree or diploma.

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CHAPTER 1

INTRODUCTION

The Indian economy is primarily agriculture oriented and its soundness is, in the absence of sufficient irrigation facilities over large areas, significantly influenced by the vagaries of the monsoons. Despite recent progress in industrialisation, the South Indian region is particularly dependent on rainfall. The yield from any given crop depends on the extent to which certain optimum conditions of rainfall, soil moisture supply, radiant energy, photoperiod and temperatures are satisfied during different stages of its growth. Weather also indirectly affects crop production through its effects on agricultural operations and on the outbreaks of pests and diseases of crops. Hence, agroclimatological and agrometeorological studies should be an integral part of successful agricultural planning and operations.

Agroclimatological studies could help in the understanding of inter-relationship between crops and the environment and enable development of better varieties, proper choice of crops and farming practices. Long term agricultural planning could be carried out by identifying regions of similar climates and delineating regions subject to different intensities of vagaries of the weather.

In this context, the determination of areas of similar climates is of particular interest. Agroclimatic classification using appropriate parameters is a very good tool to identify homoclimates for the purpose of introduction of specific crops. A realistic classification which considers soil types also would be very useful to delineate regions and periods of water deficiencies: supplementary irrigation can be provided in such cases.

With the evolution of new hybrid short duration crops, the importance of the short duration rainfall analysis has increased. A month's period is too long when compared with the life span of these crops. Moreover the year to year variability of rainfall adds complexity to the rainfall - agricultural yield relationship. This is especially true in low rainfall areas. A detailed analysis of the rainfall pattern on a weekly basis would be appropriate to evaluate the chances of success and failure of any crop under rainfed conditions.

In this investigation, the agroclimatic potential of the region has been evaluated by a detailed analysis of the rainfall of the area. The crop growing periods and the probability of adequate water availabilities during these periods have been computed. The region has also been delineated into different agroclimatic zones and the agricultural potentials at representative stations in each zone have been assessed.

Usually, under rainfed conditions the growing period exists in the humid months. Hence, for agricultural planning knowledge about the variabilities of the duration of the humid seasons are very much needed. The crucial problem affecting agriculture is the persistency in receiving a specific amount of rainfall during a short period. Agricultural operations and decision making are highly dependent on the probability of receiving given amounts of rainfall; such periods should match the water requirements of different phenological phases of the crops. While prolonged dry periods during sensitive phases are detrimental to their growth and lower the yields, excess of rainfall causes soil erosion and loss of soil nutrients. These factors point to the importance of evaluation of wet and dry spells.

In this study the weekly rainfall data have been analysed to estimate the probability of wet and dry periods at all selected stations of each agroclimatic zone and the crop growth potentials of the growing seasons have been analysed.

The thesis consists of six Chapters of which the first Chapter gives the introduction to the problem and also the scope of the study. In the first Section of the second Chapter, relevant literature on water balance studies, estimation of potential evapotranspiration, studies on rainfall distributions, climatic classifications in general and agroclimatic classifications in particular, has been reviewed. The review also includes literature on evaluation of crop growth potentials and analysis of wet and dry spells over different climatic regimes. The second Section of this Chapter explains the method of estimation of potential evapotranspiration, water balance computations, and techniques used for the rainfall analysis (Gamma distribution method) in the investigation. The criteria employed for agroclimatic classification and the method of rainfall analysis to assess wet and dry spells by Markov chain model have also been given in detail.

The third Chapter comprises of a discussion of physical and climatic features of the study region. The first Section gives details about the location and extent, physiography, drainage, soil types, natural vegetation, land-use and the major crops grown in the region. The second Section concerns itself with the rainfall, temperature, and humidity characteristics of the region. The distributions of water balance parameters, namely potential evapotranspiration, actual evapotranspiration, water deficit ana water surplus are also mapped and discussed in this Section.

The analysis of weekly rainfall, using Gamma distribution method and the agroclimatic classification, based on moisture availability index have been dealt with in Chapter IV. The crop potentials of individual stations of each agroclimatic type have been separately discussed in detail in this Chapter.

Using the first order Markov chain model, the weekly rainfall has been analysed in the fifth Chapter to determine the probabilities of dry and wet spells and to assess crop growth potentials of different growing seasons in the region.

The sixth Chapter comprises of the summary of the study and conclusions about the agroclimatic assessment of the crop growth potential of South India.

CHAPTER 2

LITERATURE REVIEW AND MATERIALS AND METHODS

The objective of the present investigation and a brief introduction to agroclimatology were presented in the first Chapter. A brief review of agroclimatological studies in general is given in this Chapter. The review, though not exhaustive is representative of the enormous amount of work done in this field. The methodology adopted in the present study along with the sources of data is also presented in this Chapter.

2.1 Literature Review:

2.1.1 Concepts of water balance:

The concept of book-keeping procedure of water balance was introduced by Thornthwaite (1948) to solve many soil moisture problems: he employed it as a basis of a new improved and rational climatic classification. Since then, further studies based on this approach have led to many revisions and extensions of the procedure itself and have resulted in numerous applications in various fields. The details of water balance and its computations have been explained by Thornthwaite and Mather, (1955, 1957) and Subrahmanyam (1982).

Water balance or water budget is a monthly, weekly or daily comparison of water supply in the form of precipitation with the water demand or potential evapotranspiration (PE), where the soil moisture acts as a sort of reserve available for use to a limited extent for the purpose of evapotranspiration during periods of water shortage. The book-keeping procedure of water balance, based on such comparison provides comprehensive information on many parameters such as amount of water stored in the soil, actual evapotranspiration, water surplus, water deficit etc. at a place in a quantitative manner. Since accurate measurements of these parameters especially AE and soil moisture, are not generally feasible on a continual basis due to technical difficulties, the book keeping procedure of water balance is extensively used in various fields. Subrahmanyam (1972, 1982) has described applicability of this approach in various aspects such as climatic classification, agriculture, hydrology etc.. The derived parameters of the water balance, especially water surplus and water deficit, can give very essential information useful for various agricultural activities.

Water balances of more than 240 climatological stations in India and vicinity are worked out by Carter (1954). This concept of water balance was introduced in India by Subrahmanyam (1956a) who used the derived parameters of water balance for climatic classification of India. Subrahmanyam (1956b) mapped the annual values of surplus and deficits over India using the modified book-keeping procedure. Subba Rao and Subrahmanyam (1961), Sastri (1969), Rama Sastri (1973), Sarma (1974)., Bora (1976), Ram Mohan (1978), Ram Mohan et al. (1986), Nair (1987) and James

(1991) have carried out similar works on regional basis. Kayane (1971) presented distribution of water balance components over monsoon Asia. Sarma and Narayana Swamy (1986) conducted a comparative study of water balance parameters over Vishakhapatnam, derived using modified book-keeping procedure by using PE values estimated from Thornthwaite (1948), Penman (1948), Khosla (1951) and Christansen (1968). They concluded that Thornthwaite method presents high water deficits and low water surpluses for most of the year compared to other methods.

Srinivasa Murthry (1973) has worked out the elements of the weekly climatic water balance by the simple book-keeping method to asses the weekly water availability to crops at Bellary, Bijapur, Gadag and Raichur. A similar study has been carried out by Ramana Rao et al. (1979) in which, they have estimated the soil moisture available in different types of soils. Suryanarayana and Goopinatha Rao (1986) have estimated the crop water availability at Bijapur by daily water budgeting.

2.1.2 Potential Evapotranspiration:

Evapotranspiration represents the total exchange of moisture from the earth surface to the atmosphere through evaporation and transpiration. There are different factors which affects the rate of evapotranspiration such as external supply of energy, capacity of air to remove the water vapour, nature of vegetation, availability of water for evapotranspiration etc.. Evapotranspiration varies from place to place and with time due to the variations in weather, land-use and soil management, plant growth etc.

Thornthwaite (1948) introduced the concept of Potential Evapotranspiration (PE). He defined it as the total water loss from a large homogeneous vegetation covered area, which never suffers from lack of water. This is a function of climate only and does not depend on any biotic and edaphic controls. Attempts for the measurement of this parameter using modified lysimeters were unsatisfactory due to the difficulties in maintaining the ideal conditions during installation and maintenance of the instrument.

A number of methods have been developed to estimate PE and extensive literature has been generated on these methods, utility and limitations. There are a number of assumptions in all these approaches, some are specific for some methods while others are universal. Under different conditions different approaches have proved better and there exists no unique method which can satisfactorily be used under all conditions.

Various theoretical approaches such as mass transfer method, water budget method, energy method, aero-dynamic method, eddy transfer method and a number of combination methods have been employed to arrive at satisfactory estimates. Penman (1948) suggested a formula based on a good physical reasoning by combining energy budget and Dalton's approach. Thornthwaite's (1948) formula is based on correlation between mean air temperature and evaporation rate. Blaney and Criddle's method (1950) requires mean monthly temperature and percentage day time sunshine hours to estimate consumptive use. Ramdas (1957) developed a semi-empirical formula to estimate PE. Mcllroy's (1960) expression requires measurement of air temperature, humidity, wind speed at screen level along with measurements of net radiation and soil heat flux. Another method based on combinations of energy balance and aerodynamic approach was developed by Tanner (1960). Homan's (1961) formula uses data on latitude converted into day length and mean temperature converted into saturation vapour density. Relationship of solar radiation with mean weekly day temperature was used by Jensen and Haise (1963). Based on vapour pressure, Papadakis (1965) evolved a formula to determine PE.

Sellers (1965) carried out a comparative study and remarked that Penman's estimates are slightly low in summer (October - April) and high in winter (May - September), Mcllroy's estimates are high in all months except in January and the annual total of his estimates is about 8% higher than that observed. Blaney and criddle's estimates are low in summer and high in winter. Values calculated by Thornthwaite's method are low in all months especially in summer. Krishnakumar et al. (1987) found out that Penman's PE estimates are higher than Thornthwaite's during winter and pre-monsoon months and lower during monsoon months, at most of the Indian stations.

Mather (1954) felt that Thornthwaite's PE values are underestimates in winter and overestimates in summer. Van Wijk and De Varies (1954) reported that Thornthwaite formula give good results in similar climates, where it is developed, but values obtained for semi-arid climates are very low. Thornthwaite's formula is fairly good for humid regions or seasons, but not suitable for dry conditions.

Eventhough these limitations to Thornthwaite's equation exist, it is widely accepted among the researchers in various fields. According to Penman (1956), Thornthwaite's formula is quite acceptable, considering its simplicity and limitations. Using modified Penman's formula, Rao et al. (1971) computed monthly ana annual PE values for about 300 stations in India and neighbourhood Bailey and Johnson (1972) remarked that noticeable error in Thornthwaite's estimates occurs in tropics where annual march of temperature is controlled more by cloud variations than the insolation received, and in mid-latitudes, PE estimates are reasonable except near glacial limits. The method is internally consistent over a wide range of annual heat indices, 17 to 146, rather than the range 25 to 140 suggested by Thornthwaite and Mather (1955). In studies of Krishnakumar and Rakhecha (1986) on the harmonic analysis of PE calculated using Penman's equation in comparison with Jagannathan's (1957) work on temperature, they inferred that monthly air temperature is highly correlated to PE, which is the basic assumption of Thornthwaite's PE estimates.

There are many reviews about various approaches and their limitations to estimate PE such as Mather (1954), Deacon et al (1958), Thornthwaite and Hare (1965), WMO (1966), Tanner (1967), Cowan (1968), Kakde (1985) etc.. Various studies suggest that in spite of some limitations the values derived from Thornthwaite's method are not very much different from measured values and it is not improper to use the technique for estimating PE where actual measurements are lacking. Since almost all physical parameters such as wind speed, humidity gradient, solar radiation etc. have been considered, the values derived using Penman's equation are widely acknowledged to be more reliable than estimates from other methods. All empirical formulae except Thornthwaite's require a number of parameters which are not easily available. On the other hand, Thornthwaite's formula requires only the mean monthly temperature of the station. He assumed that the air temperature has a positive correlation with net radiation which acts as the energy source for PE.

The detailed instructions and tables to compute PE values using Thornthwaite method are given by Thornthwaite and Mather (1957) and Subrahmanyam (1982).

Khambete and Biswas (1984) have attempted to compare the weekly PE values obtained by different methods; computed and interpolated. They have stated that in absence of the meteorological parameters required to compute weekly PE values, monthly values computed using Penman's method can be interpolated and used.

2.1.3 Studies on Rainfall Distributions:

The study of the nature of the rainfall distribution is very much important to agriculture. Large number of efforts have been carried out in this respect to study the rainfall of different time scales by fitting appropriate frequency functions. Barger and Thom (1949) opined that the Gamma distribution provides a good fit to the rainfall series under a wide range of conditions in United States. In another study Momiyama and Mitsudera (1952) fitted the Gamma distribution to the monthly rainfall over Japan. Suzuki (1964, 1967) in his investigations found that Hyper Gamma distribution gives a satisfactory fit to the monthly and annual rainfall of Tokyo and Niigata. Hargreaves et al. (1983) in an attempt to estimate the crop water requirements of the Senegal river basin has described the importance of rainfall in supplying it. In his attempt he has compared mean, actual, dependable and effective precipitation values for this place. For calculating dependable precipitation, he has done probability analysis of rainfall using Kimball equation, which is very simple, but he has suggested that the Gamma distribution is superior to the Kimball equation. In that irregularities in precipitation curves are smoothed. Hargreaves and Hargreaves (1984) and Hargreaves and Samani (1986) had recommended Gamma distribution probability model to determine dependable precipitation for calculating crop water requirements which will help irrigation scheduling and proper water management and also drought assessment. They have also described the probability analysis for rainfall studies as superior to the method of estimating effective precipitation from mean values. Samani and Hargreaves (1986) have computed the rainfall probabilities and water requirement for selected Asian and Pacific countries for which, the rainfall probabilities they have computed by Gamma distribution method.

Sankaranarayan (1933) studied the frequency distribution of SW monsoon rainfall of India, Pakistan and Burma and concluded that there is very little justification for assuming a non-normal distribution but it cannot be said that the curves are necessarily normal. Pramanik and Jagannathan (1953) examined the annual rainfall distribution over India and Pakistan and found out significant departures from normal distribution. Rao et al. (1972) have shown that by and large the SW monsoon and annual rainfall is normally distributed in India. Parthasarathy and Dhar (1975) studied the seasonal and annual rainfall of contiguous India and pointed out that for all practical purposes, Indian rainfall for the period 1901 to 1960 can be considered as normally distributed.

Mooley and Crutcher (1968) have shown that Gamma distribution model can be applied to monthly rainfall during the summer monsoon in India. Mooley and Appa Rao (1971) have obtained the distribution functions for seasonal (SW monsoon) and annual rainfall at a large number of stations in India. The frequency distributions are found to be skewed. They have stated that the normal distribution does not give a good fit to seasonal and annual rainfall over major part of India. Besides this they have said that the Gamma distribution provides a good fit to seasonal and annual rainfall in different parts of the country. Using data from 39 well distributed stations, Mooley (1973a) has studied the distribution of summer monsoon monthly rainfall over Asia. He has found that Gamma distribution is the most suitable probability model and also indicated that the monthly rainfall distribution is not Gaussian and the simple square root, cube root and logarithmic transformations are of limited utility for normalising the rainfall distribution. Mooley (1973b) has estimated the distribution parameters of the Gamma probability model applied to monthly rainfall during summer monsoon over SE Asia. The extensive use of Gamma distribution model for precipitation analysis has been described by Gupta and Panchapakesh (1980).

All these studies are carried out for annual, seasonal or even monthly rainfall. Presently, in agricultural science more emphasis is being given for evolving short duration crop varieties so that cropping can be done more than once a year, enabling the maximum exploitation of the growing period. In this context rainfall analysis of shorter intervals - pentads, weeks or decades - is more appropriate.

Mooley (1973c) has examined the statistical distribution of 24 hour rainfall associated with monsoon depressions in India and found that the Gamma probability model gives a good fit in each of the four quadrants of the depression.

Mooley and Appa Rao (1970) conducted a study to find the statistical distribution of pentad rainfall during monsoon season over India. They have concluded that these distributions are positively skewed and in such cases Gamma distribution gives a good fit to the rainfall.

Krishnan and Kushwaha (1972) analysed the mathematical distribution of accumulated rainfall for period commencing from the onset of monsoon. They conducted the study in arid and semi-arid zones of Rajasthan and stated that for the semi-arid zone distribution beyond a month is normal while for arid zone, all accumulated pentads including the entire season is not normal at all.

A similar study is carried out by Bishnoi and Saxena (1978) for Haryana state. Their study indicated that upto a cumulative period of four weeks skewness is very high and hence normal distribution cannot be fitted. They have tried Gamma distribution in such cases and found that it fits satisfactorily. Khambete and Biswas (1978) have studied the characteristics of short period rainfall in Gujarat using Gamma distribution model. A similar study was carried out for the dry farming tracts of Maharashtra by Biswas and Khambete (1978). Vittal Murthy and Uma Maheswara Rao (1980) have used Gamma distribution probability model to determine assured rainfall in cotton growing areas of Andhra Pradesh. To study the nature of the distribution of short period rainfall in dry farming tract, Sarkar et al. (1982) have subjected the weekly rainfall to statistical analysis by

Incomplete Gamma distribution method. By this method they have computed the minimum assured rainfall at different probability levels and divided the entire tract into 7 homogeneous rainfall pattern zones. The assured weekly rainfall amounts at different probability levels have been computed for the dry farming tract in Karnataka by Khambete and Kanade (1985) using Incomplete Gamma distribution method. They have stated that the week by week assured rainfall at different probability levels depict different rainfall patterns which can be grouped under five types.

The representativeness of rainfall records depend on the nature and time scale of rainfall considered. Sajnani (1964) has shown that pentad rainfall recorded at Colaba station during different months of SW monsoon are representative of that over the entire Colaba district. Hence, the results derived for individual stations could be taken as representative of areas larger than that of a district.

2.1.4 Climatic Classification:

General:

Climatic classification has been of historic importance in developing a broad understanding of factors affecting soil and cropping patterns in various environments. Most classifications have been macro in concept and have usually been applied on a climatic or global basis. With the increased availability of numerical data, development of computers and methods of analysis, new approaches in classification of climate are possible.

Approaches of classifying climate arise from the increase in geographic knowledge of the world and the increasing availability of climatic data on rainfall and temperature. Williams (1976) has pointed out that the most important purpose of climatic classification is prediction.

In this century, a large number of classifications of climate have been proposed. Koeppen (1900) made a major advance in climatic classification by his novel idea that plants can serve as meteorological instruments capable of integrating the effects of various climatic elements and enabling the climatic region to be classified in terms of vegetation. But his classification lacked the rational basis for the limiting values of temperature and precipitation. Russell (1980) has given a chronological listing of some of the different approaches to the climatic classification which is presented in Table 2.1. These earlier attempts were mostly based on the identification of average annual or seasonal or monthly rainfall and temperature regimes in relation to natural vegetation or crops. Among these classifications, the two global classifications most widely used are those of Koeppen (1936) and Thornthwaite (1948). Koeppen has used $5^{o}C$, $10^{o}C$, $18^{o}C$ and $22^{o}C$ as important criteria for separating different climates on the basis of temperature.

Thornthwaite (1948) in his climatic classification employed the efficiency of temperature and effectiveness of precipitation for the growth and development of natura vegetation. In his attempt he used the concept of water balanc

Author(s)	Year	Main criteria used
Voeikov	1874	Seasonal incidence of rainfall
Herbertson	1905	Combination of rainfall and temperature
DeMartonne	1909	Combination of rainfall and temperature
Demartonne	1948	Index of aridity
Koeppen	1918	Annual and monthly means of temperature and rainfall
Koeppen	1936	
Thornthwaite	1931	Temperature and humidity using P/E
	1948	Temperature and potential evapotranspiration
Hettner	1934	Zonal winds
Creutzberg	1950	Duration of humid months
Bagnouls & Gaussen	1953	Rainfall-temperature index
	1959	Rainfall-temperature index
Walter, Leith & Rehder	1960	Thermohydric criteria
Hendl	1963	Atmospheric circulation
Meher-Homji	1963	Rainfall-temperature index
Troll	1964	Duration of humid months
Papadakis	1966	Water, heat thresholds related to crop growth

Table 2.1. Published climatic classification and main criteria used (After J.S. Russell, 1980)

with the help of average monthly potential evapotranspiration (PE) along with the corresponding rainfall to classify climate. Thornthwaite and Mather (1955) modified this classification. Several attempts on climatic classification have been carried out in India based on this water balance concepts. Subrahmanyam (1958) concluded that Thornthwaite's scheme of classification holds good in most part of India when compared with the general pattern of the vegetation as reported by Champion (1936). Carter and Mather (1966) later modified the Thornthwaite's criteria for classifying dry climates Krishnan and Mukhtar Singh (1968) demarcated soil climatic zones of India by superimposing the moisture index and mean air temperature isopleths on a soil map of India showing major soil types. Monsoon climates of the world in general and of India in particular were delineated from the point of view of agriculture and vegetation by Subrahmanyam and Ram Mohan (1980) using the Index of Moisture Availability (IMA) defined as the ratio of Actual Evapotranspiration (AE) for any individual month of an year to the average monthly value. All the districts of India have been classified into homogeneous soil climatic zones by Krishnan (1988) for delineating efficient cropping zones. Using normal annual rainfall and mean PE values computed by Penman's method a moisture index has been computed as a basis for this climatic delineation. These climatic zones have been further delineated into soil climatic zones on the basis of major soil types.

Troll (1965) in his classification called the 'seasonal climate of the earth', defined humid months as those in which mean rainfall exceeds mean PE calculated by Penman's method. His classification was based on the duration of arid and humid months and each of this group is associated with some type of vegetation. According to him, the classification has been found to be satisfactory to explain vegetation zones of tropical regions. ICRISAT (1978) adopted this method for classification of semi-arid tropics in India. However, their recent study shows that the application of this system for delineation of semi-arid zones of India using mean monthly PE computed by Penman's method is not satisfactory, since it places in the semi-arid zone, areas of west coast as well as some regions in Bihar and Orissa that normally is under sub-humid to humid zones.

Papadakis (1966) in his classification incorporated information on average daily maximum and minimum temperatures, winter severity and length of the frost free season. The water balance concept was included, with PE being determined as a function of saturate deficit at mid-day. His method is oriented towards agriculture and crop requirements and criteria for different thermic and hygric subtypes of climate have been chosen mainly from this point of view.

In their studies Thornthwaite and Mather and Papadakis employed a comparison between the moisture requirements of plants and that available from precipitation. As the respective empirical formulae used by them to compute evapotranspiration are not universally applicable their results are not quite satisfactory. Besides this, the period used by them is too long when compared with the life span of a crop and in their methods they do not consider associated risk in farming.

Agroclimatic classifications:

From an agricultural point of view, a general purpose climatic classification should be able to predict that certain plants will grow at certain places and others will not. Williams and Masterton (1980) have made clear the fact that an approach for climatic classification is dictated by its objectives. They have pointed out that the objective of any agroclimatic classification should be to provide the required information to enable the best use to be made of climatic resources. They have brought out an important point that, the variations in the responses among different kinds of plants are rarely dealt with in the general classification systems.

Matching the duration of the crops growth cycle with the period of water availability in different regions is an important task in agricultural planning. In this connection length of periods during which rainfall (P) exceeds selected levels of evaporation is most useful index of agricultural potential. Accordingly, in the studies of Cocheme and Franquin (1967) they used various levels of water availability periods as limits of different classes. In this classification apart from rainfall, the available water in the root zone was also compared with PE, and they have prepared crop water availability calendars for different phenological phases. They used this method to study the climatic conditions of semi-arid areas in south of Sahara and in West Africa. Adopting this approach, Raman and Srinivasamurthy (1971) worked out water availability periods for crop planning for 220 stations in India. They have noticed that the climatic classifications do not show a simple relationship with the lengths of water availability periods but have observed that the differences in agricultural potential closely related to the durations of water availability periods.

Nair (1973), delineated 13 agroclimatic zones and identified cropping patterns in Kerala State based on rainfall, altitude, topographical features and soil characteristics.

Hargreaves (1971) defined a moisture availability index (MAI) as the ratio of monthly rainfall value expected at 75% probability to the estimated monthly PE. If this ratio is between 0 and 0.33 during all months in a year, the climate of the region is classified as very arid. If there are only one or two months with MAI values exceeding 0.34 in the year, the climate is classified as arid and if there are three or four consecutive such months the climate is considered as semi-arid. The probability level as well as ranges of MAI chosen in this classification appear to be rather high. He himself stated that for the same crops for special conditions a different probability level may be more appropriate. Although he has taken into account the risk factor which is very much necessary for crop planning, it can be seen that his classification has three shortcomings (1) only one risk factor has been taken into account (2) a month is too long period for modern cereal crops (3) MAI values greater than or equal to 0.34 has been considered adequate for all the growth stages of the crops.

Krishnan (1980) has reviewed the various attempts of agroclimatic classifications conducted in India. Based on the moisture availability index defined by Hargreaves, Biswas (1982) classified the agroclimate of Gujarat. For this purpose he has computed the weekly moisture availability index at different probability levels for 81 stations in the dry farming tract of

Gujarat. This tract has been divided into four agroclimatic regions. From this analysis he has identified the core of the low crop potential region and discussed the crop prospects of one station in each zone.

An agroclimatic classification of the dry farming tracts of India for the assessment of crop potential has been carried out by Sarkar and Biswas (1986). According to them, to assess the agroclimatic potential of a region it is necessary to classify it into different agroclimatic zones. They have developed a scheme for agroclimatic classification based on Hargreaves' moisture availability index (MAI), which is defined as the ratio of assured rainfall to PE, incorporating three improvements on the earlier methodology. The main classification has been further subdivided according to the duration of water stress periods and the range of average daily temperatures.

Sarkar and Biswas (1988) have classified India into 7 broad agroclimatic groups based on MAI at 50% level. The arid region is classified based on MAI at 30% level. The scheme has been applied to the dry farming tract of Maharashtra taking micro-level data. They have indicated that while a macro scale study can give some broad aspects of crop potential, it is necessary to do micro-scale analysis, so that specific areas of varying crop potential can be demarcated.

Venkataraman (1981) has held the opinion that a dependable precipitation of 20 mm per week can be deemed sufficient to meet the PE needs. He has worked out the number of weeks in which the dependable precipitation at 50% probability level equaled or exceeded 20 mm at district level stations in the dry-land areas of NW India, Maharashtra and Karnataka. Using this method they have delineated areas into homogeneous groups.

2.1.5 Studies on Crop Growth Potential:

Victor and Sastry (1981) has used the moisture availability index at different probability levels to determine the length of growing period in the Delhi region during the kharif cropping season. The PE values necessary for this have been obtained from mesh covered pan evaporation values.

Biswas and Khambete (1983) have evaluated the climatic potential for crop production at some stations in West Rajasthan and adjoining parts of Gujarat employing short period rainfall analysis. They have used moisture availability index and estimated soil moisture as the tools for this purpose. The values of minimum assured rainfall at different probability levels have been compared with the weekly rainfall average and the computed PE. On the basis of this analysis, they have indicated the possible growing season also.

Crop potential under rainfed conditions based on moisture availability index and stored soil moisture has been assessed by Subba Rao and Rama Mohan Rao (1985) for selected station in Andhra Pradesh. As a result of this study, they have indicated the optimum sowing dates and concluded that in general, coastal and northern districts of Telangana have higher crop potential than the remaining districts.

Varshney et al. (1985) have evolved a conceptual model of crop production system in rainfed areas with an objective to develop appropriate package of practices for maximising production. The model visualises the arable land as a water shortage element from which water is depleted over time, due to utilisation in crop growth and is replenished by rains.

Samui and Jog (1986) have analysed the climatic data of five districts of Maharashtra for assured weekly rainfall at different probability levels. They have computed the deficits of water availability and identified the areas where dry land agriculture is highly risky. They have used moisture availability index to predict the suitable time of planting of kharif crops.

Sambasiva Rao and Subramaniam (1986) assessed the soil moisture availability in different agroclimatic locations of Maharashtra from the computed probabilities of I_{ma} for crop planning. The I_{ma} probabilities obtained are examined for the moisture adequacy of crops in the region and the periods which need supplemental irrigation are identified.

An agroclimatic study for potential productivity evaluation under rainfed conditions of Nadia districts in West Bengal has been conducted by Khan and Chatterjee (1987). The probability estimates of weekly rainfall and PE have been used by them as a tool for this study. Based on this study they have concluded that in Nadia district the probability of continuance of rain is fairly dependable after 19th week and rainfed crops sown after this period will escape maximum risks of water deficits. They have used the water balance method to calculate available water storage and crop growth periods have been identified for different soil types.

Murali Mohan Rao and Reddy (1990) have prepared agroclimatic charts for the cropping season in Bijapur area in Karnataka. They used weekly PE and weekly moisture availability periods for this purpose and suggested possible cropping systems for different types of soils.

2.1.6 Studies on Wet and Dry Spells:

In the semi-arid regions, the monsoon rainfall is not made up of a long continuous period of rainy days but occurs in spells lasting for a few days interspersed by dry spells. Problems related to the estimation of probability distributions of lengths of dry spells and wet spells have been dealt with since the past half century. The respective behaviour of seasonal weather has been studied earlier by many using a variety of mathematical and probability models.

Williams (1952) suggested a logarithmic model for studying the frequencies of occurrences of dry and wet spells. Longley (1953), opined that the probability that a dry day follows a dry day increases slightly with the length of the dry period.

An analysis of rainless days of Delhi has been carried out by Sarma (1952). The probability of day falling in rainless spell of specified duration has also been worked out by him. Srinivasan (1954) analysed monthly rainfall data of Rayalaseema and concluded that consecutive rainfall amounts are independent and perhaps shorter period may show persistency. The method of logarithmic model has been followed by Ramabhadran (1954) to study the wet spells of Pune. Srinivasan (1964) applied the same method to study the rainfall persistence in India during summer monsoon months. Later Manohar and Krishnaih Setty (1978) analysed the daily rainfall data of Raichur to study the wet spells applying logarithmic series. To identify drought prone areas, Chowdhury et al. (1979) have analysed the daily rainfall of kharif season for 26 stations in Maharashtra. They have fitted the logarithmic distribution to dry spells of the region. Kamte et al. (1981) examined the persistency in sequences of wet and dry periods over Bombay during the southwest monsoon season. They have concluded that there is a slight tendency for wet pentads to be followed by further wet pentads. They observed no tendency for dry pentads to be followed by further dry pentads.

The runs of wet and dry spells along the west coast of India during SW monsoon have been studied by Raman and Krishnan (1960) using theory of extreme values. They have discussed the use of persistency as an aid for forecasting wet periods following runs of rainy days or dry days of different lengths. A similar study has been made for five stations in Rajasthan by Gupta (1966).

A statistical analysis of weekly rainfall of selected stations in Karnataka has been carried out by Narayana Iyengar (1987) who found out the significant week to week dependence of rainfall. Mooley (1971) has studied the monthly and bimonthly rainfall over South West Asia during the summer monsoon season and has concluded that the monthly rainfall is pair-wise independent during the season and further, the first half of the summer monsoon is independent of rianfall during second half. Mooley and Appa Rao (1972) studied the dependence and independence of pentad rainfall during monsoon season.

Gabriel and Neumann (1957) suggested geometric probability model to describe the distribution of the length of a weather cycle (dry sequence followed by a wet sequence). The occurrence pattern of rainy days at Tel Aviv was shown to be closely following Markov chain expectations (Gabriel and Neumann, 1962). Similar conclusions was brought out by Gaskey (1963), by studying the pattern of rainy days over a 10 year period at Denver. Hopkins and Robillard (1964) examined the frequency statistics of duration of dry spells during the April - September growing season recorded in 45 years observations at Canadian Prairie provinces and stated that a two-state Markov chain model provides very good approximations in this aspect. Additional evidence to support the feasibility of using Markov chain model has been reported by Weiss (1964) and Feyerherm and Bark (1965, 1967). The persistence of sequences of favourable working conditions for road construction has been studied by Maunder et al. (1971), using initial and conditional probabilities of Markov chain model.

Several attempts have been made in India to study the sequence of wet and dry spells employing Markov chain model. A Markov chain model has been fitted to the daily rainfall data recorded at Calcutta by Basu (1971). According to him the wet spell and weather cycles are found to obey geometric distributions. Sundararaj and Ramachandra (1975) investigated the validity of Markov-dependent geometric models for wet and dry spells and weather cycles at Hebbal and found it satisfactory. Virmani (1975) in his attempt to describe the agricultural climate of Hyderabad region has employed first-order Markov chain model to estimate probabilities of weekly rainfall. From the curves of initial and conditional probabilities, he has evaluated the persistence of rainfall during the growing seasons. Based on these, decisions regarding pre-sowing cultivations and sowing dates have been taken and the length of the growing period also has been estimated. Kulkarni et al. (1976) applied a two-state Markovian model to rainfall distributions. Medhi (1976) has concluded that there exists a good ground for assuming that the weather conditions of Gauhati for each of pre-monsoon and monsoon season can be described by the Markov chain model of order one. A study of dry spell probabilities with particular reference to the developmental stages of bajra crop in kharif season has been conducted for Delhi region by Victor and Sastry (1979) employing Markov chain model. Using the same technique, occurrence of wet and dry spells of Bihar and Kasargode district in Kerala have been studied respectively by Chowdhury (1981) and Sambasiva Rao (1984). Rao et al. (1986) have analysed the rainfall data of Jaisalmer region using first order Markov chain model to identify conditions favourable for establishment of grass lands with relatively low risk. In their effort to examine the rainfall variability and crop production in north coastal Andhra, Subramaniam and Raju (1988) have discussed the probability of occurrence of wet and dry spells on monthly and weekly basis with the help of first order Markov chain model.

2.1.7 Agroclimatic analysis and agricultural strategies:

Huda et al. (1988) has illustrated the usefulness of agroclimatic analysis to transfer improved soil and water management practices for ensuring efficient crop production. Various approaches adopted by various research workers to adjust with the weather variations are explained by Singh and Ramana Rao (1988). Dry farming, choice of suitable crop varieties, alternate crop strategies, mid-season corrections, crop-life saving measures etc. are the different approaches for weather management. Chatterjee et al. (1988) described the methods to adjust the weather variations in eastern rainfed region of India which is characterised by high rainfall and low radiation receipts during kharif season causing high pest incidence and inundations differing in magnitude and duration. Here the reduction in production during kharif season has to be compensated by increasing the productivity of rabi crops.

Various methods to manage the weather variations of arid western plains of India have been explained by Ramakrishna et al. (1988). Apart from the usual adjustments for weather variations, they have suggested micro-climatic modifications like mulches for conserving soil moisture and tree shelter belts to improve agricultural productivity from the arid region. They have put forward the idea of optimising land and fertiliser use for improved production.

2.2 Materials and Methods

The present investigation has been carried out for 39 stations widely distributed in the study region (Figure 2.1). Details of the selected stations are given in Table 2.2.

2.2.1 Water Balance Studies:

The climatic water balances of all stations on a monthly basis have been worked out using the modified book-keeping procedure of Thornthwaite and Mather (1955). Normal monthly rainfall values required for this purpose have been computed from the monthly rainfall data for the period 1931 - 1984 collected from the India Meteorological Department (IMD). The input parameters for the water balance procedure, apart from precipitation, are Potential Evapotranspiration (PE) and the field capacity (FC) of the station.

The normal monthly PE values are calculated by Thornthwaite's (1948) method. According to Thornthwaite, Unadjusted Potential Evapotranspiration (in cm)

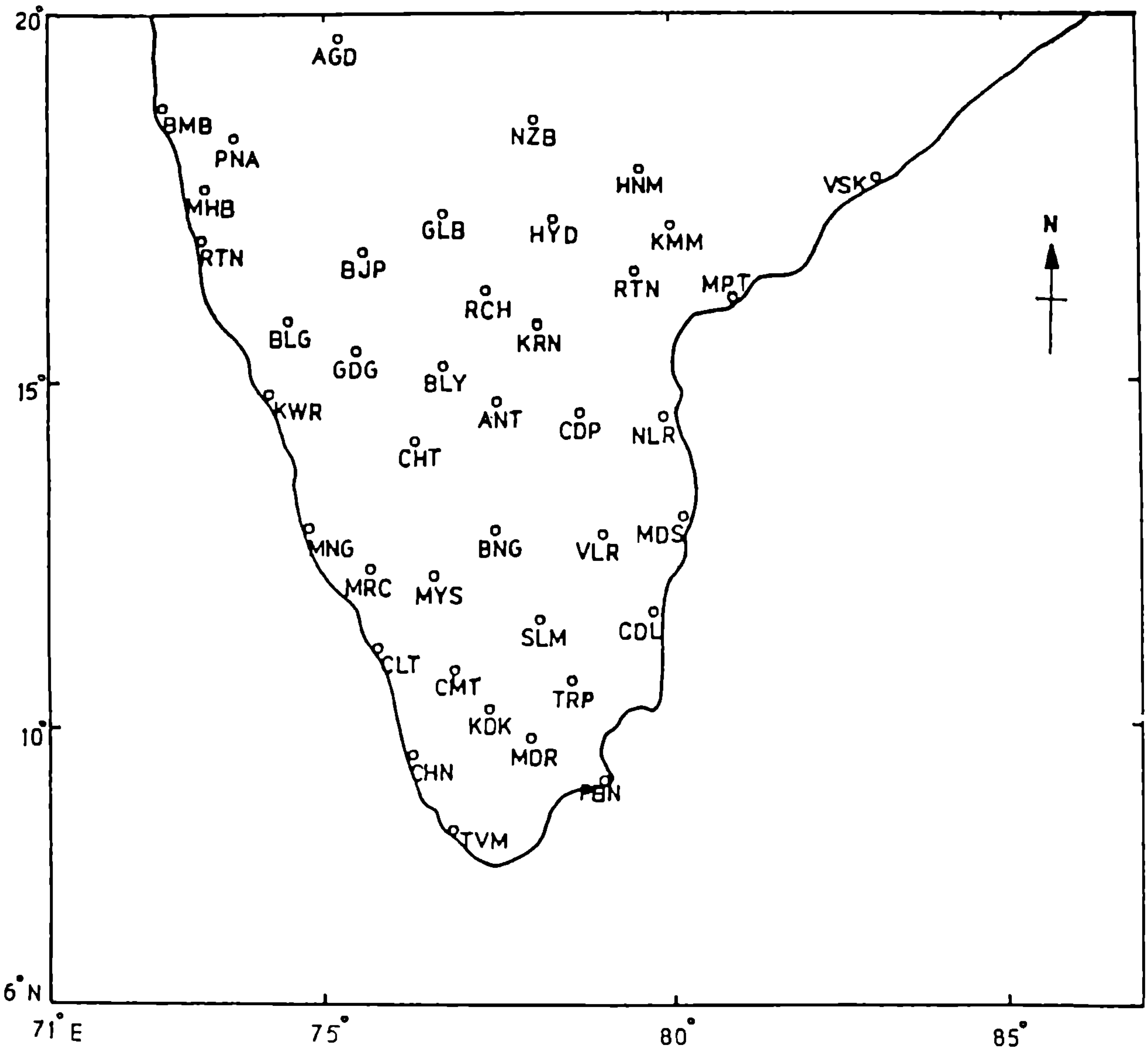


Figure 2.1 Location map

Station	Abbreviation	Latitude °N	Longitude °E	Height m
Anantapur	ANT	1441	7737	350
Aurangabad	AGD	1953	7520	581
Bangalore	BNG	1258	7735	921
Belgaum	BLG	1551	7432	753
Bellary	BLY	1509	7651	449
Bijapur	BJP	1649	7543	594
Bombay	BMB	1854	7249	11
Calicut	CLT	1115	7547	5
Chitradurga	CHT	1414	7626	733
Cochin	CHN	958	7614	3
Coimbatore	CMT	1100	7658	409
Cuddalore	CDL	1146	7946	12
Cuddapah	CDP	1429	7850	130
Gadag	GDG	1525	7538	650
Gulbarga	GLB	1721	7651	458
Hanamkonda	HNM	1801	7934	269
Hyderabad	HYD	1727	7828	545
Karwar	KWR	1447	7408	4
Khammam	KMM	1715	8009	112
Kodaikanal	KDK	1014	7728	2343
Kurnool	KRN	1550	7804	281
Madras	MDS	1300	8011	16
Madurai	MDR	955	7807	133
Mahabaleshwar	MHB	1756	7340	1382
Mangalore	MNG	1252	7451	22
Masulipatnam	MPT	1611	8108	3
Mercara	MRC	1225	7544	1152
Mysore	MYS	1218	7642	767
Nellore	NLR	1427	7959	20
Nizamabad	NZB	1840	7806	381
Pamban	PBN	916	7918	11
Pune	PNA	1832	7351	559
Raichur	RCH	1612	7721	400
Ratnagiri	RTN	1659	7320	35
Salem	SLM	1139	7810	278
Tiruchirappalli	TRP	1046	7843	88
Trivandrum	TVM	829	7657	64
Vellore	VLR	1255	7909	214
Vishakhapatnam	VSK	1743	8314	3

Table 2.2. Details of selected stations

$$UPE = 1.6 * [(10\ t)/I]^a$$

where t = mean monthly temperature in ^{o}C

$$I \text{ annual heat index} = \sum_{n=1}^{12} i_n$$

i_n= mean heat index of nth month = $(t_n/5)^{1.514}$

$$a = 0.49239 + 0.01792*I - 0.0000771*I^2 + 0.000000675*I^3$$

But when the monthly temperature is more than 26.5°C, another equation has been applied.

$$UPE = - 41.586 + 3.2233*t - 0.043254*t^2$$

These unadjusted PE values have been corrected for day length and also for the number of days in a month using the tables given by Subrahmanyam (1982).

Using the normal temperature data supplied by the India Meteorological Department (IMD) for the period 1931 - 1984, the normal monthly PE values have been estimated employing the above method.

Since there are no measured values of field capacities for all stations, as an approximation, the field capacities of all stations have been chosen as 300 mm.

The monthly water need (PE) for each station has been compared with the monthly water supply (P) from precipitation. Whenever the water supply is not sufficient to meet the water need, the difference has been considered as the water loss, and if there is water loss in successive months, the accumulated potential water loss (APWL) has been calculated for each month. Using the accumulated potential water loss and the field capacity values, the soil moisture status has been computed on a monthly basis, using the formula

$$S = FC * \exp(APWL/FC)$$

In such cases, the actual evapotranspiration (AE) is the sum of precipitation and the change of soil moisture content (ΔS) from the previous month. This change in soil moisture content is the soil moisture utilisation. In these months, the AE will be less than PE, and this shortage is considered as the water deficit for that month. On the other hand, when precipitation is greater than PE, the AE will be at its potential rate. The excess rainfall over water need recharges the soil; and when the soil moisture reaches its field capacity, the excess water is considered as the water surplus. In these months, there will not be any water deficit.

Using this procedure, water surplus and water deficit for all stations on a climatic monthly basis have been computed. The distribution of all these water balance parameters, namely, precipitation, PE, AE, water deficit and water surplus over the study region have been mapped and discussed on seasonal and annual basis.

2.2.2 Gamma Distribution Method:

It is seen that short-period rainfall distribution is highly skewed especially in low rainfall regions. This happens due to the fact that the frequency of zero rainfall or small amounts is very high (especially in low rainfall regions) and that of large amounts is very small (Khambete and Biswas, 1978). Mooley and Appa Rao (1971) have found that the normal distribution does not give a good fit to seasonal and annual rainfall over major parts of India. They have also brought out that the square root and logarithmic transformations are of limited utility in normalising the weekly rainfall. They have stated that, since normal distribution is a special case of Gamma distribution, the Gamma distribution probability model can be applied to weekly rainfall. Mooley (1973) has applied Gamma distribution probability model for Asian summer monsoon monthly rainfall series. He has also shown that the Incomplete Gamma distribution is a good fit to the pentad rainfall at Indian stations during both the monsoon seasons (Mooley and Appa Rao, 1970). Hence Gamma distribution probability model can be used for the analysis of weekly rainfall to get the minimum assured rainfall.

The weekly rainfall distributions include zero and non zero values of rain but Gamma distribution is a good fit to non zero values only. Thom (1951) has given a suitable distribution for this type of data containing zero and non zero values. It is known as mixed Gamma distribution and is given by

$$G(X) \quad q + p\,F(X) \qquad (1)$$

where $F(X)$ is the Gamma distribution function, q is the probability of zero precipitation and therefore $p = 1 - q$. $G(X)$ is the probability of rain $<$ X, where X is the minimum assured rainfall. The mixed Gamma distribution is used to analyse the weekly rainfall of the study region. In equation (1)

$$F(X) \quad \int_0^X \frac{x^{\gamma-1}\, e^{-X/\beta}}{\beta^{\gamma}\,\Gamma(\gamma)}\, dx \qquad (2)$$

where X, γ, β > 0 and F(X) = 0 for X > 0 and γ and β are the shape and scale parameters respectively and $\Gamma(\gamma)$ is the Gamma function of γ.

For obtaining the rainfall probabilities, the parameters γ and β have to be estimated. This is done by the method of moments.

If P(X) is the probability of minimum assured rainfall, then P(X)+G(X) = 1. (G(X) is the probability of rain < X). Therefore

$$P(X) = 1 - G(X) \qquad (3)$$

$$= 1 - [q + p\, F(X)]$$

$$= 1 - q + p \int_0^X \frac{x^{\gamma-1}\, e^{-X/\beta}}{\beta^{\gamma}\,\Gamma(\gamma)}\, dx$$

Here, P(X) is the probability level for which the weekly minimum assured rainfall is calculated. The equation is solved for X by the iteration method for different probability levels (25%, 50%, 75%, and 95%).

The daily rainfall data supplied by the IMD for the period 1931-1984 for the selected stations have been used for the analysis. From the daily rainfall data, weekly rainfall values for standard weeks have been calculated and then the analysis is carried out to estimate the minimum assured rainfall using the method described above.The standard weeks are given in Table 2.3.

Week No.		Dates	Week No.		Dates
1	January	01 - 07	27	July	02 - 08
2		08 - 14	28		09 - 15
3		15 - 21	29		16 - 22
4		22 - 28	30		23 - 29
5		29 - 04	31		30 - 05
6	February	05 - 11	32	August	06 - 12
7		12 - 18	33		13 - 19
8		19 - 25	34		20 - 26
*9		26 - 04	35		27 - 02
10	March	05 - 11	36	September	03 - 09
11		12 - 18	37		10 - 16
12		19 - 25	38		17 - 23
13		26 - 01	39		24 - 30
14	April	02 - 08	40	October	01 - 07
15		09 - 15	41		08 - 14
16		16 - 22	42		15 - 21
17		23 - 29	43		22 - 28
18		30 - 06	44		29 - 04
19	May	07 - 13	45	November	05 - 11
20		14 - 20	46		12 - 18
21		21 - 27	47		19 - 25
22		28 - 03	48		26 - 02
23	June	04 - 10	49	December	03 - 09
24		11 - 17	50		10 - 16
25		18 - 24	51		17 - 23
26		25 - 01	**52		24 - 31

* In a leap year week No. 9 will be from 26 February to March 4, that is 8 days instead of 7.
** The last week will have eight days, 24 - 31 December.

Table 2.3. The standard weeks

2.2.3 Agroclimatic Classification:

To have an agroclimatic classification based on the water requirements of the crops, data on actual evapotranspiration (AE) is necessary. But to get data on AE, which varies with growth stage and also from crop to crop, is very difficult. But from the definition of PE given by Thornthwaite, it is clear that PE covers the maximum water requirement of a fully grown crop. Thus, a comparison of the minimum assured rainfall and PE enables the evaluation of the water availability of the region which forms a good basis for the agroclimatic classification of the region. The MAI (moisture availability index) values provide the above mentioned comparison and it is applied as the tool in the present agroclimatic classification.

Hargreaves (1971) used the ratio of monthly assured rainfall at 75% probability level and average monthly potential evaporation calculated by Penman's method to classify agroclimates of northeast Brazil.

The weekly PE, required for the calculation of MAI has been interpolated from the monthly values of PE, assuming that the PE is uniformly distributed throughout the month. The monthly PE values are calculated by Thornthwaite's (1948) method as described earlier and from these values normal weekly PE values have been found out.

From the minimum assured rainfall at different probability levels and the estimated normal PE values, weekly MAI at different probability levels for all the stations have been computed. The sum of the amounts of assured rainfall during the period for which the value of MAI is greater than 0.3 is defined as the accumulated assured rainfall (AAR). The AAR at 75%, 50% and 25% have been calculated and the characteristics of its spatial distributions over the region are discussed. The spatial distributions of duration of MAI of different magnitudes ($\geqslant$ 0.3, $\geqslant$ 0.5, $\geqslant$ 0.7 and $\geqslant$ 0.9) have been presented and important features bought out.

Although Hargreaves (1971) emphasized the importance of continuity of the period when MAI is greater than 0.34 and took into account the risk factor, which is necessary for crop planning, Sarkar and Biswas (1986) have pointed out the following shortcomings:

a. only one risk factor has been taken into account

b. a month is too long a period for modern cereal crops

c. an MAI value greater than 0.34 has been considered adequate for all the growth stages of the crops.

Replay (1966) have stated that during the early stages of crop growth, the water need is about one quarter of the PE and the maximum demand may even slightly exceed the PE if the size of the field is not too large and there is considerable advection of sensible heat into the crop field. But according to Arnon (1972), due to the plant's built-in natural protective capacity, it can narrow down its stomatal opening to restrict transpiration when there is moisture stress and grow almost normally as long as the moisture supply does not fall below about three quarters of the PE. Holmes and Robertson (1963) say that after the completion of grain formation, the water demand falls off rapidly, becoming small at the ripening stage. From these points, Sarkar and Biswas (1986) assumed that plants will grow normally if MAI varies between 0.3 and 0.7 from germination to completion of grain formation.

Taking into account the above mentioned limitations and views they have applied the following modifications to the classification proposed by Hargreaves.

a. Weekly MAI is taken rather than monthly

b. Different probability levels are included instead of one so that the planner could select the level accordingly to his need.

c. The interval is taken as MAI $\geq$ 0.3 and $\geq$ 0.7 depending upon the crop growth phase.

On the basis of MAI at 50% level, they have put forward the different agroclimatic classes: and further sub-divisions have been made on the basis of the water stress period. On these types they have superimposed the soil type to get the soil agroclimatic classification. They have defined MAI at 50% level as the optimum moisture availability index because of the following reasons. Weekly MAI values of many individual years may have higher values than indicated by that particular probability level and may have a better chance of agricultural success. They have also taken into account that for lower probability levels, for most of the stations the MAI is 1.0 or more and very small or zero for higher probability levels. Hence the use of comparatively small or large probability levels may lead to unrealistic results.

Hence, in the present investigation, the agroclimatic classification of the study region has been carried employing the revised criteria given by Sarkar and Biswas (1988): the sub-divisions are based only on the soil types. The various agroclimatic types and the corresponding MAI both in magnitude and duration is given in Table 2.4.

Classes	No. of weeks when MAI at 50% level at least	
	$\geq$ 0.3	$\geq$ 0.7
D	< 10	< 1
E	$\geq$ 10	$\geq$ 1
F	$\geq$ 11	$\geq$ 4
G	$\geq$ 14	$\geq$ 7
H	$\geq$ 18	$\geq$ 9
I	$\geq$ 20	$\geq$ 10
J	$\geq$ 24	$\geq$ 12

Table 2.4. Agroclimatic types (Sarkar and Biswas)

Based on the classification criteria given in Table 2.3, using the MAI values at 50% level, the agroclimatic types of the individual stations have been identified and then the various agroclimatic zones of the region have been delineated. At this point it is worth mentioning that the soil type, in a given rainfall situation plays a dominant role in defining the agroclimate of the region. Taking this fact into consideration, the agroclimatic pattern already obtained has been superimposed on the soil map and various soil-agroclimatic sub-divisions have been identified. The soil map given by Champion and Seth (1967) has been employed for this purpose.

The growing period is defined as the period during which MAI is greater than or equal to 0.3. The different characteristics of the growing period, namely, the duration, degree of water availability, continuity and AAR etc. have been discussed for each agroclimatic type and for individual stations of each types separately.

Though the classification is based on MAI at 50% level, crop potential at 25%, 75% and also at 95% (for humid stations) have been discussed.

2.2.4 Markov Chain Model:

For calculating the probabilities of wet weeks, it is necessary to define a wet week. According to Virmani (1978), for the semi-arid tropical rainfall situations, at least 10 mm of dependable weekly rainfall should be adopted as a criterion for effective rainfall during monsoon crop season. Hence, in this study, a week is defined as wet (dry) if the rainfall for the week is greater than or equal to (less than) 10 mm.

The probability of receiving 10 mm of rainfall during a week [P(W)] is termed as initial probability. The probability of the following week becoming wet if this week is wet [P(WW)] is called conditional probability. These probabilities are calculated in this study employing the method given by Oldeman and Frere (1982). Here

$P(W) = F(W)/n$ and $P(WW) = F(WW)/F(W)$

Where P(W) is the probability of a wet week

F(W) is the number of wet weeks

F(WW) is the number of wet weeks followed by wet weeks

n is the number of years

P(WW) is the probability of occurrence of a wet week followed by wet week.

The weekly rainfall data for the period 1931 -1984 has been analysed thus to estimate P(W) and P(WW) for all the selected stations. The spatial pattern of P(W) for representative weeks of each month have been drawn to study the seasonal variation of P(W) over the region. For the agroclimatic classification of the study region described earlier in this chapter, the assured rainfall of 50% probability level is taken as the dependable rainfall. Therefore, P(W) becoming less than 50% is considered to be indicating probability of dryness and the period during which it is greater than 50% is taken as the growing period.

The pattern of these probabilities for the individual stations are presented: based on the extent of wetness, the dry spells during the growing period, the crop suitability and efficiency of different growing periods are assessed for different agroclimatic zones separately.

This methodology of rainfall probabilities is used to demarcate the risk associated with dry seeding of rainy-season crops. At stations where onset of seasonal rainfall during the commencement of growing period is abrupt and probabilities of continuance of wet weeks are high, the scope of dry seeding is excellent. Based on this criteria, stations where dry seeding is possible is demarcated.

The results of these studies based on the methodology described above are discussed in subsequent Chapters.

CHAPTER 3

PHYSICO-CLIMATIC FEATURES OF SOUTH INDIA

Physiography plays a vital role in determining the climate of any region which in turn controls every aspects of agriculture. Hence a brief survey of the physiographic features - soils, drainage, natural vegetation, land-use - and the climatic features of the region are included in the present Chapter.

3.1 Physical Features:

3.1.1 Location and Extent:

The region selected for this study includes four major states of South India namely Andhra Pradesh, Karnataka, Tamil Nadu and Kerala. A few stations in the southwestern parts of Maharashtra south of 20°N latitude are also selected for analysis for the sake of continuity. The study area is bounded in the south by about 8° 2'N, in the west and in the east by about 72° 49'E and 83° 14'E respectively. It is bound on the west by the Arabian Sea, on the east by the Bay of Bengal and by the Indian Ocean in the south. The northern boundary is fixed as 20°N.

3.1.2 Physiography:

The Western Ghats and the Eastern Ghats are the major mountains in this region. The Western Ghats lie parallel to the west coast extending northwards from the southern tip of the west coast extending northwards from the southern tip of the peninsula right upto Aravally hills of Rajasthan. The Eastern Ghats are broken mountain chains which are parallel to the coast along the coastal Andhra Pradesh. Both these mountain ranges are linked at the Nilgiri hills. The Western Ghats act as a wall separating Kerala from adjoining states, with an average height of 1 km. The Anaimalai and Nilgiris are the tallest mountains in the Western Ghats and are separated by the Palghat Gap of width about 30 km: this gap has a significant effect on the meteorology of Kerala. The coastal belt of Kerala extends over a distance of 580 km along the west coast with a width varying between 15 km and 120 km. The landmass of Kerala is delineated into three natural zones, namely, the lowlands, midlands and highlands, all of which run parallel from North to South. The highlands consist of mountain ranges while the lowlands are a strip of area running along the coast, characterised by beaches, swamps, and lagoons. In between lowlands and highlands is the midlands region characterised by undulating terrain which is rich in agricultural products. The Western Ghats shelters the entire Tamil Nadu region from the full blast of rain bearing winds of South West monsoon. The north eastern coastal plains of Tamil Nadu are known as Coromandel coastal plains. Here the lowland elevation is below 150 m and its width varies between 80 km and 95 km. In a southwest direction from this coastal plain, lie the Tamil Nadu hills. The summits in this region are of height 1000 m to 1600 m. Between Western Ghats and Eastern Ghats, north of Tamil Nadu, is the Deccan Plateau. The region in Karnataka consists mainly of a plateau whose northern part is having more elevation than the southern part and the height varies roughly between 300 m to 900 m. In the State of Karnataka the width of the coastal belt varies between 50 to 80 km and covers a distance of about 225 km. The Eastern Ghats separates the Deccan Plateau from coastal region of Andhra Pradesh: in the southern districts of Andhra Pradesh, Eastern Ghats is broken into various ranges to form a general plateau with elevations rising to 1 km whereas in the northern districts, the Eastern Ghats are more continuous with higher elevations not exceeding 2 km are found. The width of the lowlying Andhra coastal belt varies between 100 km in the South and 40 km in the North.

3.1.3 Drainage:

The gift of copious rainfall during monsoon months in the windward side of Western Ghats has helped the formation of a number of perennial rivers in this region. The drainage network of Kerala consists of 44 rivers out of which 41 flow westward. Among these, Periyar, Bharathapuzha, Pamba and Chaliyar are the major ones. The principal rivers which traverse the region west of Western Ghats in Tamil Nadu are Palar, Ponnaiyar, Cauvery, Vaigai and Thamaraparni; all flowing from west to east into the Bay of Bengal. The river Cauvery is the most important river of South India. The Deccan Plateau is drained by the four major river systems of Krishna, Cauvery, Tungabhadra and Godavari.

3.1.4 Soils:

Soil types and their distribution in the study region are depicted in Figure 3.1 (Champion and Seth, 1967). Four major types of soils found in this region are black soils, red loams, coastal alluvium and lateritic soils. Generally, coastal alluvium and lateritic soils are distributed along the coasts; laterites are found more along the west coast than east coast. The southern part of study region is characterised mainly by red loam soils, whereas in northern part it is black soils. Different varieties of black soil such as medium black, deep black and mixed red and black are found here.

3.1.5 Natural Vegetation:

In India, the natural vegetation almost everywhere is of the tropical type. The species and luxuriance of the natural vegetation vary to a great extent according to the distribution of rainfall. Changes in soil conditions also give rise to different types of vegetation in many areas. The high rainfall regions of the Western Ghats have dense tropical wet evergreen forests whereas monsoon forests (deciduous forests), savanna and bush are predominant over the rest of the peninsula, where the rainfall is moderate. The arid and semi-arid central parts with low rainfall have scrub and bushes.

The different types of natural vegetation over the study region is given below:

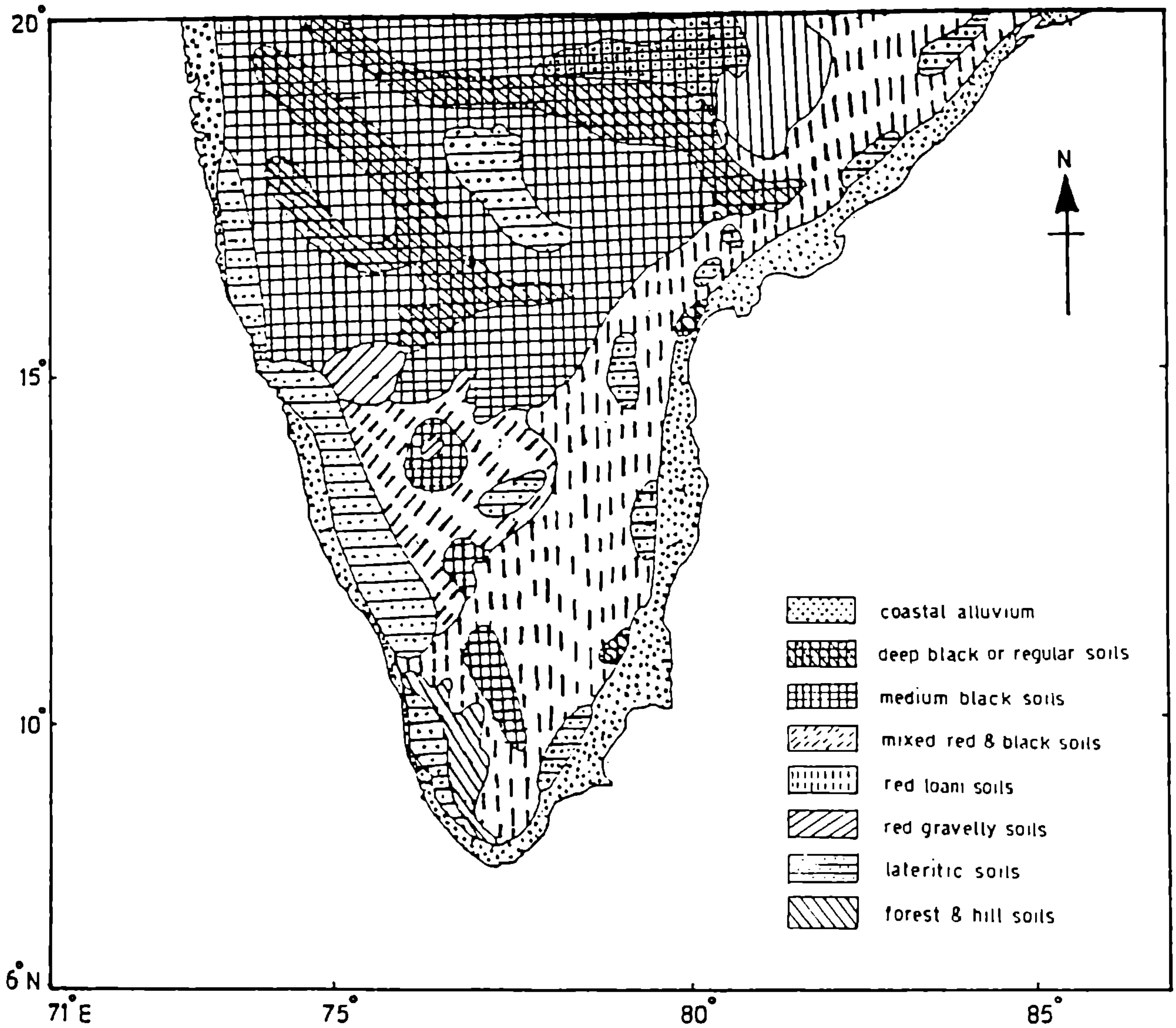


Figure 3.1 Soil types of South India

1. Moist tropical types

    a. Tropical wet evergreen

    b. Tropical moist semi-evergreen

    c. Tropical moist deciduous

2. Dry tropical types

    a. Tropical dry deciduous

    b. Tropical dry evergreen

    c. Tropical thorn

Figure 3.2 depicts the pattern of natural vegetation of the region. The tropical wet and semi-evergreen forests occur in areas of heavy rainfall (> 250 cm) as a strip along Western Ghats. It is bordered by the semi-evergreen on the drier side which in turn merges with the tropical moist deciduous forests. The vegetation in these forests is very dense and trees often reach 45 m in height. These forests provide a variety of products of which timber, fire-wood and bamboo are particularly important. Tropical moist and dry deciduous forests occupy most of the land surface of the region with moderate rainfall of 100 - 200 cm. The moist deciduous forests form a long strip parallel to the Western Ghats. Trees in these forests drop their leaves during the hot dry weather and rise to about 25 - 60 m in height. The dry deciduous forests occupy areas where rainfall is between 100 and 150 cm: these forests have a more open and dwarfish composition. The deciduous forests are economically most important as they possess a large number of commercially important timber tree species of which sandalwood is most

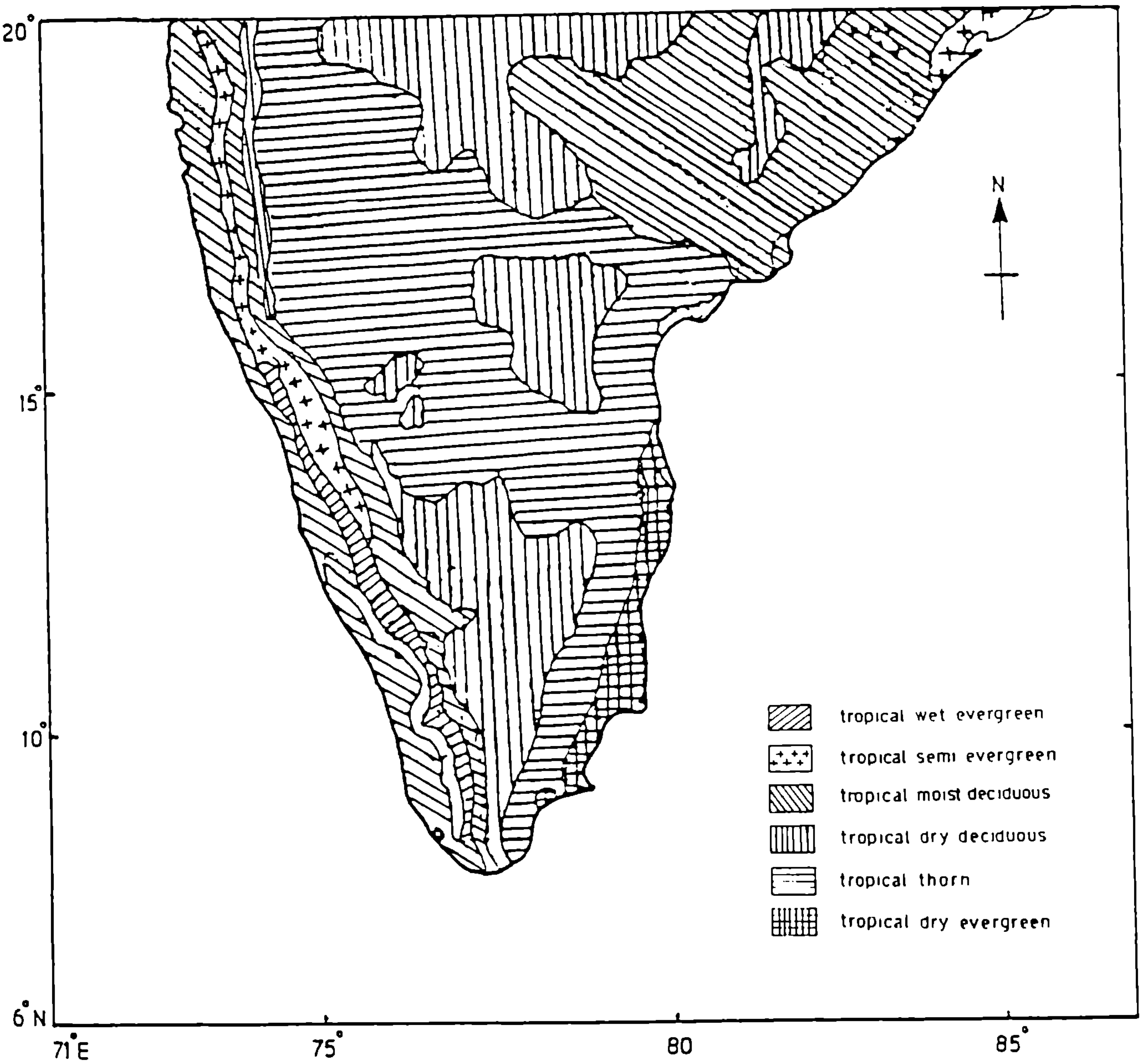


Figure 3.2 Natural vegetation of South India

important. The tropical dry evergreen forests are confined only to coastal Tamil Nadu which receives rainfall mostly during the retreating phase of the monsoon season. It is characterised by low canopy of grasses and shrubs. In areas where annual rainfall is below 75 cm tropical thorn forests exist and the vegetation of these forests consists of widely scattered trees and bushes.

3.1.6 Land Utilisation:

The data of land utilisation of the four States are given in Table 3.1 (The fertiliser association of India, 1989). The smallest state Kerala's geographical area is only about 14% of that of the biggest State Andhra Pradesh. But in Andhra Pradesh, only 38% of the geographical area is used for cropping which is the least among the four states. The highest percentage of geographical area used for cropping is in Kerala. The highest percentage of area used for cropping more than once is in Kerala which also has the highest percentage of area under irrigation.

3.1.7 Crops:

The principal crops of the four states are given in Table 3.2 (The fertiliser Association of India, 1989). Rice is cultivated as a major crop in all the four states. Except in Kerala, in the other three states, pulses, groundnut, cotton, sugar cane and other cereals are grown as major crops. But in Kerala a variety of crops are seen of which coconut is the most important one. Pepper, cashewnut, cardamom, coffee, tea, rubber and cocoa are the special varieties found only in Kerala. But

State	Geographical area	Area cropped			Area irrigated		
		Net	more than once	gross	net	more than once	gross
Andhra Pradesh	27,440	10,425	1,730	12,155	3,552	746	4,298
Karnataka	19,050	10,736	1,510	12,246	1,854	442	2,296
Kerala	3,885	2,211	689	2,900	3,057	870	3,927
Tamil Nadu	12,994	5,778	951	6,729	2,438	507	2,945

(area in 1000 hectares)

State	Net cropped area %	% of net cropped area	
		cropped more than once	irrigated
Andhra Pradesh	38.0	16.6	34.0
Karnataka	56.4	14.0	17.3
Kerala	57.0	31.1	100.0
Tamil Nadu	44.5	16.5	42.0

Table 3.1. Land utilisation of the study region

many cereals grown efficiently in the other three states are not grown in Kerala. Wheat is grown only in Andhra Pradesh and Karnataka. Rice, Jowar and groundnut are the major crops of Andhra Pradesh and Tamil Nadu, but in Karnataka apart from these three crops, ragi is also cultivated in large areas.

Crops	Andhra Pradesh	Karnataka	Kerala	Tamil Nadu
Rice	3207	1048	604	1955
Wheat	10	267	-	-
Jowar	1737	2465	3	689
Ragi	173	1116	2	168
Maize	303	205	-	20
Bajra	312	417	-	293
Bengalgram	49	243	-	-
Redgram	338	-	-	88
Blackgram	-	-	-	227
Greengram	495	-	-	81
Horsegram	196	-	-	-
Tur	-	463	-	-
sugarcane	143	203	8	195
Chillies	170	127	-	44
Groundnut	1911	1056	-	991
Seasamum	167	163	12	145
Cotton	574	476	-	244
Tobacco	107	47	-	9
Coconut	-	213	775	189
Sunflower	-	1056	-	-
Pepper	-	-	146	-
Cardamom	-	-	64	-
Betelnut	-	-	61	-
Mango	-	-	68	45
Plantain	-	18	57	54
Jack fruit	-	-	64	-
Cashewnut	-	-	122	-
Tapioca	-	2	173	67
Coffee	-	-	66	-
Tea	-	-	35	-
Rubber	-	-	36	-
Onion	-	40	-	20

Table 3.2. Area under principal crops (in 1000 hectares)

3.2 Climatic Features:

3.2.1 Rainfall:

The rainfall pattern of the region is of the monsoonal type, being influenced both by the southwest as well as the northeast monsoons. Thus, the region enjoys rainfall throughout the year except during the two winter months.

The pattern of annual rainfall of the region is shown in Figure 3.3. The isohytes along west coast is parallel to the Ghats and a sharp gradient is observed from the windward to the leeward side of the Ghats, the rainfall amounts ranging between 350 cm to less than 100 cm. The region of maximum rainfall is seen around North Kerala and South Karnataka coast; from this region, rainfall decreases in both north and south directions. The hill stations also experience heavy rainfall, North Tamil Nadu and South Andhra coasts receive more than 100 cm rainfall. A pocket of low rainfall found in the central part of the region protrudes from southwest part of Maharashtra to North Interior Karnataka and Rayalaseema where the annual rainfall is less than 75 cm.

Rainfall during the winter season (Figure 3.4a) is scanty compared to the other seasons. The highest amount of about 7 cm is observed around Pamban on the east coast; rainfall decreases further northward along the east coast. Along the west coast too it decreases northward the highest amount being recorded around Trivandrum region. The central parts of the region comprising of parts of Karnataka, Rayalaseema and southwest parts of

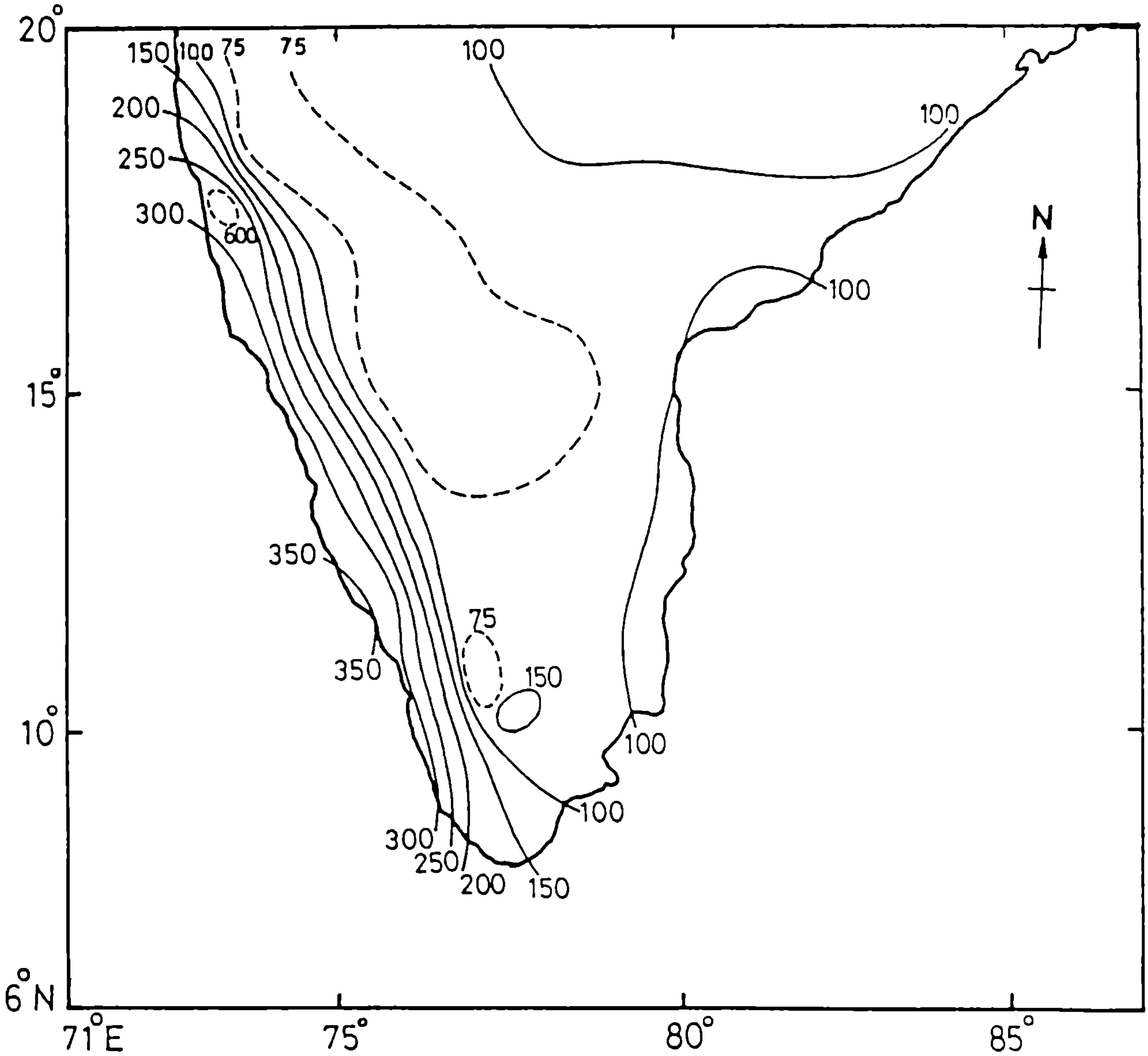


Figure 3.3 Spatial distribution of annual rainfall over South India (cm)

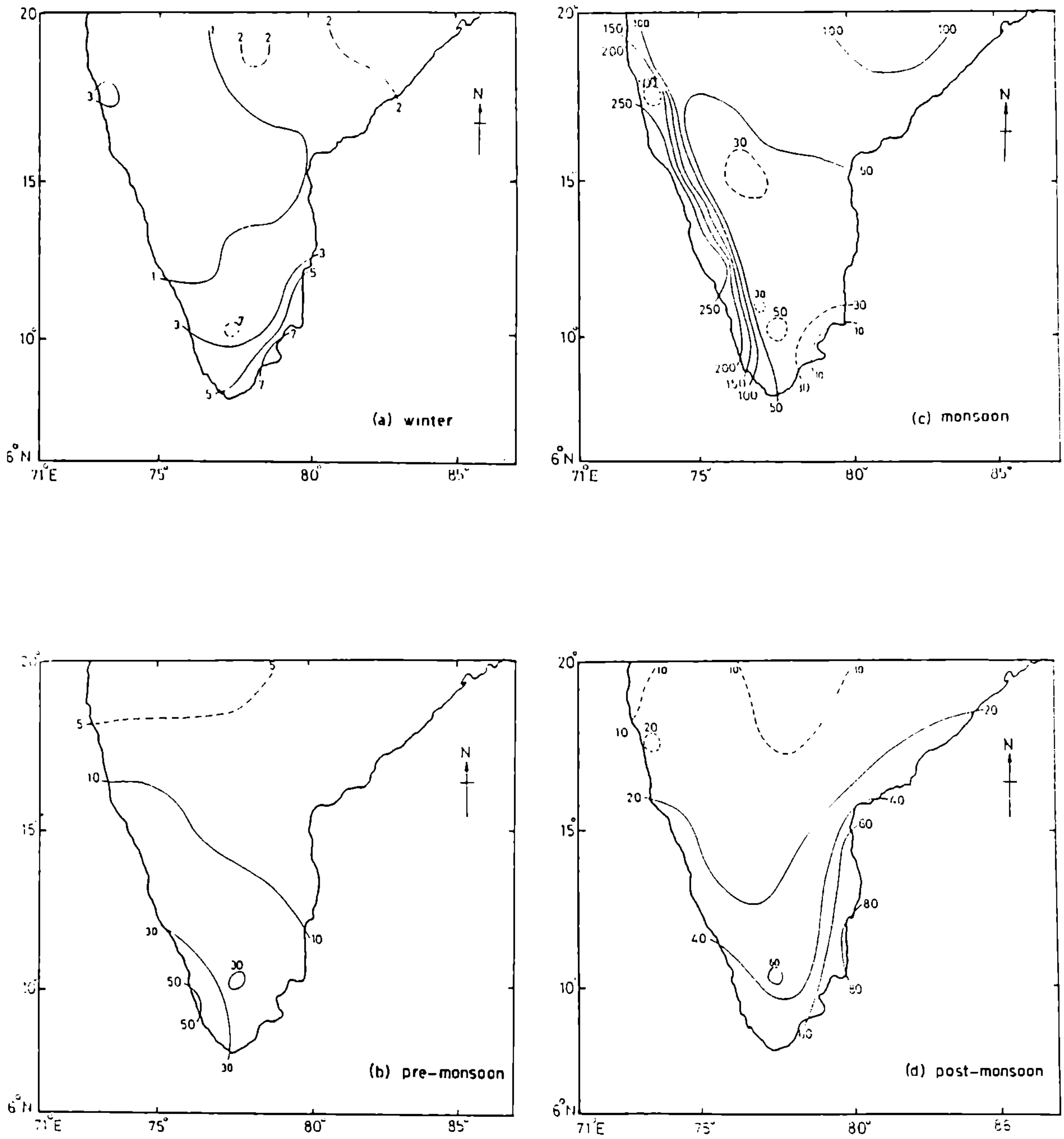


Figure 3.4 Spatial distributions of seasonal rainfall (cm)

Maharashtra form the core area of low rainfall, where it is less than 1 cm. A slight increase is observed towards Telangana and North Andhra coast.

The highest rainfall during the pre-monsoon season is found to occur along South Kerala coast around Cochin and from this region it decreases in both north and south directions (Figure 3.4b). From this pocket of high rainfall, values show a decrease in the north-east direction.

During the monsoon season, the entire region receives significant rainfall. From Figure 3.4c, it can be seen that in the Ghats region the spatial pattern of rainfall during this season is similar to that of the annual pattern. As in the case of annual pattern, the maximum amount of rainfall for this season is observed along the west coast, but is slightly shifted northward to the the South Karnataka coast. The rainfall gradually decreases on the leeside of the Ghats, where two minimum rainfall pockets are observed, one in North Interior Karnataka around Bellary and Anantapur region and the other in South Tamil Nadu coast around Pamban.

During the post-monsoon season, the spatial distribution of rainfall (Figure 3.4d) is entirely different from that of the previous seasons. The rainfall decreases towards north along the west coast and in the central region but along the east coast rainfall increases from the extreme southern parts to a maximum around Cuddalore, and then decreases further northward.

The spatial pattern of coefficient of variation for the region is as in the Figure 3.5. The region having maximum coefficient of variation (greater than 30%) is centered around the low rainfall region comprising of north interior Karnataka, Rayalaseema, and region around Coimbatore. Generally, the hill stations, Kerala and Karnataka coasts and also the region around Bangalore exhibit low values (< 20%). Along the east cost, the values are comparatively higher than the west coast.

The number of rainy days in the region (Figure 3.6) varies from more than 125 along Kerala and South Karnataka coasts to less than 50 in the central arid region comprising of parts of north interior Karnataka, Rayalaseema, Telangana and southwest parts of Maharashtra and South Tamil Nadu. It can be seen that the number of rainy days is more than 100 along the entire west coast except in the extreme north parts. The number decreases towards east and on the leeside of the Ghats where it is less than 50.

3.2.2 Temperature:

The mean annual temperature over the study region is mapped in Figure 3.7a. An increase from about 27 ^{o}C along west coast to more than 29 ^{o}C along the coastal Andhra Pradesh and Tamil Nadu is seen. The temperature gradient is large in the eastern sector of the region and further, temperature variations are more on the east coast. Hill stations report markedly low temperatures.

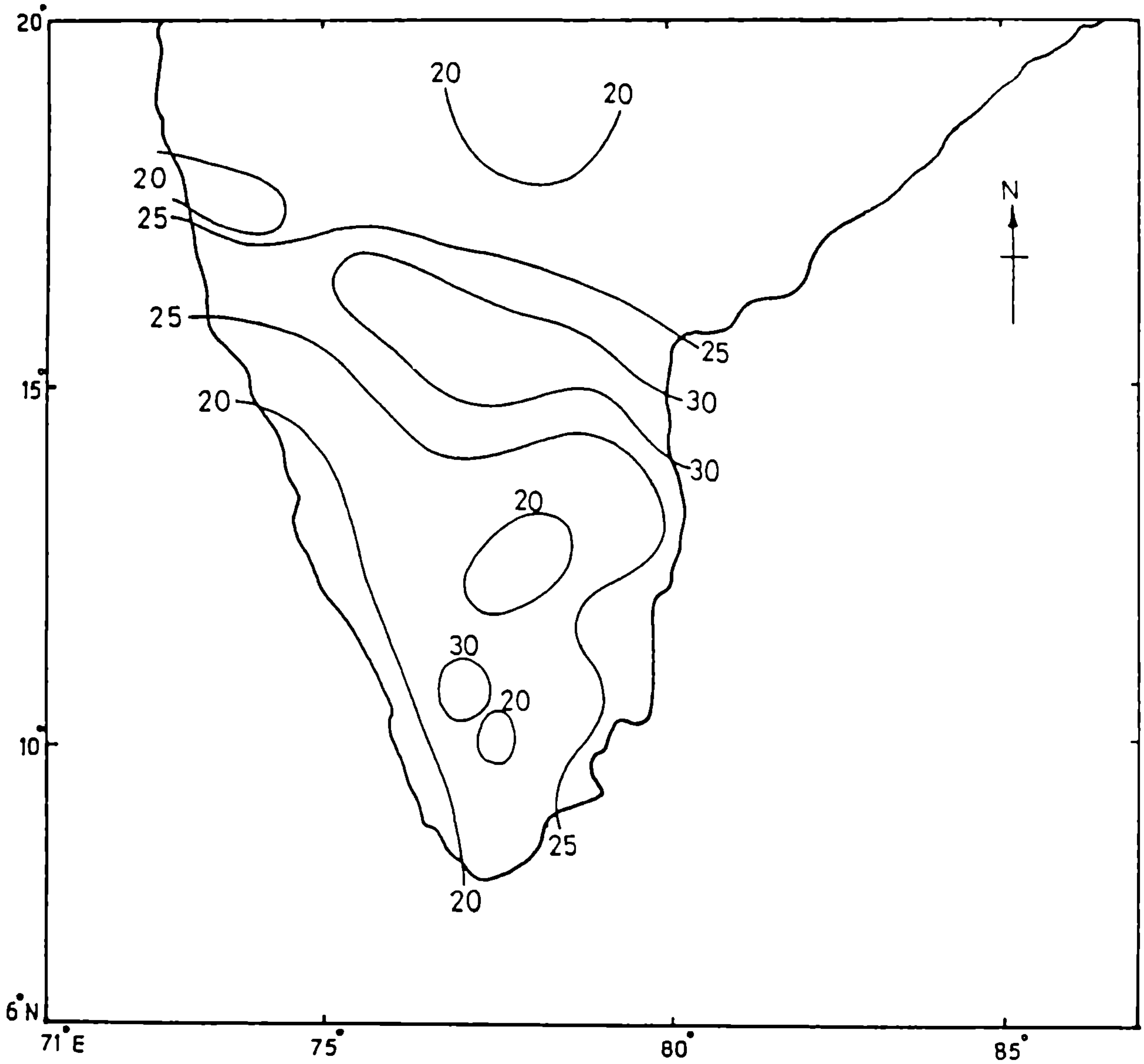


Figure 3.5 Spatial distribution of coefficient of variation of annual rainfall (%)

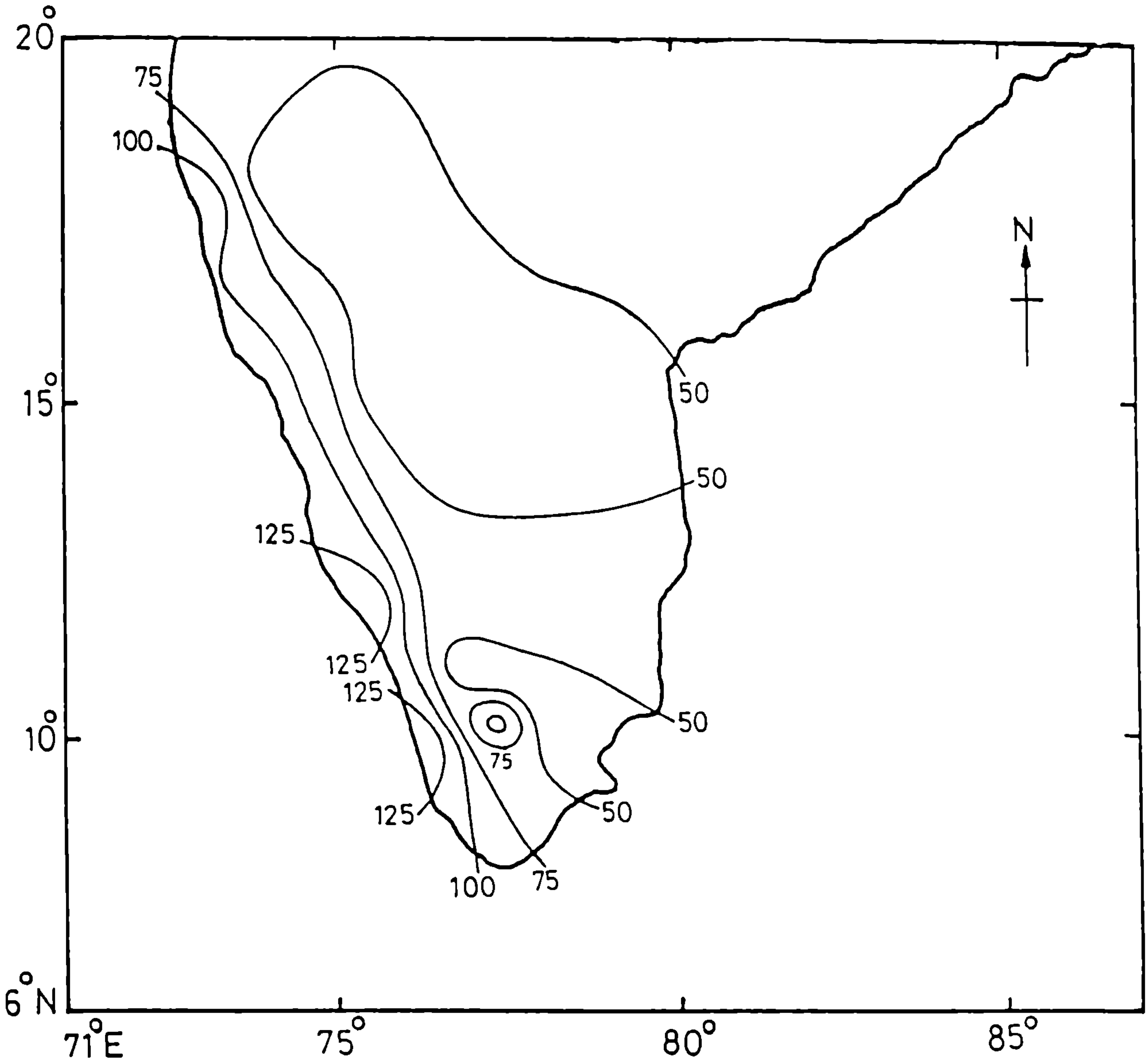


Figure 3.6 Distribution of number of rainy days

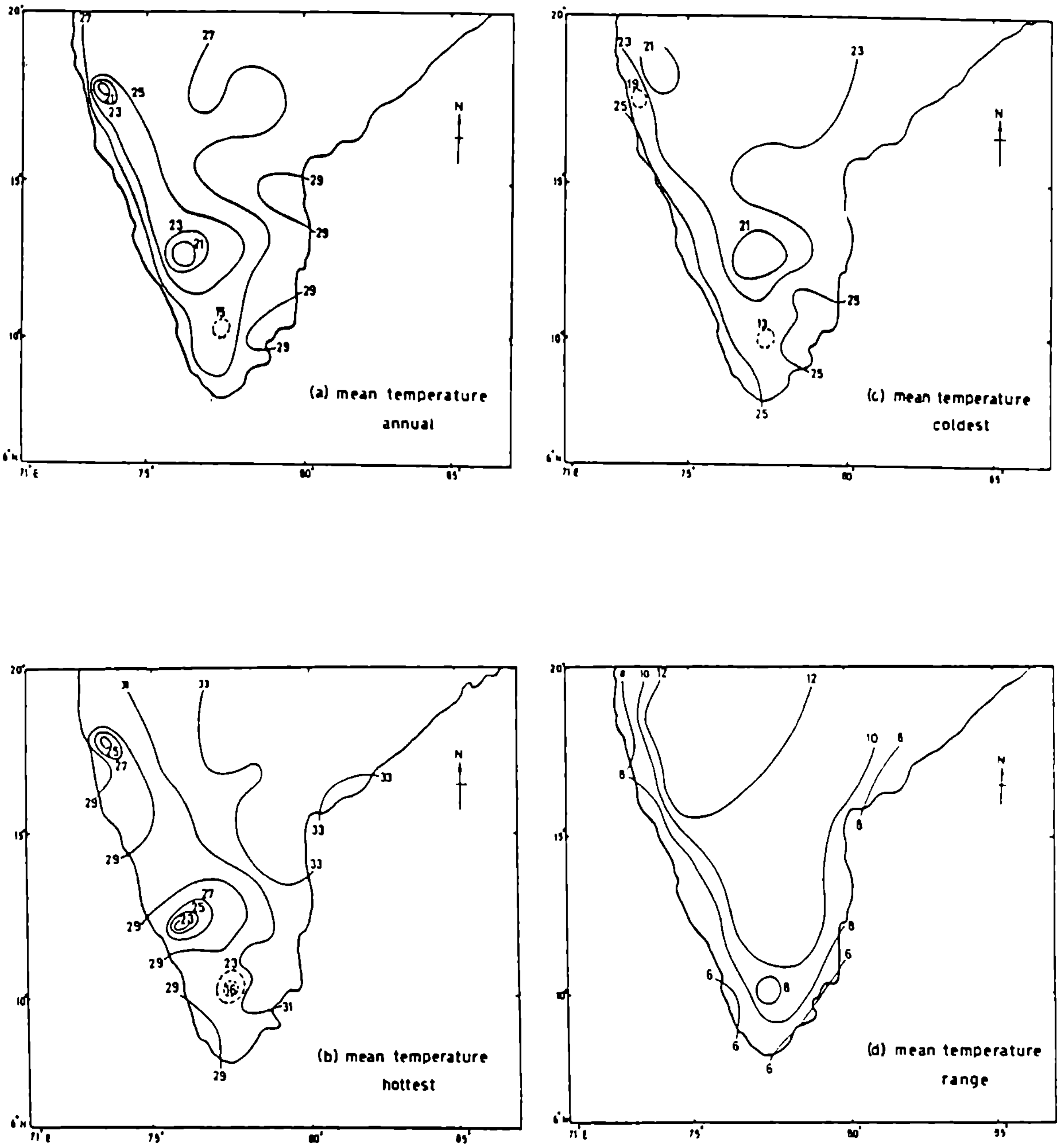


Figure 3.7 Temperature characteristics of South India °C

The pattern of mean temperature of the hottest month for the region is given in Figure 3.7b. Temperature along the west coast is more or less 29°C while along the east coast it varies from around 30°C in Tamil Nadu coast to about 34°C in coastal Andhra Pradesh. Generally, high temperatures are found in the eastern part of the region where the gradient is also more.

The spatial distribution of mean temperature of the coldest months is depicted in Figure 3.7c. Generally, southern parts of the coasts show high values. Along the west coast it varies from about 24°C on the Bombay coast to about 26°C on the Kerala coast. Similarly, along east coast it varies from about 23°C in coastal Andhra Pradesh to about 25°C in Tamil Nadu coast. In the interior peninsula, the isotherms show a tongue-shaped curve centered around Bangalore, demarcating areas of coldest mean temperature where, it is around 20°C.

The variation of annual temperature range for the region is depicted in Figure 3.7d. In general, the coastal areas have low temperature ranges (< 8°C) and the southern parts of both the coasts show lower ranges than the northern parts. The lowest temperature range is observed at Pamban while the highest range is at Pune.

3.2.3 Relative Humidity:

Mean relative humidity over the region shows variations as in Figure 3.8. It can be seen from the figure that high values of humidity are found along the west coast, the values being

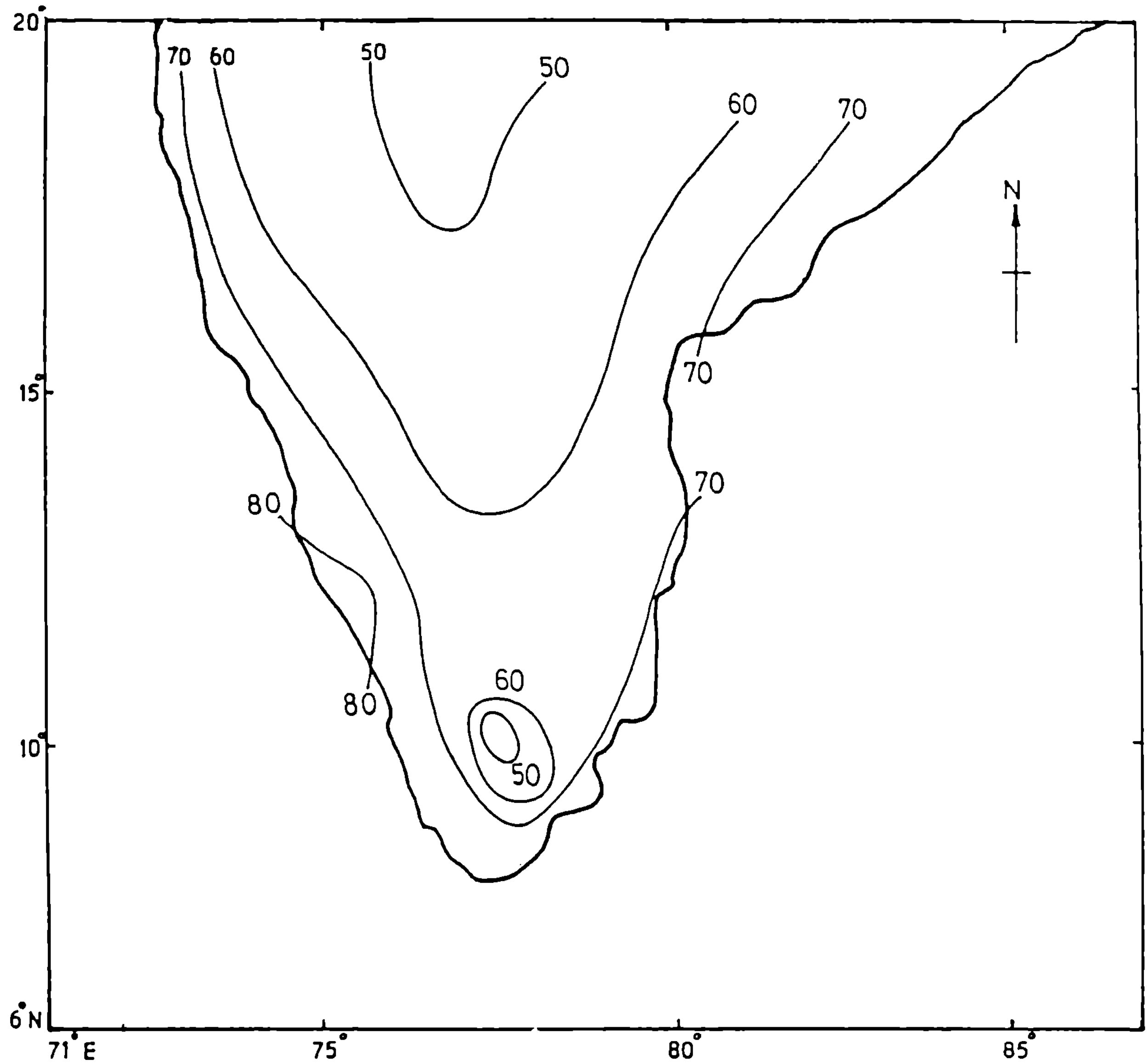


Figure 3.8 Distribution of mean relative humidity over South India (%)

higher in the southern parts compared the northern part; but along the east coast, low values are found in the central region. Generally, the relative humidity over the region varies from about 70% along the coast to less than 50% in interior Karnataka, Telangana and Marathwada. In the interior parts of the region too north-south gradient is observed.

3.2.4 Potential Evapotranspiration:

The distribution of annual Potential Evapotranspiration (PE) over the study region is presented in Figure 3.9. Over the region, it varies between 130 cm in the interior parts of Karnataka to greater than 180 cm in the southern parts of Tamil Nadu around Tiruchirappalli. Along the west coast, potential water need is more or less uniform and is around 170 cm but along the east coast it shows higher values in southern parts; generally, west coast has low values compared to east coast. Hill stations report markedly low water need.

Compared to the distribution of annual PE, its seasonal variations have greater practical importance in agriculture. Among all the four seasons water need is least during the winter period. (Figure 3.10a). Highest values (> 25 cm) of PE during this season are found along Kerala and Karnataka coasts. Towards north, it decreases and a pocket of low PE is found in the northwest part of the study region (around Pune).

During the pre-monsoon period, water demand everywhere in the region is higher than that of winter values (Figure 3.10b).

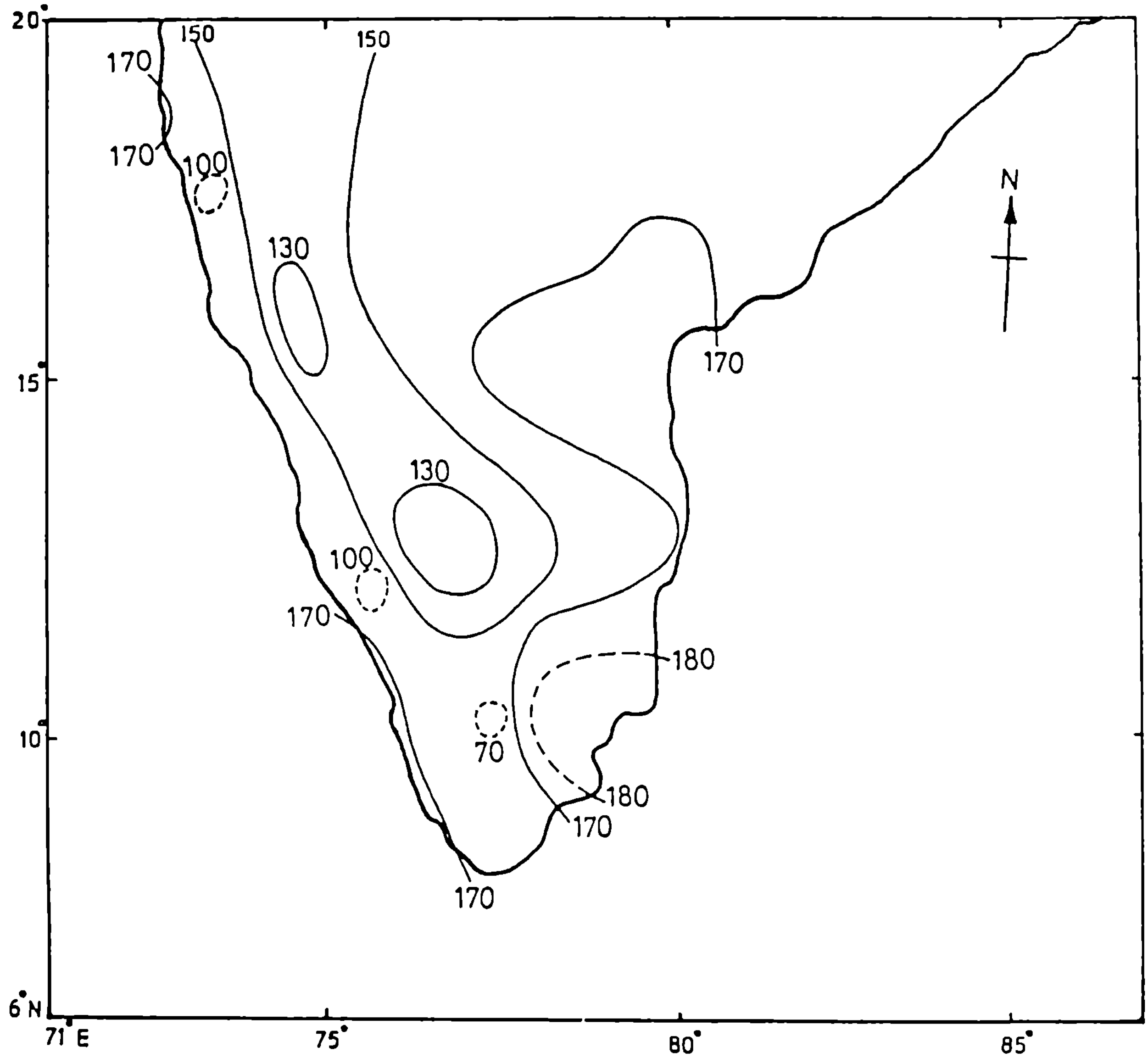


Figure 3.9 Distribution of annual PE
over South India (cm)

But along the west coast the values are lower compared to the east coast. In this season, too, the minimum PE is observed in South Interior Karnataka and a pocket of high value is found around Rayalaseema and North Tamil Nadu region.

Figure 3.10c shows the distribution of PE during the monsoon season. The maximum water need is experienced during this period. Along the west coast, low values (< 40 cm) are observed around north Kerala and south Karnataka and from this region it increases in both north and south directions. In this season, too, the pocket of minimum values is observed in south interior Karnataka.

During the post-monsoon season, the values of PE decrease all over the region (Figure 3.10d). Generally, Kerala coast shows higher values during this period. Along both the coasts, values decrease towards north. Region of low values is found around south interior Karnataka and Telangana.

3.2.5 Actual Evapotranspiration:

For the development and management of water resources, date of actual evapotranspiration (AE) which is the amount of water that evaporates and transpires from soil and plants is more important than PE.

The distribution of annual AE is shown in Figure 3.11. The annual AE over the region varies from more than 140 cm along Kerala coast to less than 60 cm in north interior Karnataka and Rayalaseema. Along the east coast values are less compared to

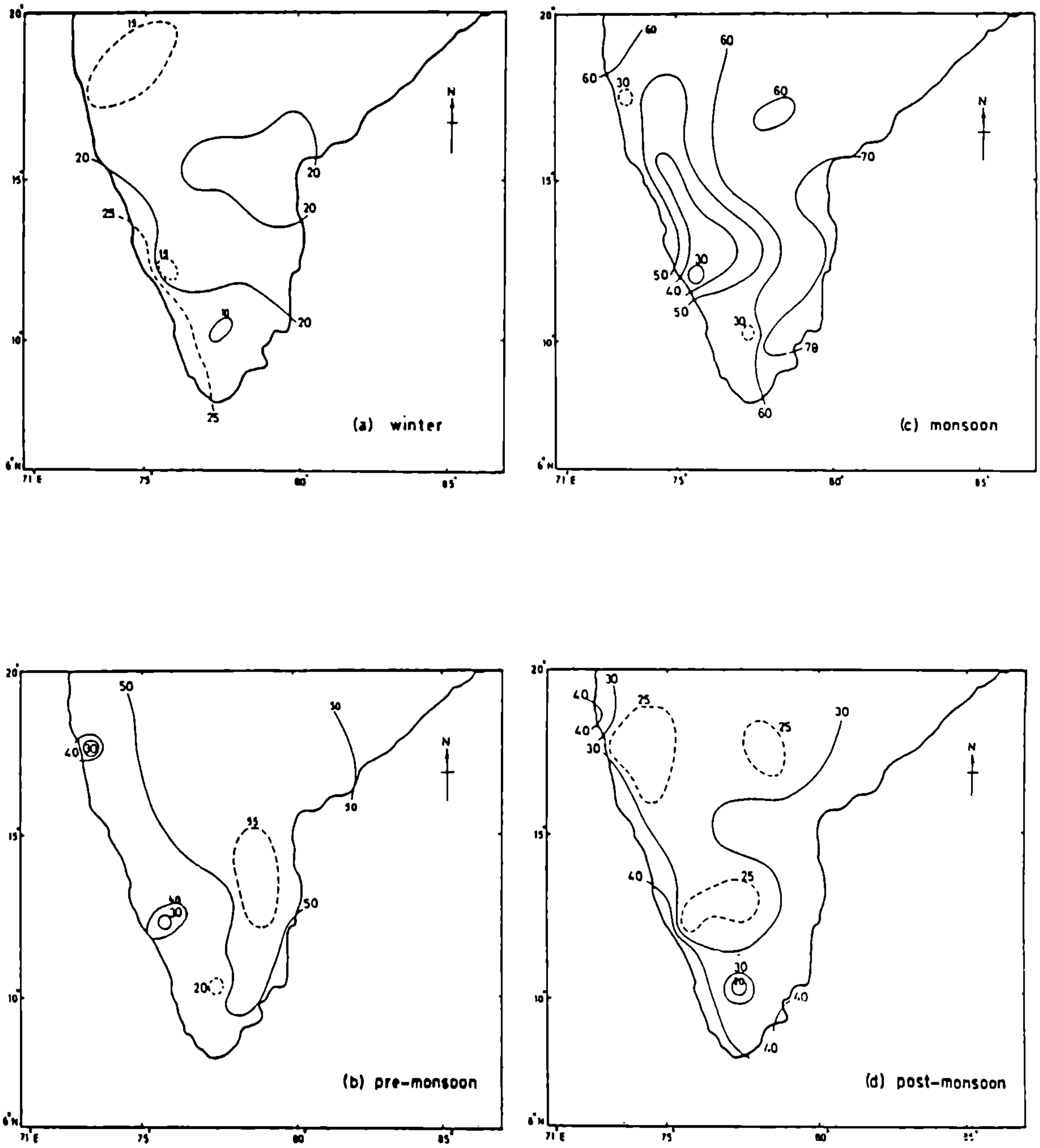


Figure 3.10 Distributions of seasonal PE over South India (cm)

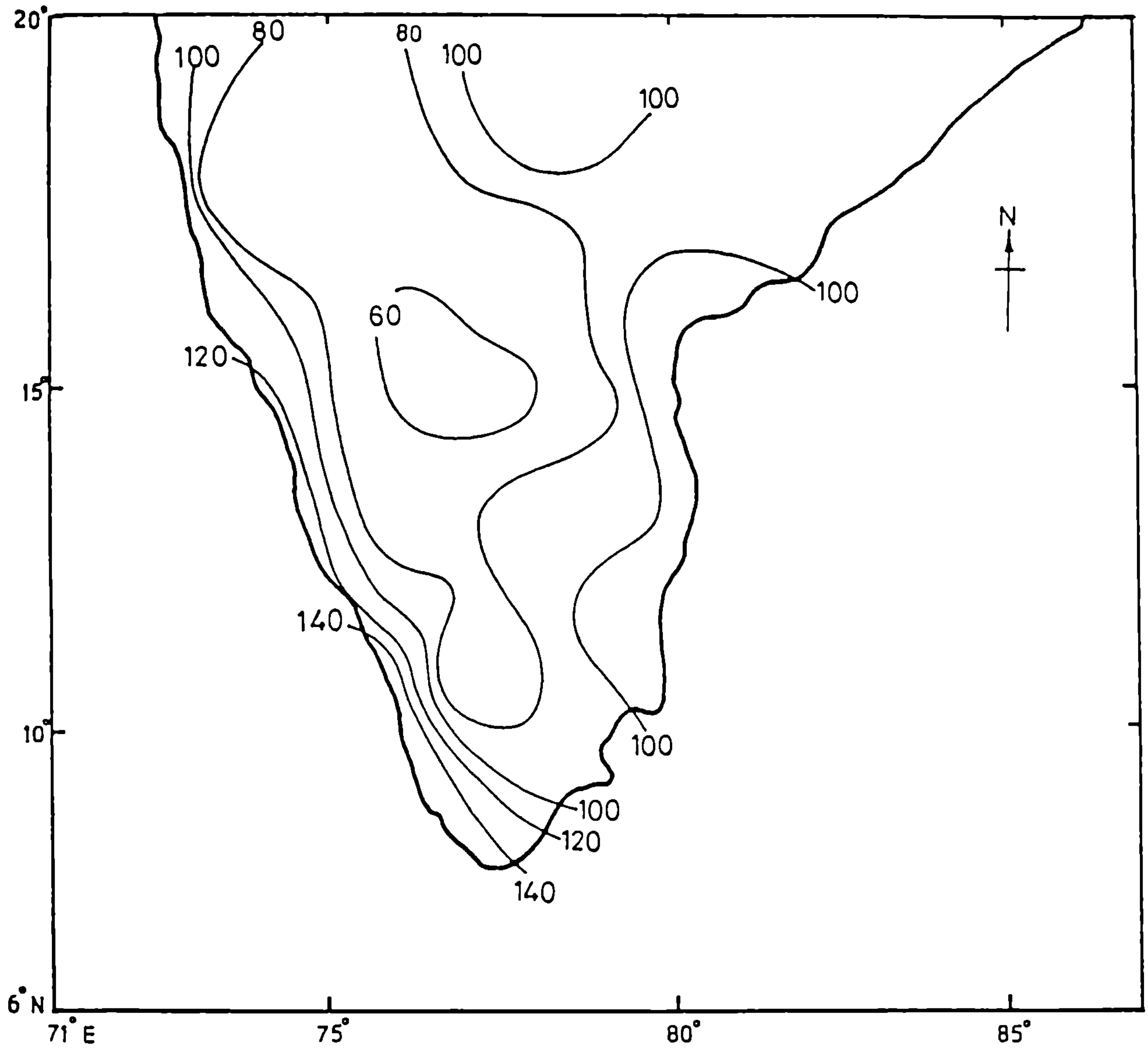


Figure 3.11 Distribution of annual AE
over South India (cm)

the west coast. In the case of AE there is not much difference in values between elevated stations and the neighbouring areas as in the case of PE. The difference in magnitude of AE and PE over the region point to the inadequacy of moisture over the region.

The distribution of AE over the region during winter season is almost the same as that of its annual pattern (Figure 3.12a). In this season, the value of AE varies from more than 15 cm along Kerala and Tamil Nadu coasts to less than 1 cm in North Interior Karnataka, Rayalaseema and Telangana.

During the pre-monsoon period, AE over the region varies as in Figure 3.12b. It varies from slightly more than 30 cm on the Kerala coast to less than 10 cm in north interior Karnataka, Rayalaseema and Telangana. Along both the coasts, values decrease from south to north.

In the monsoon season, AE values over the region vary generally from about 60 cm in the north eastern parts of Telangana to less than 30 cm around Bellary in the central part (Figure 3.12c). The values are greater than 50 cm all along the west coast and east coast. Higher values are found along coastal Andhra Pradesh. Pamban which lies in the extreme south portion registers the least AE (< 10 cm) during this season which is less than that in the central arid zone. Similarly, Coimbatore in the southern part also exhibits AE less than that of the central region.

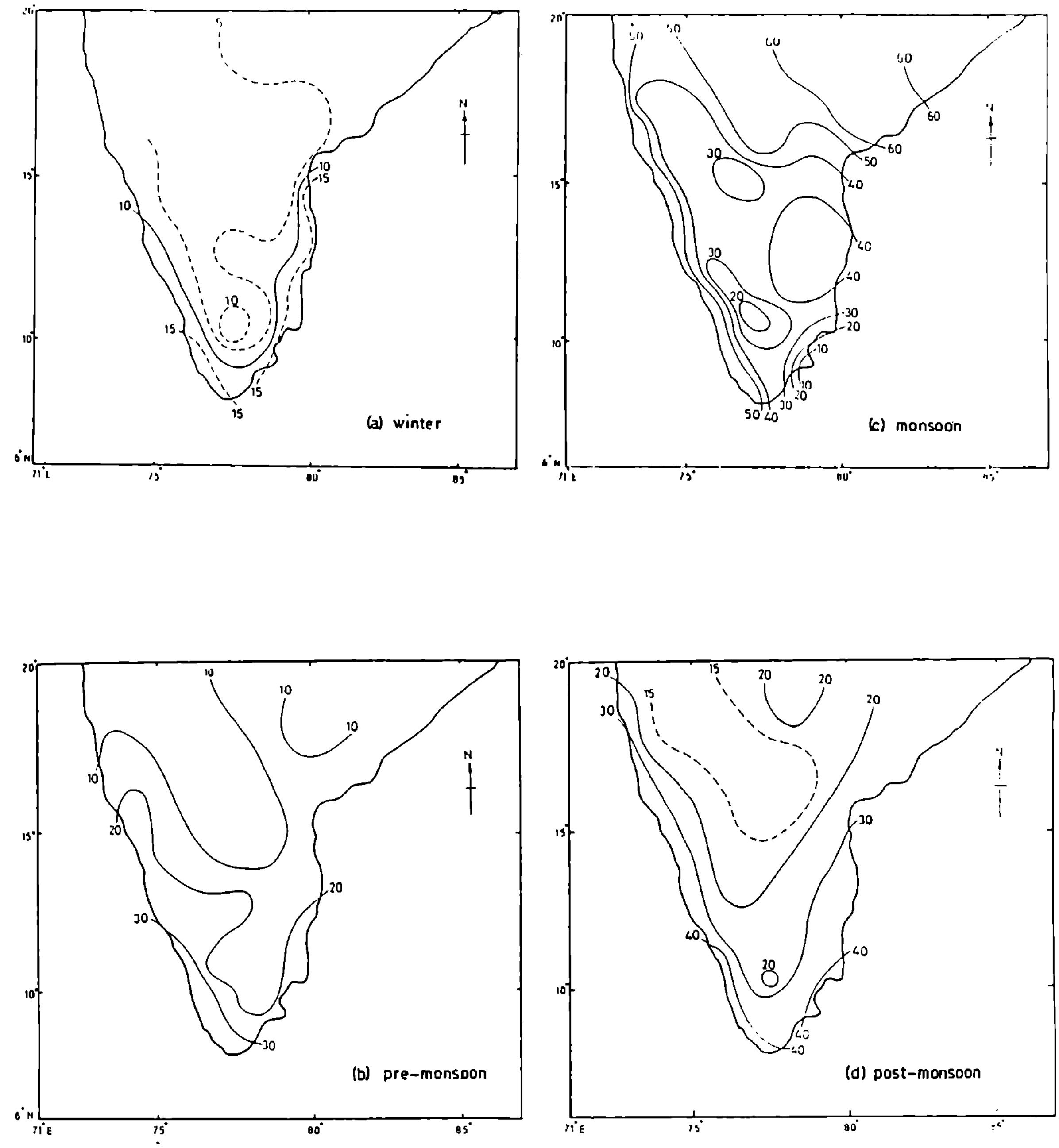


Figure 3.12 Distributions of seasonal AE over South India (cm)

The distribution of AE during post-monsoon season is shown in Figure 3.12d. It varies between 40 cm along the Kerala and South Tamil Nadu coasts to less than 15 cm in parts of north interior karnataka, Telangana and Marathwada. Along the coasts it decreases towards north. During this season, the region of minimum AE in the central part is shifted north west.

3.2.6 Water Surplus:

The distribution of annual water surplus over the region is shown in Figure 3.13a. Like the pattern of annual rainfall, the distribution of annual water surplus also follows the orientation of Western Ghats. Along the west coast, it shows values greater than 100 cm except in the southern most part around Trivandrum. Generally, the southern parts of the west coast have higher values with the northern Kerala coast recording the highest surplus. Along the east coast, centered around Cuddalore and Madras, a region of very low value (< 20 cm) of water surplus is observed. In the rest of the region, the annual water surplus is nil. Thus, on an annual basis water surplus is confined solely to the windward side of the Western Ghats.

During the winter season, no part of the region has any water surplus and among all the selected stations, only Kodaikanal has water surplus during the pre-monsoon season (Figure 3.13b).

The surplus pattern in the monsoon season is almost the same as that of annual pattern (Figure 3.13c). Since the

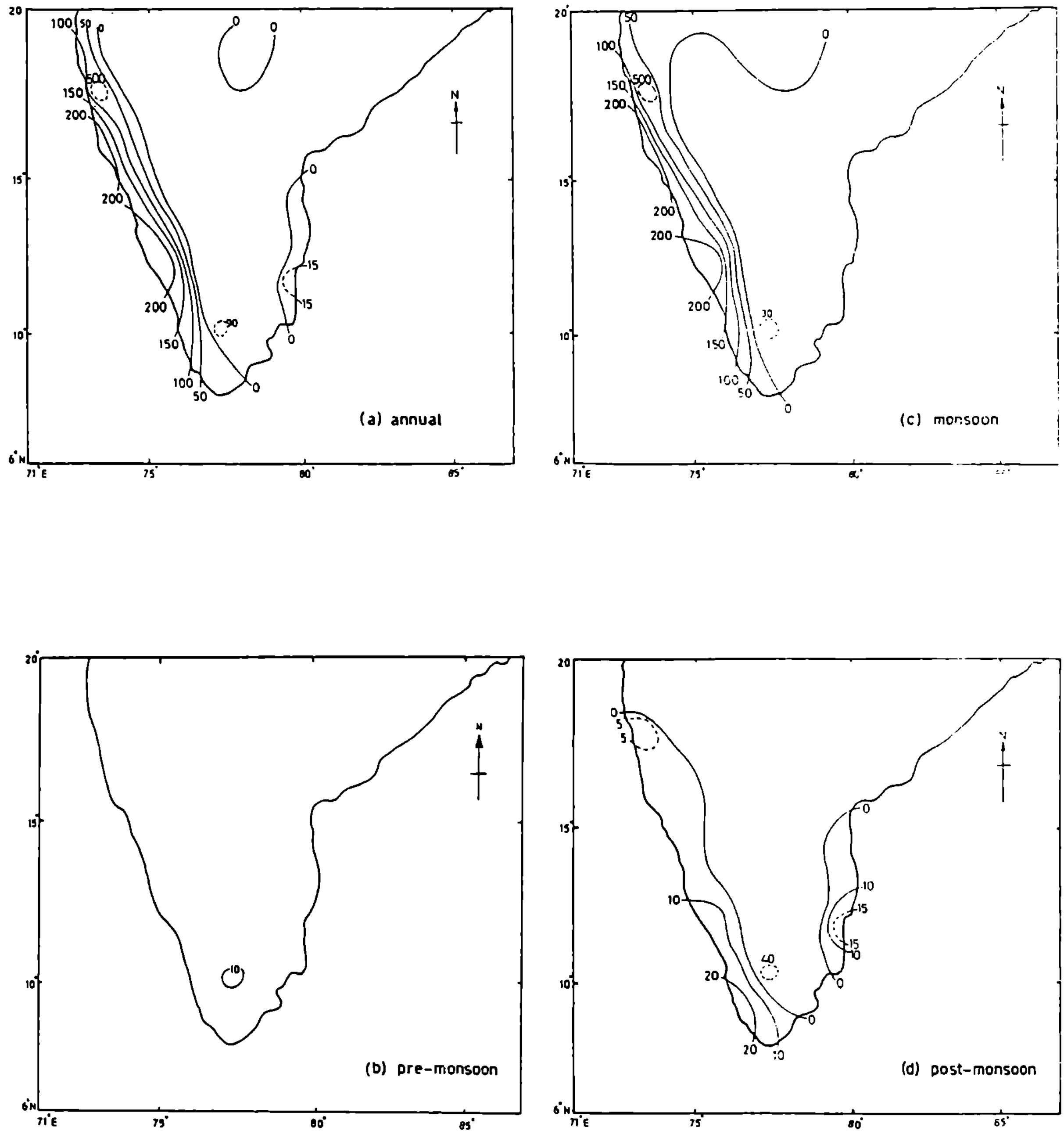


Figure 3.13 Distributions of water surplus over South India (cm)

isohytes of monsoon season in the ghats region align with the topography of the ghats, the water surplus in this region during this season too has the same pattern. Since the hill stations receive good amount of rainfall, they have large amounts of water surplus. Apart from the west coast and Western Ghats region, no other place in the study region has any water surplus during this season.

The pattern of water surplus for the region during the post-monsoon season is shown in Figure 3.13d. It varies roughly between 10 cm and 20 cm along the Kerala and south Karnataka coasts while in the northern parts values are low. As in the case of annual surplus pattern, a surplus is observed (< 20 cm) around Cuddalore and Madras.

3.2.7 Water Deficit:

Figure 3.14 gives the pattern of annual water deficits over the study region. Generally, the deficit varies between 30 cm along Kerala coast to about 110 cm around Bellary and Anantapur. Along the west coast, deficits are less compared to the east coast. The maximum deficit along the east coast is found to occur around Pamban. Kodaikanal exhibits zero deficit on an annual basis. In the central part comprising of South Interior Karnataka, Rayalaseema and Telangana, a pocket of high deficit is observed, conspicuously portrayed by the close circles of isolines.

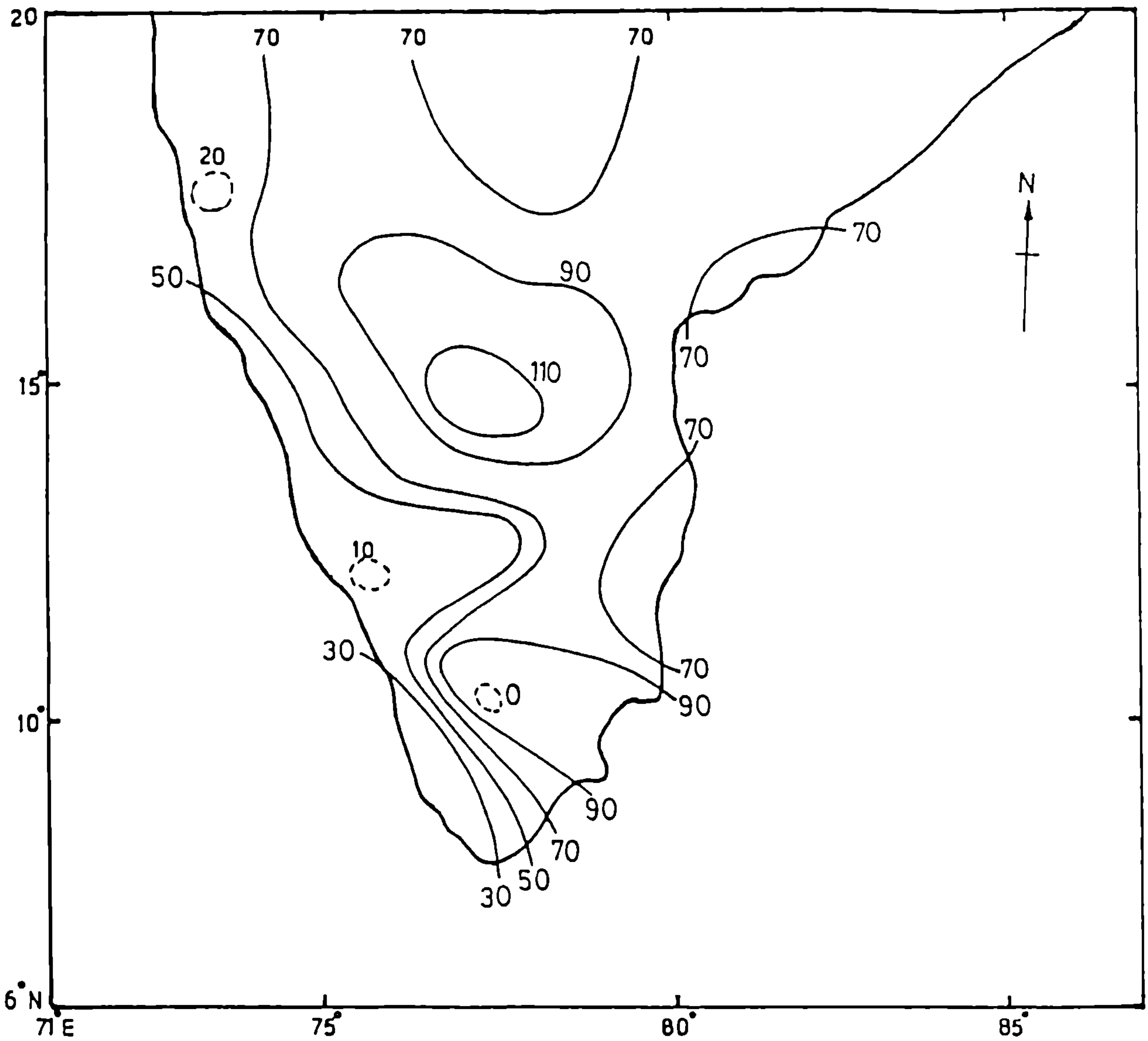


Figure 3.14 Distribution of annual water deficit over South India (cm)

The water deficit during the winter season is mapped in Figure 3.15a. The winter deficit ranges between 20 cm around Bellary, Kurnool and Cuddapah region and 5 cm along the east coast. Along the west coast, the deficit varies between 10 and 15 cm except around Trivandrum region. In this season, west coast experiences larger water deficits than the east coast. The reason for this is that during the post-monsoon season, the east coast receives significant rainfall. Kodaikanal reports zero water deficit during this season.

Comparing with the winter season, the water deficits during pre-monsoon season are larger (Figure 3.15b). During this season, for the entire region, water deficit increases from south to north. It varies from more than 10 cm along Kerala coast to more than 40 cm in Rayalaseema, Telangana and North Interior Karnataka. In this season, too, Kodaikanal experiences nil water deficit.

During the monsoon season, along the west coast and in the ghats region no water deficiency is experienced (Figure 3.15c). On the leeward side of the ghats the water deficit increases and the highest values of deficits are observed in the South Tamil Nadu coast. The arid region around Rayalaseema, Telangana and North Interior Karnataka have comparatively lower water deficits than this region.

The water deficit during the post-monsoon season is depicted in Figure 3.15d. The entire west coast which does not

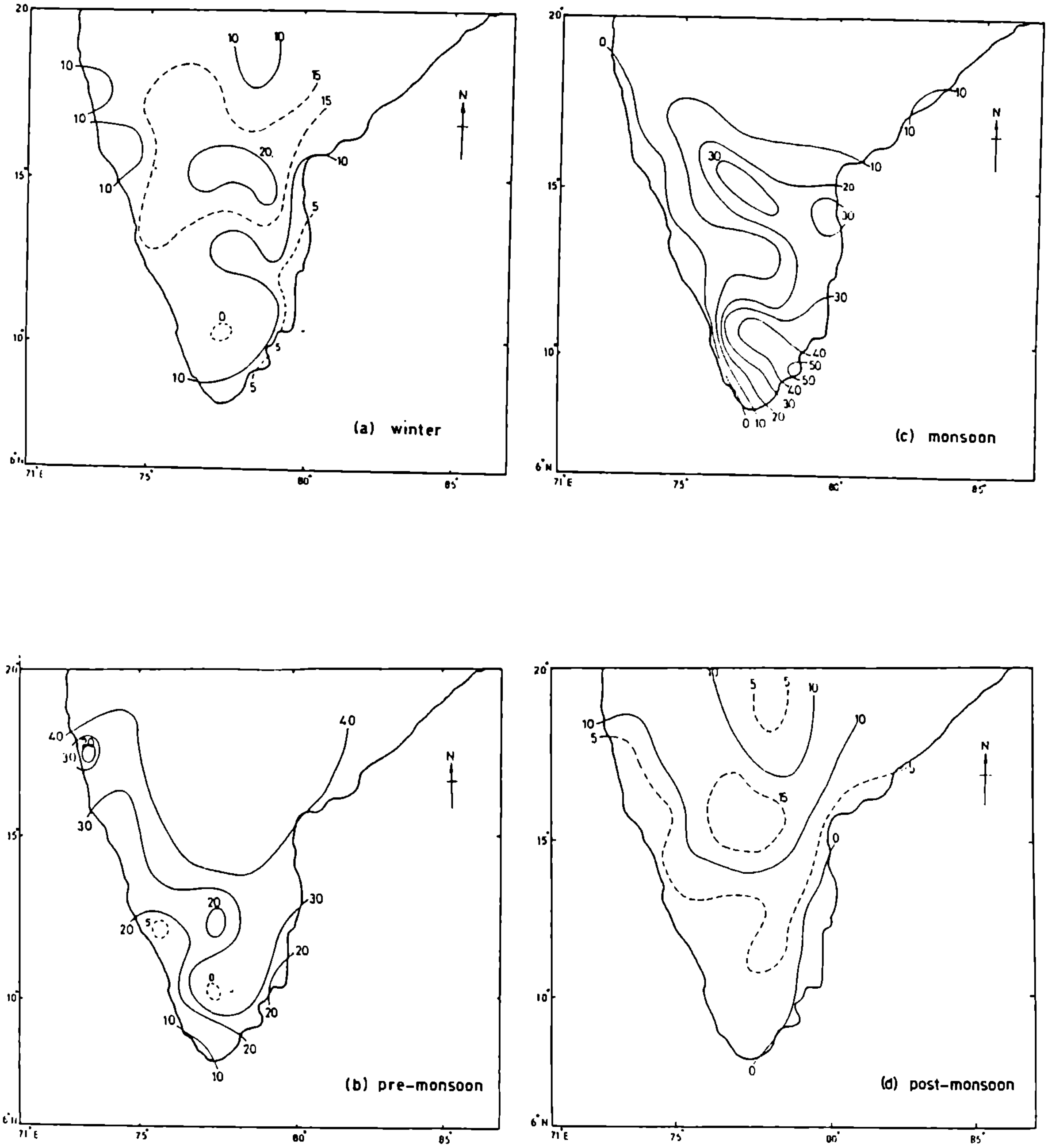


Figure 3.15 Distributions of seasonal water deficit over South India (cm)

experience any water deficit in the previous season is found to have small amounts (< 5 cm) of deficiency in the post-monsoon season. During this season, the South Tamil Nadu coast has no water deficiency where the previous season's highest value had been reported. This is due to the north east monsoon rainfall occurring in this region. Generally, the deficit increases from south to north and the central arid zone surrounding Rayalaseema, north interior Karnataka and Telangana experience highest deficit.

CHAPTER 4

AGROCLIMATIC CLASSIFICATION AND EVALUATION OF CROP POTENTIALS

In recent years, research work have been oriented towards evolving new short duration crop varieties, so that the growing periods under different climatic conditions may be utilised to the maximum extent possible. Successful agriculture with these crops is very much dependent on the rainfall distribution in the region. Therefore, a detailed analysis of rainfall data is a pre-requisite for successful agricultural activities. In this Chapter, the weekly rainfall data of 39 stations pertaining to the period 1931-1984 has been analysed by fitting Gamma distribution model.

By this method the minimum assured rainfall at different probability levels (95%, 75%, 50%, and 25%) have been computed. Using the minimum assured rainfall and potential evapotranspiration (PE) values, the moisture availability indices (MAI) on a weekly basis have been calculated for all these probability levels.

The values of MAI at different probability levels and AAR have been employed as indicators of the crop growth potential of the region. It is necessary to add here that the duration of the growing period and crop growth potentials discussed in this

Chapter are indicative of rainfed conditions only: where irrigation is possible and resorted to, the growing periods would be necessarily longer and the crop growth potentials higher.

4.1 Distributions of AAR:

The spatial distributions of AAR at 75%, 50% and 25% probability levels for the region are represented in Figure 4.1.

The AAR at 75% probability level (Figure 4.1a) varies from more than 150 cm along the west coast to zero in the regions around Bellary, Cuddapah and Vellore. The maximum value is observed along the Karnataka coast around Mangalore; from this region the value diminishes both towards north and south along the coast. Along the West Coast and in the Ghats region the isohytes follow the topography and a sharp gradient is seen from the windward side to the leeward side of the Ghats. Along the East Coast, values are less than 10 cm except around Pamban. In the northeastern sector of the region in Telangana the values are greater than 10 cm. The hill stations generally report high values.

The pattern of AAR distributions at 50% and 25% level too are similar to that of the 75% level, but the difference in magnitudes are pronounced. At 50% (Figure 4.1b), the values range from more than 250 cm along the Karnataka coast to less than 10 cm around Bellary and Anantapur region. Along the North Tamil Nadu coast and the regions around Bangalore, Salem, Telangana and North Andhra coast, it is found to be more than 50 cm.

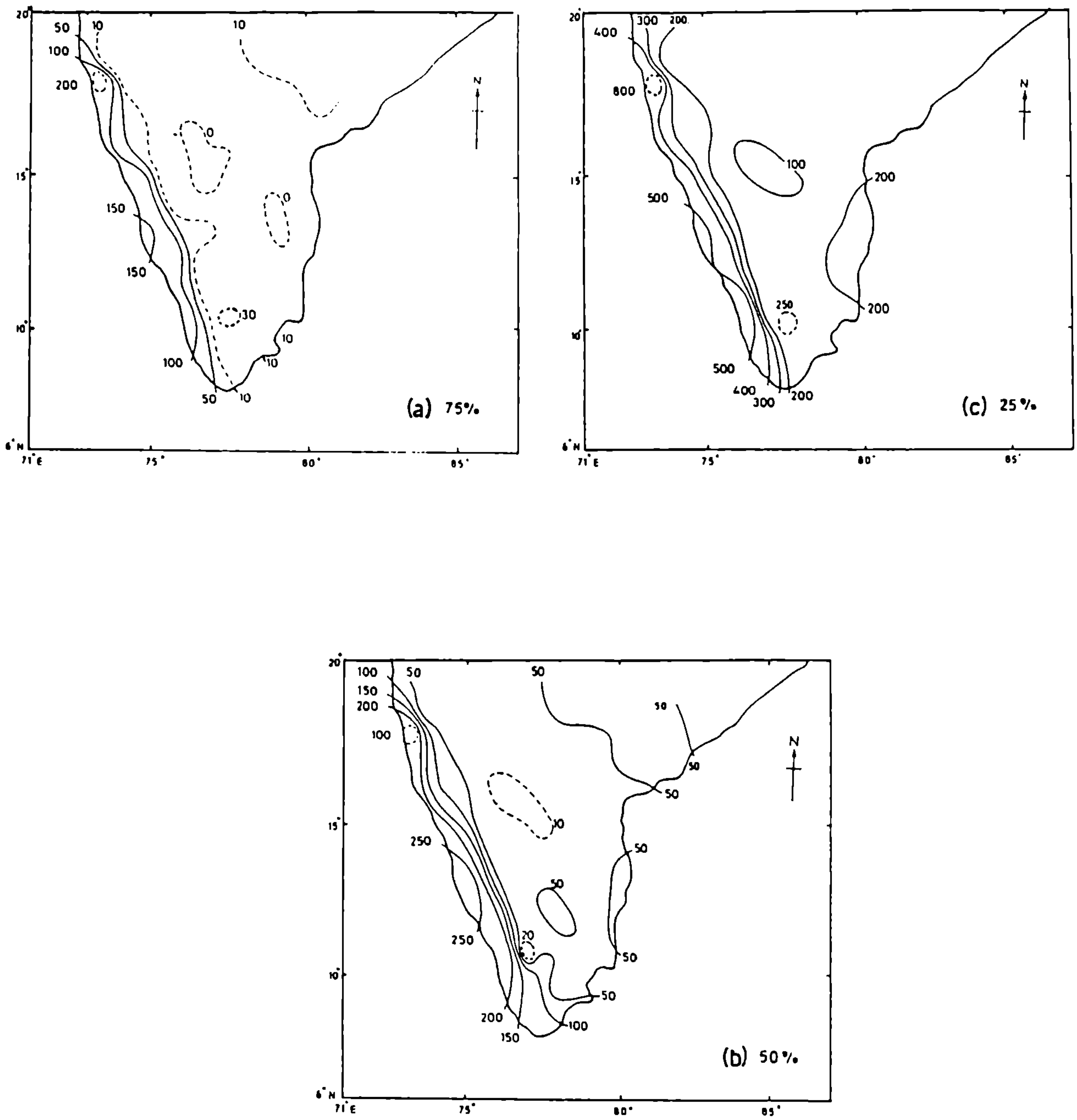


Figure 4.1 Distributions of AAR at different probability levels (cm)

At 25% probability level (Figure 4.1c), the values vary between more than 500 cm along the Karnataka and North Kerala coasts and a pocket of low values around Bellary and Anantapur region, where it is less than 100 cm. Along the North Tamil Nadu coast, the values are greater than 200 cm.

Duration of MAI:

Generally the spatial distribution of duration of MAI of different magnitudes (greater than or equal to 0.3, 0.5, 0.7 and 0.9) at 75% are of similar pattern (Figures 4.2a to 4.2d). Along the west coast, the values are greater than 20 weeks (MAI $\geq$ 0.3) especially along Karnataka and Kerala coasts, and decrease towards the leeward side of the Ghats. On the leeward side, in Rayalaseema, North Interior Karnataka, Telangana and North Tamil Nadu coast, the values are near zero every where. Along the east coast, some isolated regions have more than 5 weeks duration of MAI greater than 0.3.

At 50% level, patterns (Figures 4.3a to 4.3d) are different from that of 75% level except in the case of MAI $>$ 0.9. Generally, durations are larger than 35 weeks (MAI $>$ 0.3) along Kerala and South Karnataka coasts and the east coast has comparatively lower values. The core of low values (roughly less than 5 weeks) is found around Bellary and Anantapur region. The northeastern sector of the study region (Telangana) shows a slight increase in the values.

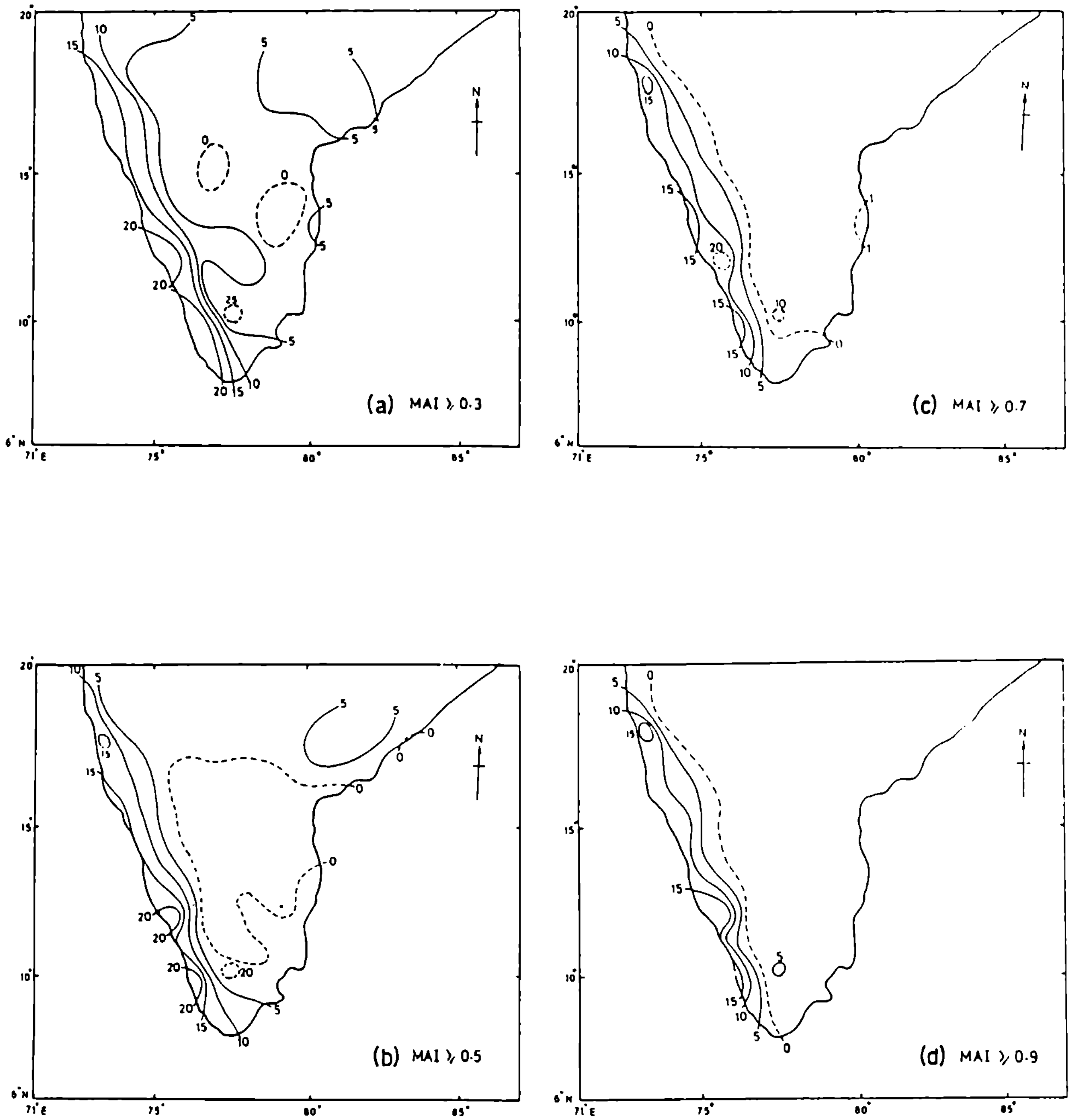


Figure 4.2 Distributions of duration of MAI (weeks) at 75% probability level

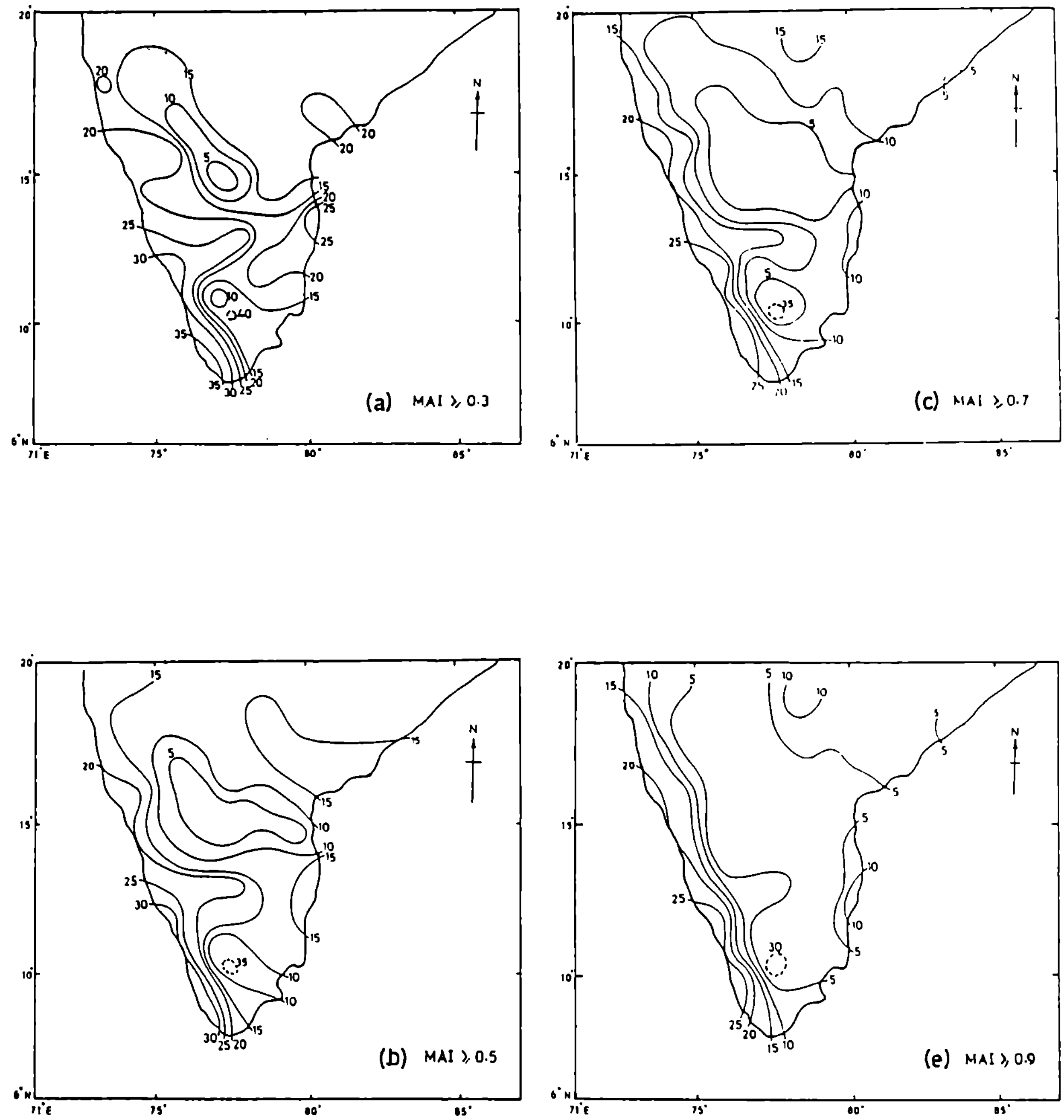


Figure 4.3 Distributions of duration of MAI (weeks) at 50% probability level

The duration of MAI of different magnitudes at 25% level (Figures 4.4a to 4.4d) varies generally from greater than 35 weeks (MAI ≥ 0.3) along the South Kerala coast to about 10 weeks around Bellary (MAI ≥ 0.9). The east coast experiences comparatively low values.

Agroclimatic Zones:

In order to assess the agricultural potential of the region it is necessary to classify it into specific agroclimatic zones. In this study the South India has been classified into various zones (Figure 4.5) based on the duration and magnitude of MAI at 50% level and soil types, as described in Chapter 2. It consists of 7 major zones varying from J type to D type. The central part encircling Bellary and Anantapur region is the driest part (D type). Aridity decreases in all directions from this zone, but the gradient is more towards the southwest compared to other directions. The most humid type J is observed on the west coast and in the mountain regions of Kodaikanal in Tamil Nadu. From this high level station, a sharp decline in degree of humidity in the climatic type is observed towards the windward side of the Ghats. The alignment of climatic types in the western sections of the peninsula is almost parallel to the Ghats. The features of the individual zones are discussed below in detail. This classification has been superimposed on the soil map, which sub-divides each of the zones (Figure 4.6). Table 4.1

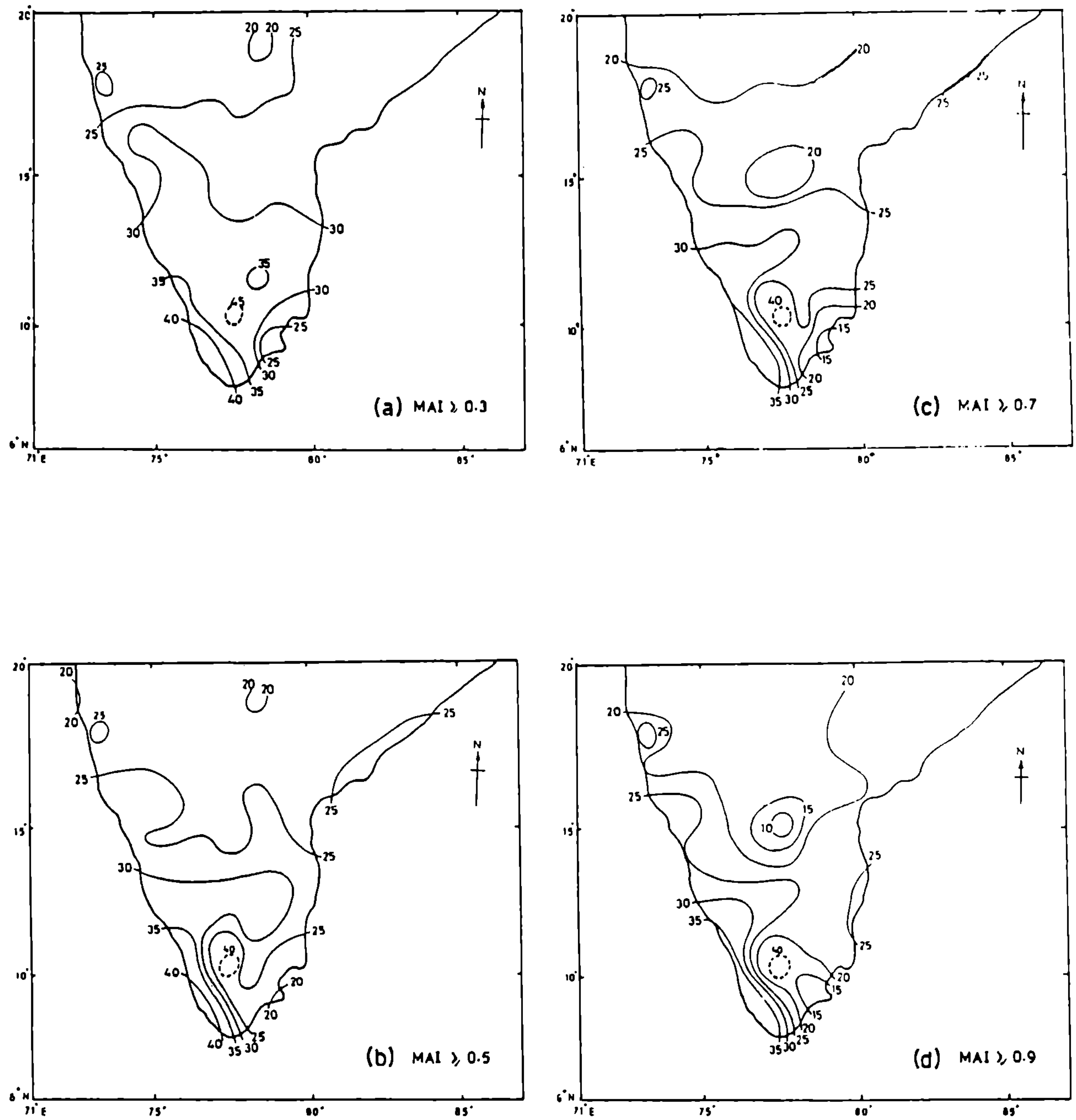


Figure 4.4 Distributions of duration of MAI (weeks) at 25% probability level

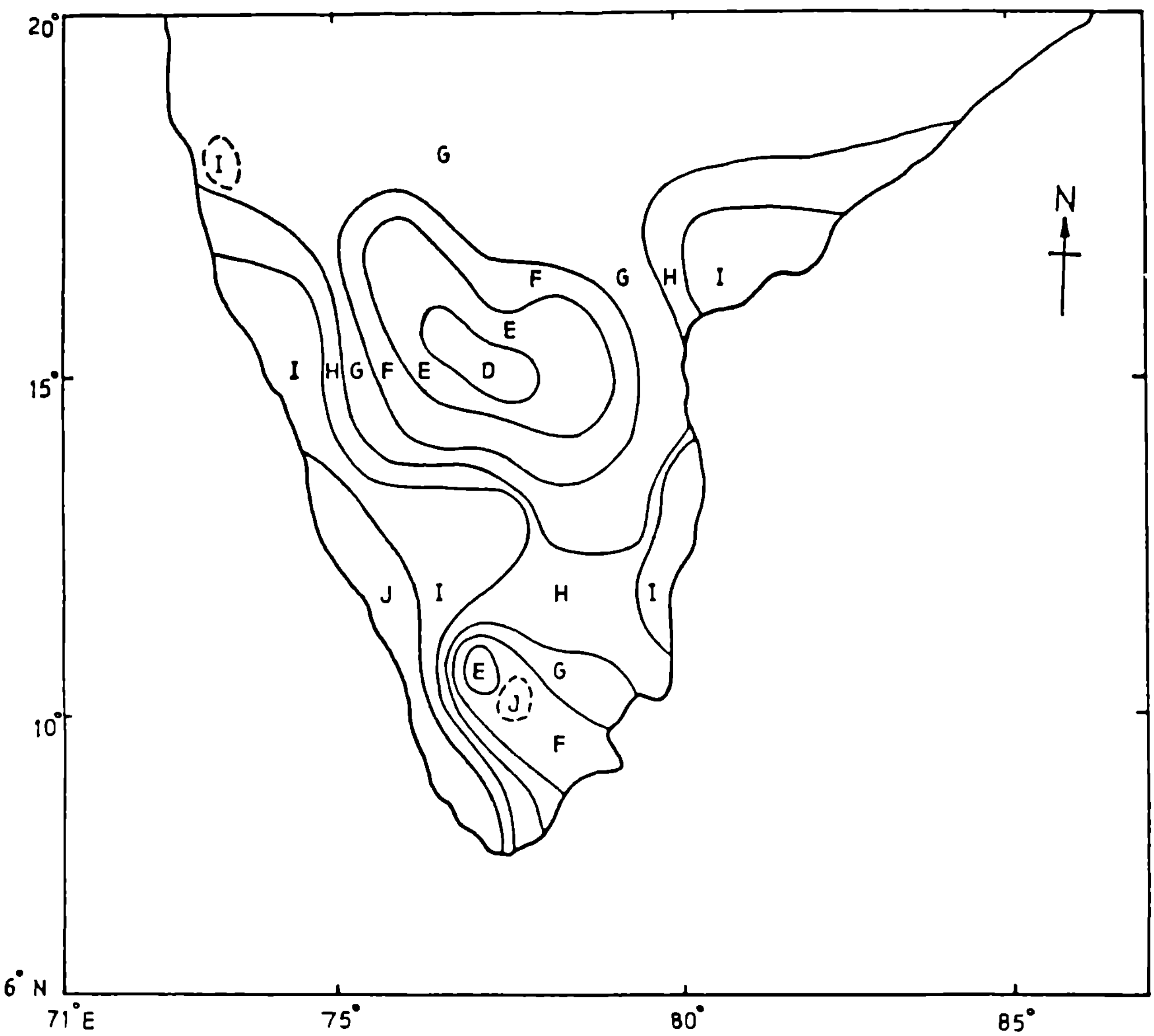


Figure 4.5 Agroclimatic types of South India

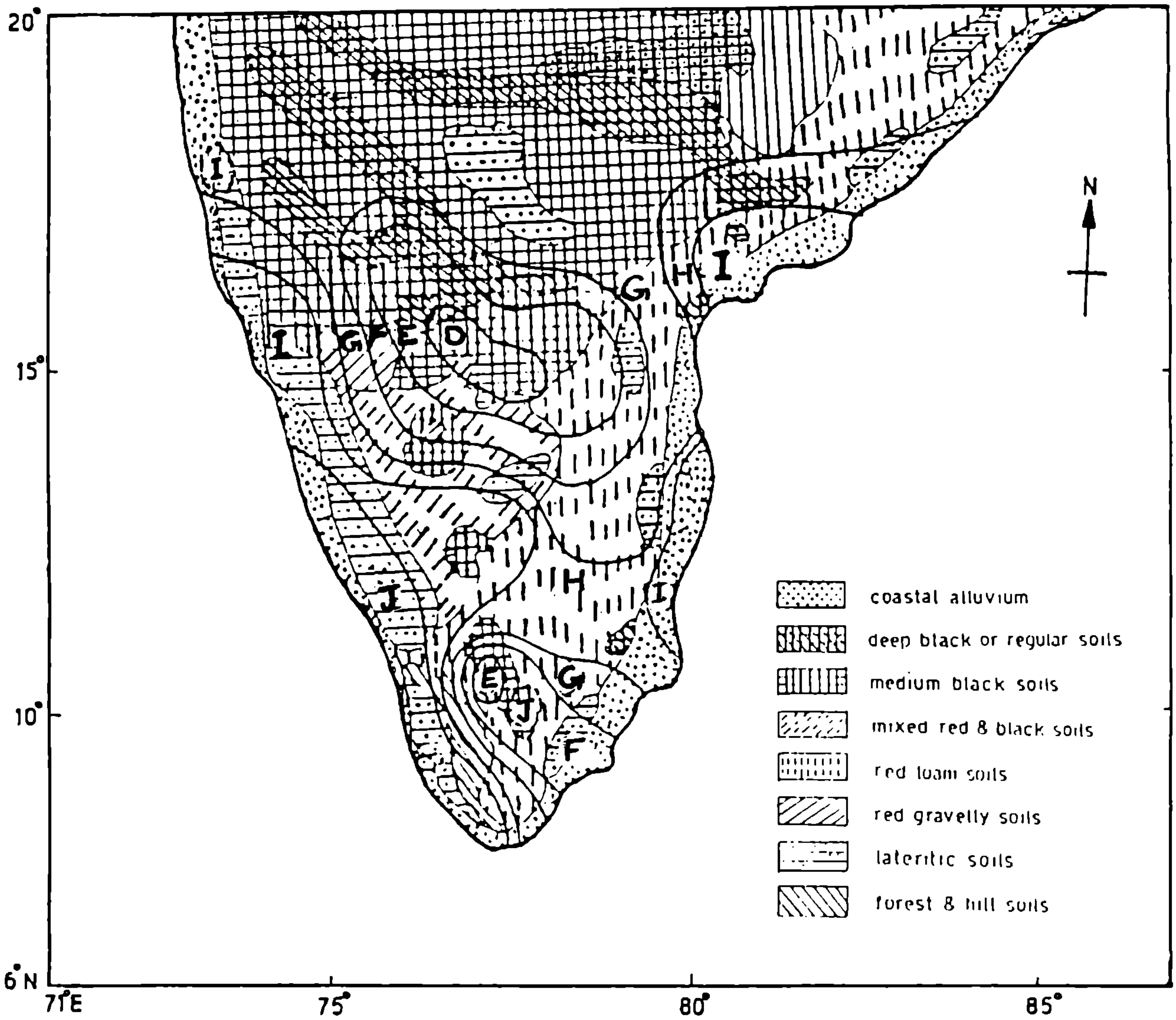


Figure 4.6 Soil-agroclimatic subdivisions of South India

Major agro-climatic zones	No. of sub-divisions	Soil types	Stations
		coastal alluvium	
			TVM, CHN, CLT, MNG, MRC
J	3	laterite	
		medium black	KDK
		coastal alluvium	CDL, MDS, MPT MHB, KWR
		laterite	
		red loams	
			KMM
I	6	medium black	BLG
		mixed red & black	BNG
		forest loam	
		coastal alluvium	VSK RTN
		laterite	
		medium black	
H	6	red loam	SLM
		mixed red & black	
		deep black	
		coastal alluvium	NLR, BMB
		red loam	TRP, VLR
		laterite	
			HYD
G	7	medium black	PNA
		deep black	GLB, HNM, NZB, AGD
		red gravel	
		mixed red & black	
		coastal alluvium	PBN
		deep black	RCH
		medium black	GDG
F	6	mixed red & black	CHT
		red loam	MDR
		red gravel	
		deep black	
			KRN, BJP
		medium black	
E	4	mixed red & black	
			CMT, CDP
		red loam	
		deep black	
		red loam	
			ANT
D	4	medium black	
			BLY
		mixed red & black	

Table 4.1. Soil-agroclimatic sub-divisions

gives the sub-divisions of the major agroclimatic types based on major soil types. Out of the 36 sub-divisions so delineated, 7 sub-zones are under G type, 6 zones, each under I, H and F types of agroclimates. E and D types have 4 sub-divisions each and J type has the minimum number of sub-divisions 3.

J type:

This agroclimatic zone, which is the wettest of all restricts itself to a narrow strip along the west coast extending northward along the Kerala coast upto Mangalore and to the Kodaikanal hill region (Figure 4.5). The varied soil types found in this region are mainly coastal alluvium and lateritic soils on the west coast and medium black in the hilly tracts. These soil types bring forth three different sub-divisions within this zone (Figure 4.6).

At 75% level, the accumulated assured rainfall (AAR) of this zone, (Figure 4.1a) varies from 50 cm to 150 cm in the coastal region. But in a small pocket in the hilly region, it is around 30 cm only. Generally, AAR is greater in the northern coastal regions. The growing period in this zone (number of weeks with MAI $\geqslant$ 0.3) varies generally between 20 and 25 weeks, but in the high altitude region, it is found to be slightly greater than 25 weeks (Figure 4.2a). It is interesting to note that though the AAR of the hilly area is less than that at the coastal stations, its growing period is longer. At 50% probability level, the AAR of this zone varies along the coast from 150 cm in the extreme southern parts to 250 cm in the northern part. The high altitude regions has AAR less than that of the coastal region, around 100 cm (Figure 4.1b). The growing period at this probability level is found to vary from 25 to 35 weeks along the coast and is around 40 weeks in the hilly regions (Figure 4.3a). The AAR varies from around 400 cm to 500 cm in the coastal region and is around 300 cm in the hilly region at 25% level (Figure 4.1c). At this probability level, the growing period is between 30 and 45 weeks along the coast; in the mountain region of Kodaikanal it is found to be more than 45 weeks (Figure 4.4a).

Crop Potential at individual stations:

Table 4.2 gives the summary of the results for the individual stations of J type of agroclimate.

Trivandrum:

Soils found at Trivandrum are mainly coastal alluvium and laterites. At 50% probability level MAI is greater or equal to than 0.3 (Figure 4.7a) from 13th week to 48th week (last week of March - last week of November, 36 weeks), and therefore the growing period for this station at this probability level is during these weeks. During this period, water stress occurs only during one week (44th), and the water availability is comparatively less for the first few weeks and from 35th to 38th week (last week of August to mid-September). At this probability level, the AAR of this station is 115 cm. It is obvious from the figure that at 50% level of probability, since MAI during the last part of growing period is high, stored soil moisture

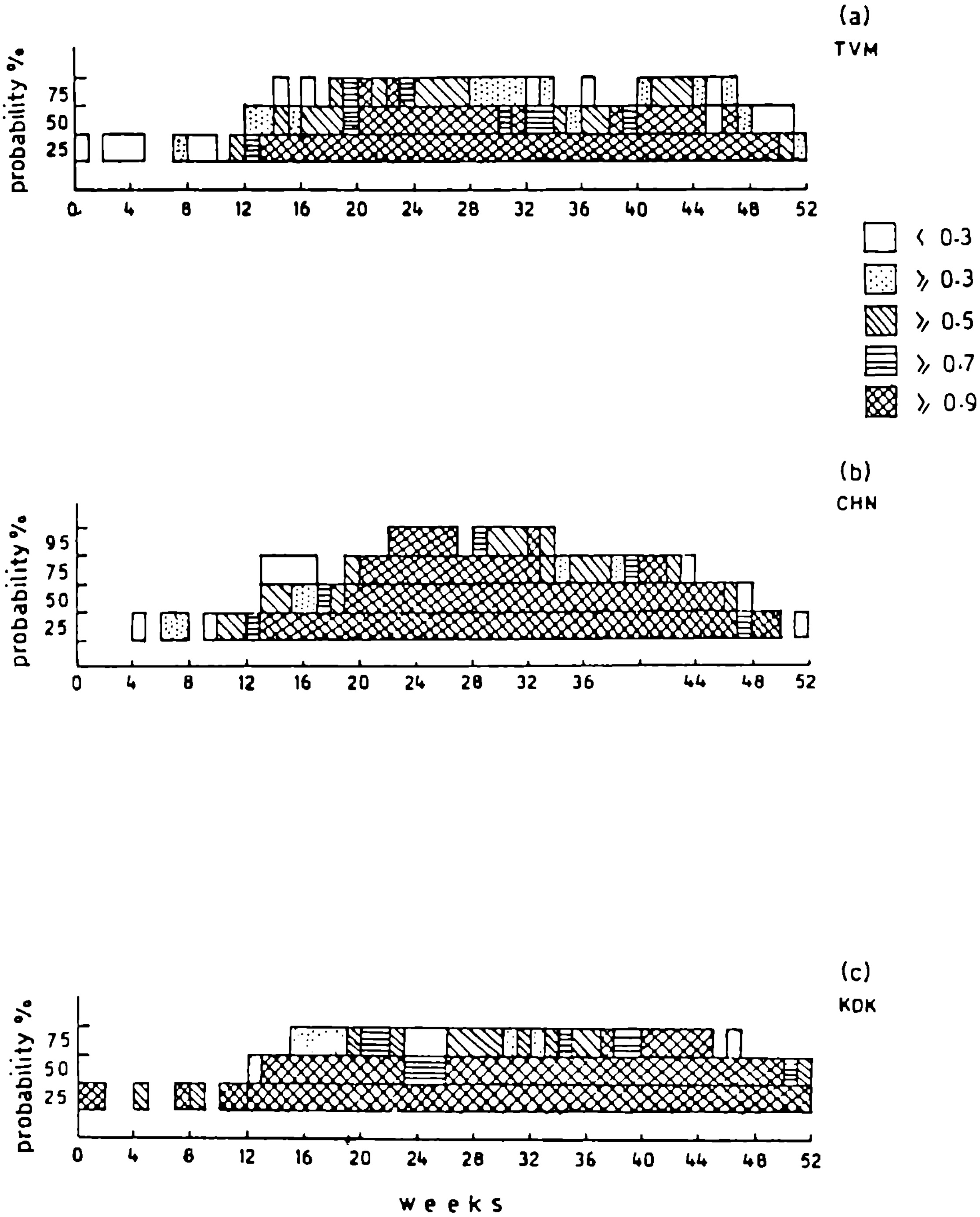


Figure 4.7 Magnitude and duration of MAI at different probability levels for stations of J type agroclimate

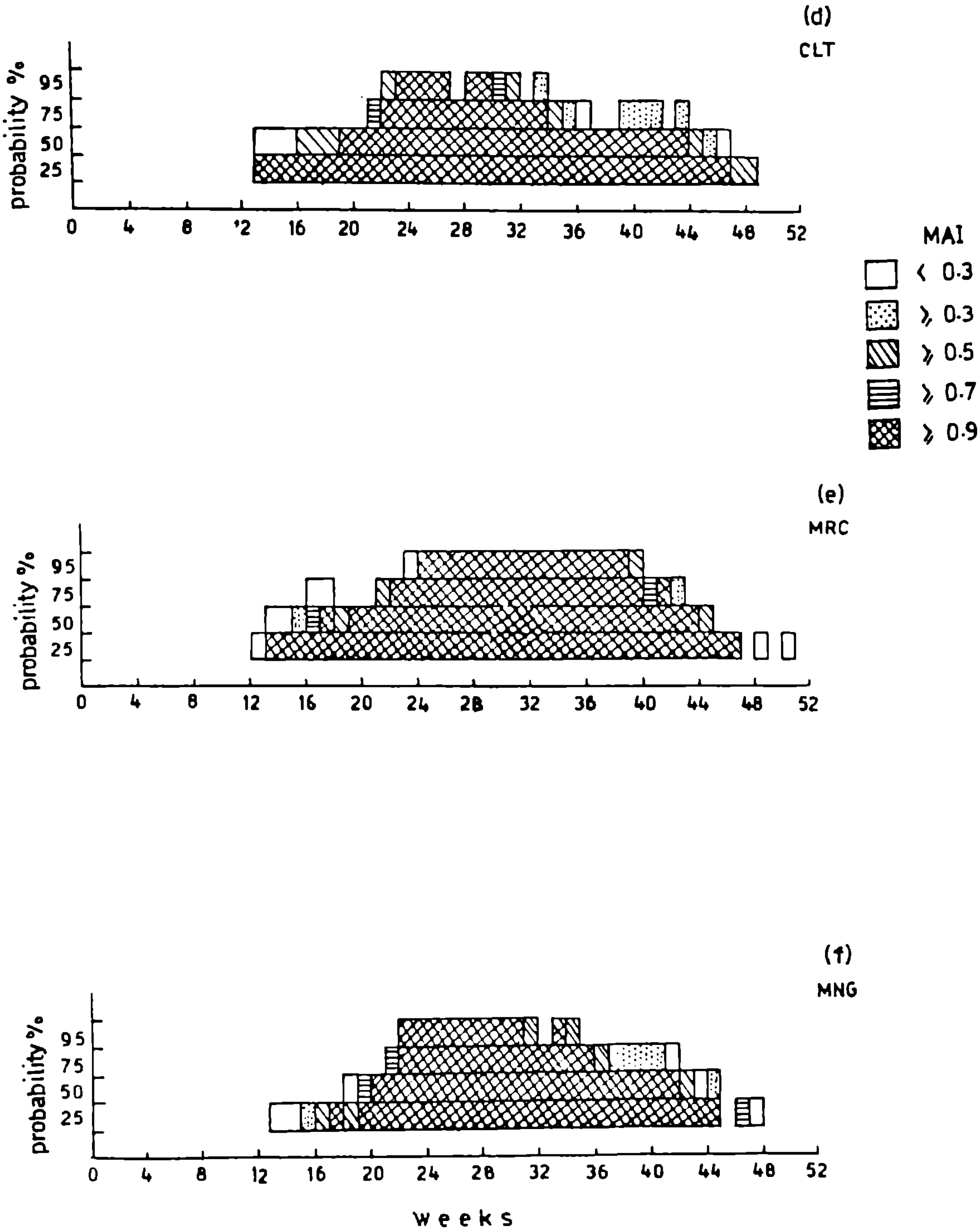


Figure 4.7 (contd.) Magnitude and duration of MAI at different probability levels for stations of J type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)	No. of breaks
TVM	25	41	40	38	37	389	12-52 (41)	-
	50	35	30	23	18	115	13-48 (36)	1
	75	21	13	4	2	40	18-33 (16)	1
							40-46 (7)	1
	95	-	-	-	-	-	- -	-
CHN	25	42	40	38	36	510	7-50 (44)	1
	50	34	32	28	27	234	14-47 (34)	-
	75	24	22	16	15	108	20-43 (24)	-
	95	11	11	7	6	34	23-34 (12)	1
KDK	25	47	47	45	45	286	1-52 (52)	3
	50	40	39	38	34	103	13-52 (40)	-
	75	28	22	12	6	33	16-47 (30)	2
	95	-	-	-	-	-	- -	-
CLT	25	36	36	34	34	536	14-49 (36)	-
	50	30	29	25	25	245	17-46 (30)	-
	75	19	14	13	12	112	22-44 (23)	2
	95	10	9	7	6	35	23-34 (12)	2
MRC	25	34	34	34	34	478	14-47 (34)	-
	50	30	29	27	26	259	16-45 (30)	-
	75	22	21	20	19	133	22-43 (22)	-
	95	16	16	15	15	43	25-40 (16)	-
MNG	25	31	30	28	27	510	16-47 (32)	1
	50	25	24	23	22	285	20-45 (26)	1
	75	20	16	15	14	160	22-41 (20)	-
	95	12	12	10	10	64	23-35 (13)	1

Table 4.2. Agroclimatic status at different probability levels for J type stations

will be available for the crops to thrive even after the cessation of the rainy season. Thus, the actual growing period can be longer than 36 weeks. Double cropping of long duration crops can be carried out.

At 75% level, MAI exceeds 0.3 from 19th to 34th week (first week of May - second week of August) with mid-season water stress in the 33rd week. After six weeks water stress (35th - 40th) MAI becomes greater than 0.3 from 41st to 47th week (second week of October - third week of November). It is therefore clear that at 75% probability level also there is a good chance of double cropping.

Cochin:

Cochin also represents the same sub-zone of this agroclimatic type with coastal alluvium and lateritic soils. From Figure 4.7b, it can be seen that for this station MAI at 50% level is greater than 0.3 from 14th to 47th week (first week of April - last week of November) with no water stress period in between. The AAR of this station for this period is 234 cm. MAI is continuously greater than 0.9 from 20th week to 46th week (mid-May to mid-November) indicating the abundance of moisture during this period. Thus, at this station, the growing period can be considered to be from 14th to 47th week (34 weeks). At this place too, the growing period of 34 weeks can be divided into two for double cropping. Here, after the beginning of the growing period, MAI remains greater than 0.9 indicating more than sufficient moisture. Therefore, there will be enough stored soil moisture at the end of the rainy season and the growing period can be longer than the 34 weeks. Care should be taken while selecting crop varieties so that the excess moisture will not become detrimental to crop phases requiring less moisture. At this place raising long duration crops of high water requirement is quite easy; of course, storing of excess water is also feasible.

At 75% level, MAI is greater than 0.3 from 20th week right up to 43rd week (mid-May to last week of October) without any water stress; MAI becomes greater than 0.9 just one week after the commencement of the growing season, but during the last stages, MAI becomes less than 0.9. Still, at this level, too, the growing period is about 24 weeks, sufficiently long enough for double cropping with moderately long duration crops. At this level of probability, too, there will be stored soil moisture.

At 95% level, MAI is greater than 0.3 from 23rd week to 34th week (first week of June - last week of August) with water stress in the 28th week. At this high percentage probability level, too, MAI is greater than 0.9 for 6 weeks at this station. The growing period at this level is 12 weeks long, sufficient for cultivating a moderately long duration crop having high water requirement without irrigation. All the above features indicate the suitability of this place for cultivation without irrigation facilities.

Kodaikanal:

This station represents a different subdivision of this zone with medium black soils. Figure 4.7c gives the variation of moisture availability index among weeks at different probability levels at this place. At 50% level, MAI exceeds 0.3

from 14th week to the 52nd week (April - December), which is the last week of the year, with no mid-season water stress. From the beginning of the period itself, MAI becomes greater than 0.9. The AAR for this hill station is 103 cm, comparatively less than that of other stations of the same agroclimate. But because of the low water need of this place, the large water availability is spread throughout the year. MAI at this level never becomes less than 0.5 and less than 0.7 only for one week giving rise to a good soil moisture storage. Hence, multiple cropping can be done with moderately long duration crops having large water requirement. But care should be taken while selecting crops so that the excess moisture factor should not become hazardous to sensitive crop phases.

At 75% level, MAI becomes greater than 0.3 from 16th week to 45th week (mid-April to second week of November), but from 24th to 26th week (June) water stress period occurs. Thus, at this probability level, too, the growing period consists of 30 weeks; double cropping is possible with long duration crops, provided, for the first cropping the crops are so selected that their water requirement is low.

Calicut:

Soils found at this place also are similar to that at Trivandrum and Cochin. Figure 4.7d depicts the magnitude and duration of MAI for this station at different probability levels. At 50% level, MAI is greater than 0.3 from 17th week to 46th week (last week of April to mid-November), providing a growing period of 30 weeks duration with no intermediate water stress period. AAR of this station is 245 cm. Since MAI values are high during the last phase of the growing season, the actual growing period extends for a few more weeks and hence at this station too double cropping of long duration crops is possible at 50% probability level. The factor of excess moisture is to be considered while planning.

At 75% level of probability the growing period begins in the 22nd week and lasts till 44th week (last week of May - last week of October) - a period of 20 weeks. But mid-season water stress occurs twice (37th to 39th and 45th weeks) during this period. Since MAI values are low during the last stages of the growing period, soil moisture status after the cessation of the rain will be poor. At this probability level also, double cropping can be carried out. But crops should be of shorter duration and the next crop should be of drought-tolerant variety to phase the water stress during the last part of the growing season.

At 95% level cultivation is possible from 23rd to 34th week (first week of June - last week of August). In this period, water stress of one week duration occurs twice (28th and 33rd week). Single cropping of a moderately long duration crop is possible here in 95% of years.

Mercara:

Mercara also comes under the same subdivision with coastal alluvium and lateritic soils. Figure 4.7e gives details of variation of MAI and its duration at different probability levels at Mercara. At 50% level the growing period is from 16th week to 45th week (mid-April to mid-November), a duration of 30 weeks. The AAR of this station is 259 cm. At this probability level, no water stress is observed within the growing period. Prospects of stored soil moisture will be good due to the high moisture availability during the last stages of the growing period and hence moderately long duration crops having high water requirement can be grown twice during the year without any irrigation. From the high value of MAI it is clear that excess of water will be there and hence storing can be done. Since moisture is in excess, crops having their phases of developments sensitive to excess moisture cannot be recommended at this place.

At 75% level, MAI becomes greater than 0.3 from 22nd week indicating the commencement of growing period and remains so till the end of 43rd week (last week of May - first week of October). At this probability level, too, no water stress is experienced. With the help of the soil moisture due to the high moisture availability, crops can survive even after the cessation of the rainy season and thus double cropping of short duration crops is possible within this growing period without irrigation.

At 95% level MAI exceeds 0.3 from 25th to 40th week (second of June - first week of October) and during this period it is less than 0.9 only twice indicating the abundance of moisture at this high probability level too. Thus 16 weeks are available for crop growth at this probability level. One moderately long duration and one short duration crop can be cultivated in a year, since there will be stored soil moisture to support plants after the withdrawal of rainy season. It is to be noted that crops have to be so selected that the abundant moisture does not adversely affect them.

At this station no water stress period is observed within the growing period at any probability level.

Mangalore:

Mangalore also represents the same sub-division of J type agroclimatic zones with coastal alluvium and lateritic soils. At Mangalore the magnitude and duration of MAI at different probability levels are as shown in Figure 4.7f. At 50% level MAI is greater than 0.3 from 20th week to 45th week (mid-May to second week of November) with water stress in the 44th week. The AAR for this station is 285 cm at this level. Here the growing period consists of 26 weeks, but the stored soil moisture can prolong the growing period. Double cropping can be carried out at this place with moderately long duration crops having high water requirement. Excess water can also be stored.

At 75% level MAI exceeds 0.3 from 22nd week up to 41st week (last week of May - second week of October) resulting in a growing period of 20 weeks. At this probability level, no water stress is observed but stored soil moisture will be low after the rains. Even then, double cropping can be done with two short duration crops under rainfed conditions.

At 95% level too MAI exceeds 0.3 from 23rd week to 35th week (June - August) with water stress in the 33rd week. At this level, the growing period has a duration of 13 weeks, and a moderately long duration crop having life span slightly more than 13 weeks can be grown.

A comparison of AAR and growing periods for all the selected stations is possible from Figure 4.8. The differences in the order of magnitudes in AAR and also the differences in duration of growing periods can be studied from this Figure.

It can be seen that among the six stations whose agroclimates are of J type, Mangalore has the highest AAR at 50% level. Though the AAR of Kodaikanal is less, it has the longest growing period. This is due to the fact that, this station receives rainfall in post-monsoon season too and hence its moisture available period is spread over a larger number of weeks. Among the other five stations, a northward decrease in growing periods is observed. The commencement of growing period gets delayed as one proceeds from south to north except at the hill station Kodaikanal. The earliest commencement is at the southern most station Trivandrum and the latest at Mangalore.

Apart from Trivandrum and Kodaikanal, all the other stations in this agroclimatic region have 95% chance of cropping under rainfed conditions. At 50% level, the prospects of soil moisture after the withdrawal of rains are high for all these stations.

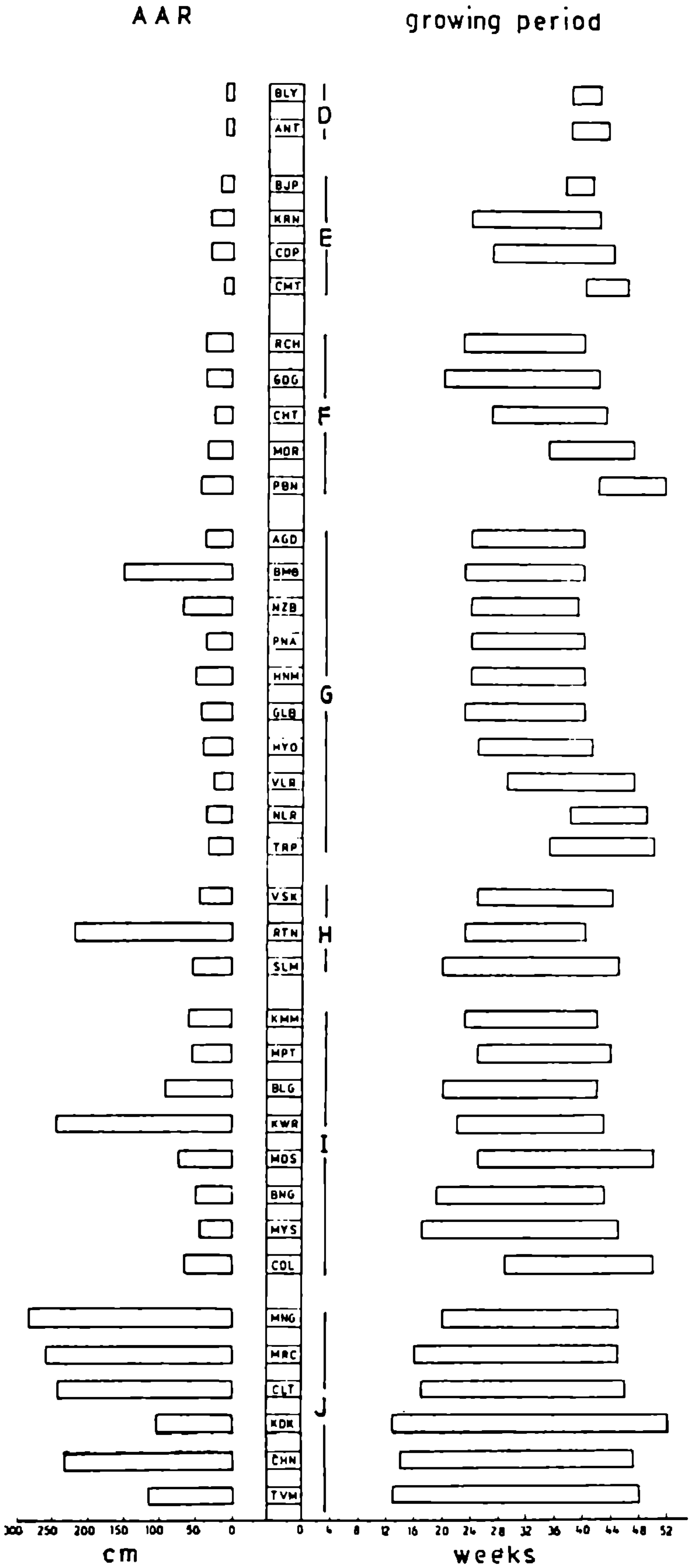


Figure 4.8 Growing periods and AAR at 50% probability level

I type:

This zone lies adjacent to the J type region parallel to the Ghats along the West Coast (Figure 4.5). In the north, along the west coast, it is found to begin from extreme south west parts of Maharashtra, and in the central region of the Ghats, protrude into south interior parts of Karnataka and is then restrict to a narrow strip parallel to the Ghats. The hill station of Mahabaleshwar also comes under this zone. On the east coast, it comprises of a narrow belt along Madras and Cuddalore region and a small region further north around Masulipatnam coast. The varied soil types found in this zone are generally coastal alluvium, laterites, medium black, mixed red and black, red loam and forest soils which results in six sub-divisions of the zone (Figure 4.6) with individual soil characteristics.

At 75% level (Figure 4.1a), the AAR in this zone varies between 150 cm and 200 cm in the northern part along the west coast and it decreases to below 10 cm in the middle part protruding into South Interior Karnataka and finally varies between 10 cm and 50 cm in the extreme south. At the hill station of Mahabaleshwar, it is found to be greater than 200 cm. In the east coast region, it ranges between 5 and 10 cm. The growing period at this probability level (Figure 4.2a) varies from 15-20 weeks in the northern part and from 10-15 weeks in the south. But in the central portion of the zone in Karnataka and in the east coast region, the growing periods are around 5 weeks only. At 50% level, the AAR in this zone varies between 200 cm and 250 cm (Figure 4.1b) in the north while in the south between 100 cm and 150 cm. In South Interior Karnataka and on the east coast region too, it is only around 50 cm. At this probability level, the growing period in this zone varies between 20 and 25 weeks in the entire zone (Figure 4.3a). From Figure 4.1c it can be seen that the AAR of this zone at 25% level varies between 450 cm and 500 cm in the north and between 200 cm and 300 cm in the south along the west coast and in the narrow belt along the east coast. It is less than 200 cm in the central part of west coast and in the small pocket surrounding Masulipatnam. The growing period at this level generally varies between 25 and 30 weeks in the northern part, 30-35 weeks in the central and southern parts of the west coast and also in the narrow belt of east coast (Figure 4.4a).

Crop Potential at individual stations:

Table 4.3 gives the summary of the results for the individual stations of I type of agroclimate.

Cuddalore:

This station comes under the sub-division of I type with coastal alluvium soils. Figure 4.9a gives the variation of magnitude and duration of MAI at Cuddalore. At 50% level MAI begins to exceed 0.3 from 29th week and continues to be so till 50th week (mid-July to mid-December) with water stress in the 31st week. Thus, the growing period for this place at 50% level comprises of 22 weeks. Since MAI values are high during the end of the growing period, the soil moisture status after the

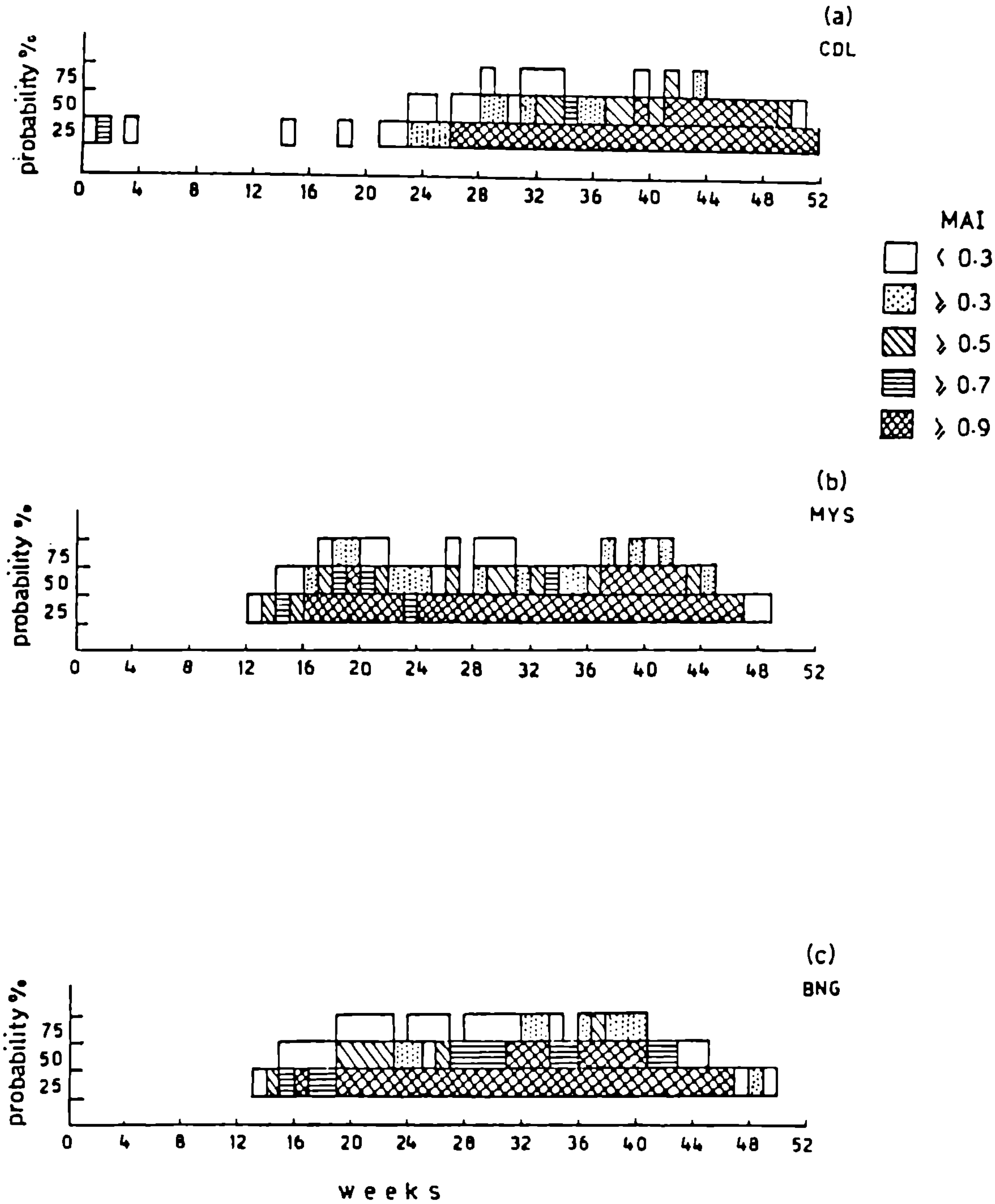


Figure 4.9 Magnitude and duration of MAI at different probability levels for stations of I type agroclimate

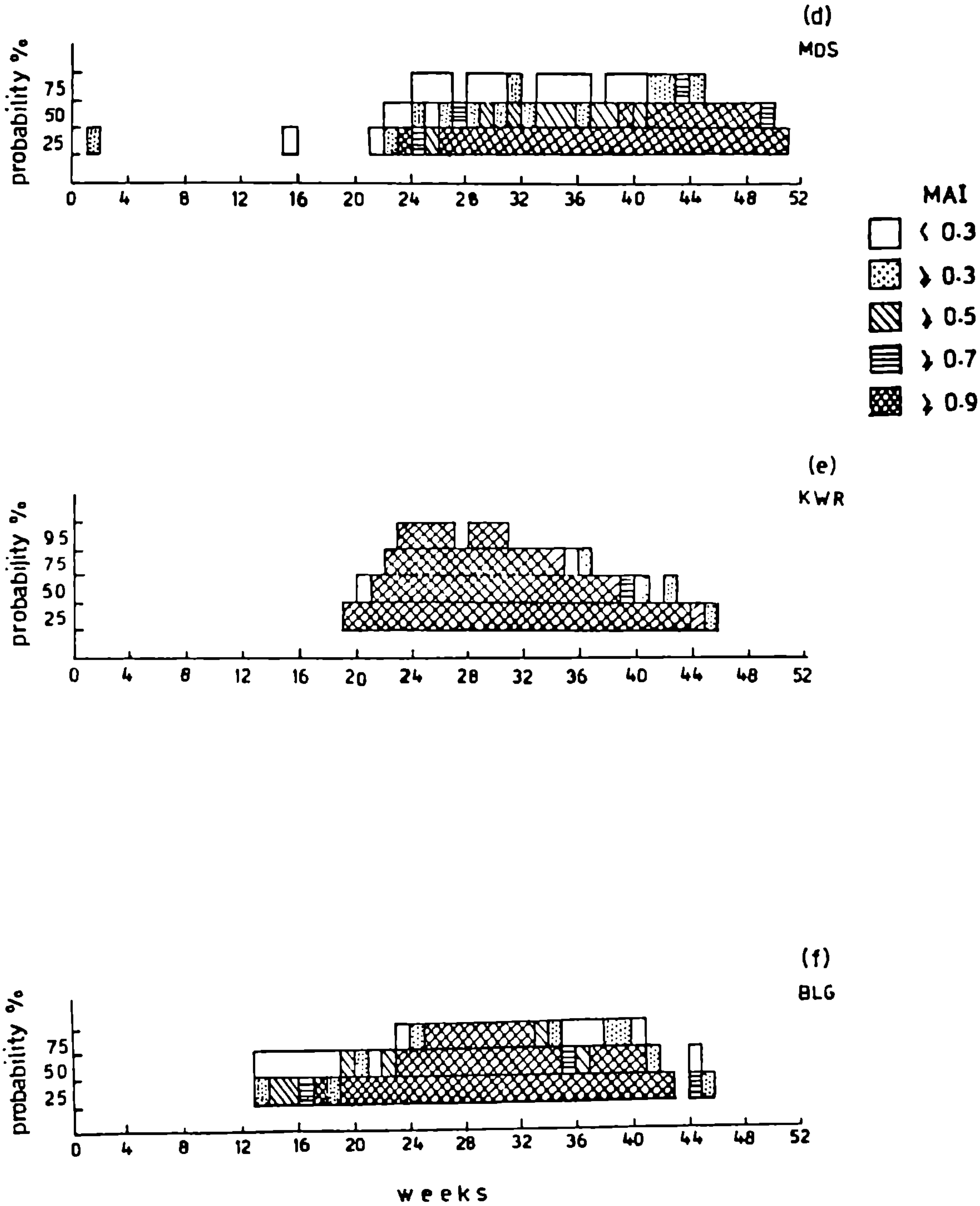


Figure 4.9 (contd.) Magnitude and duration of MAI at different probability levels for stations of I type agroclimate

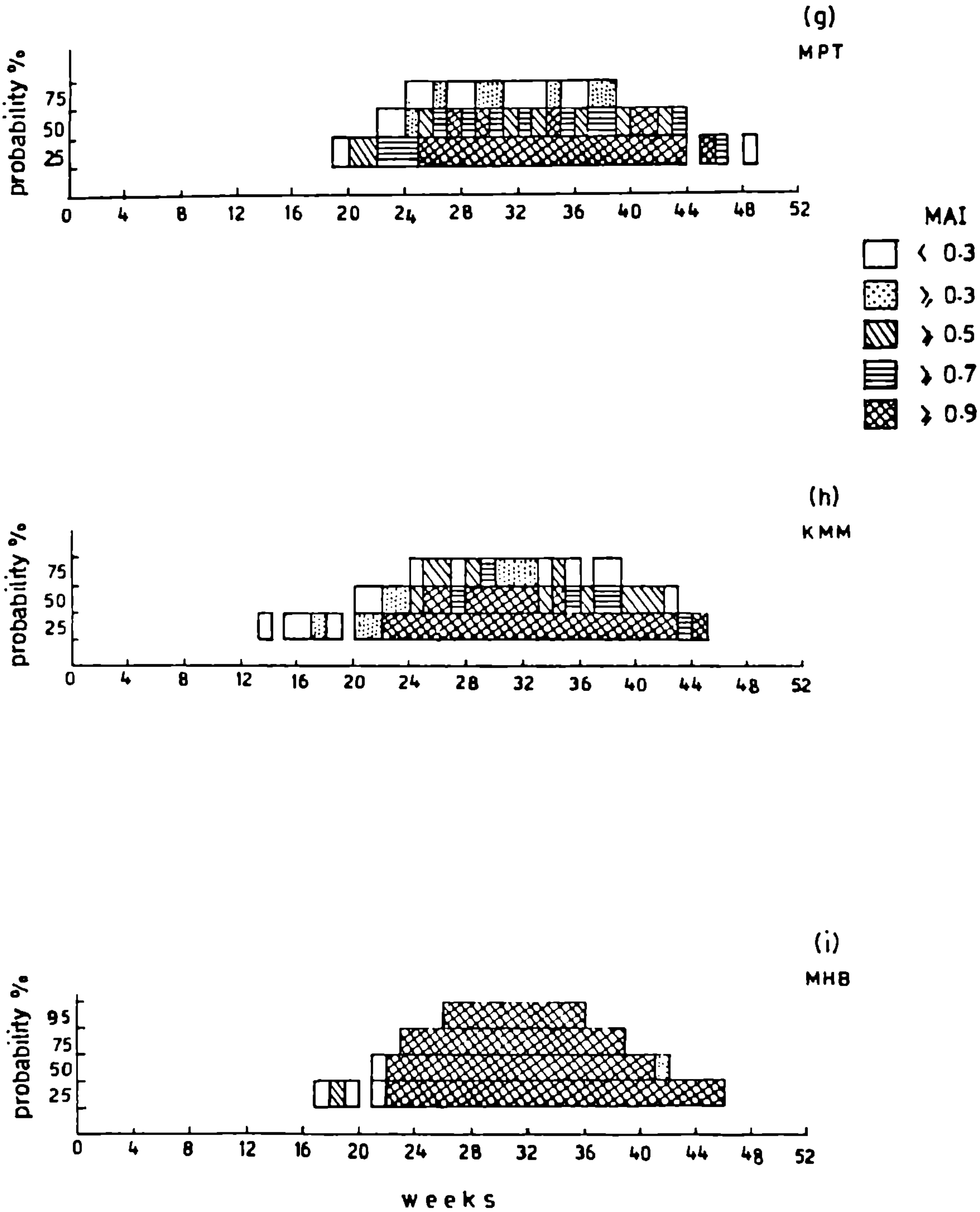


Figure 4.9 (contd.) Magnitude and duration of MAI at different probability levels for stations of I type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)		No. of breaks
CDL	25	29	26	26	26	287	24-52	(29)	-
	50	21	16	10	9	65	29-50	(22)	1
	75	2	1	-	-	4	-	-	-
	95	-	-	-	-	-	-	-	-
MYS	25	34	34	32	30	162	14-47	(34)	-
	50	27	18	10	7	46	17-45	(29)	2
	75	5	-	-	-	5	-	-	-
	95	-	-	-	-	-	-	-	-
BNG	25	34	33	32	29	174	15-49	(35)	1
	50	23	21	16	8	54	20-43	(24)	-
	75	7	1	-	-	7	33-41	(9)	1
	95	-	-	-	-	-	-	-	-
MDS	25	29	28	27	26	240	23-51	(29)	-
	50	25	19	11	9	74	25-50	(26)	1
	75	3	1	1	-	6	42-45	(4)	-
	95	-	-	-	-	-	-	-	-
KWR	25	27	26	25	25	466	20-46	(27)	-
	50	21	19	19	18	246	22-43	(22)	1
	75	15	14	14	13	131	23-37	(15)	1
	95	7	7	7	7	40	24-31	(8)	1
BLG	25	32	29	27	25	263	14-46	(33)	1
	50	22	20	17	16	93	20-42	(23)	1
	75	13	9	8	8	31	25-40	(16)	1
	95	-	-	-	-	-	-	-	-
MPT	25	26	26	24	20	172	21-47	(27)	1
	50	20	19	13	5	56	25-44	(20)	-
	75	6	-	-	-	8	-	-	-
	95	-	-	-	-	-	-	-	-
KMM	25	26	23	23	22	155	18-45	(28)	1
	50	20	18	12	8	62	23-42	(22)	-
	75	8	5	1	-	15	26-35	(10)	2
	95	-	-	-	-	-	-	-	-
MHB	25	26	26	25	25	848	19-47	(29)	1
	50	20	19	19	19	494	23-42	(20)	-
	75	16	16	16	16	273	24-39	(16)	-
	95	10	10	10	10	96	27-36	(10)	-

Table 4.3. Agroclimatic status at different probability levels for I type stations

rainy season is good, and hence actual growing period can be longer than 22 weeks. The AAR of this station is 65 cm. During the first half of the growing period, MAI values are comparatively lower. While during the second half of the growing period, MAI values are quite high (> 0.9) for most of the weeks; only twice it becomes less than 0.7. From this, it can be concluded that at this station double cropping is possible with one moderately long duration crop and one short duration crop. But the first crop should be of low water requirement and drought-hardy. For cropping during the second half of the growing period, water availability is large and hence crops having high water requirement can be grown.

It is clear from the Figure that at 75% level MAI exceeds 0.3 only during two weeks. It becomes obvious that at this probability level cropping is not possible under rainfed conditions.

Mysore:

At Mysore, medium black and mixed red and black soils are found to form another sub-division. Figure 4.9b shows that at 50% level MAI is greater than 0.3 from 17th week to 45th week (last week of April - second week of November). Thus the growing period at this station is spread over a period of 29 weeks. AAR of this station is 46 cm. The figure shows that mid-season water stress periods of one week duration occur twice (26th and 28th week) during the growing period. It can be seen that MAI values are low and fluctuating during the first half of the growing period. Hence, the crop cultivated during this period should be less sensitive to moisture availability changes and should have low water demand. In the case of second half of the growing period, the crop can be of high moisture requirement, provided it is so selected that periods of water availability match the water requirements. Double cropping with moderately long duration crop is possible.

At 75% level MAI becomes greater than 0.3 for 5 weeks but consecutively for 2 weeks only. Crop prospects are bleak at this probability level.

Bangalore:

Bangalore represents the sub-division of this agroclimatic zone with mixed red and black soils. Figure 4.9c shows that at this station, at 50% probability level MAI is greater than 0.3 from 20th to 45th week (mid-May to second week of November) with water stress in 26th week. This provides a growing period of 27 weeks with AAR of 54 cm. At this place, too, the growing period is long enough for double cropping with moderately long duration crops. But during the first half of the growing period, MAI values are not that high and hence crops with low water requirements have to be grown. During the second part of the growing period, MAI values are high enough to support high moisture demanding crops. The MAI status during the last part of the growing period is not high enough to provide an enriched soil moisture storage after the rainy season.

At 75% level, MAI is greater than 0.3 from 32nd to 41st week (August to mid-October) with one water stress period of two weeks duration (35th - 36th) amidst. A drought-hardy variety crop of short duration can be grown at this place with 75% chance of success.

Madras:

Like Cuddalore, Madras also represents the sub-division with coastal alluvium soils. At this station, MAI at 50% level exceeds 0.3 from 25th to 50th week (mid-June to mid-December) with water stress in between, thus giving a growing period of 26 weeks (Figure 4.9d). The AAR at this place is 74 cm during this period. But MAI during the last stages of growing period is high enough to recharge soil moisture and support plants for some more time. Double cropping can be carried out here with moderately long duration crops. Since MAI during the first half of the growing period fluctuates, the crops during this period should not be sensitive to moisture variations. But during the second half, MAI values are high for most of the weeks, and hence agriculture can be carried out during this period with high moisture demanding crops.

At 75% level, this station has MAI greater than 0.3 from 42nd to 45th week (mid-October to mid-November) and among these weeks only once it becomes greater than 0.5. Hence it can be understood that at this high probability level, crop prospects are negligible.

Karwar:

The major soil type found in this region is laterite. Figure 4.9e gives the details of MAI variations at Karwar at different probability levels. It can be seen that in almost all weeks during the growing period at all the probability levels MAI is greater than 0.9. At all the probability levels stored soil moisture is available for plant use after the withdrawal of rains. At 50% level, growing period begins in the 22nd week and ends in the 43rd week (last week of May - last week of October) thus lasting for 22 weeks. One week (42nd) of water stress is observed in the last part of the growing period. The AAR at this probability level is 246 cm. Double cropping can be done with one moderately long duration crop and a short duration one. Since sufficient moisture is available during the growing period, crops of high water requirement can be grown easily: storing of water is also possible.

At 75% level, the growing period lasts for 15 weeks (June to mid-September). At this level, too, a moderately long duration crop with high water requirement can be grown.

At 95% level, also, there is abundance of moisture from 24th to 31st week (mid-June to last week of July) resulting in a growing period of 8 weeks. One week (28th) of water stress is observed during this period. A short duration crop with high water demand can be grown here without any risk.

Belgaum:

Belgaum represents the sub-division of the zone with medium black soils. At this place, at 50% level, the growing period begins from 28th week and lasts till 42nd week (mid-July to mid-October) comprising of 23 weeks (Figure 4.9f). During this period water stress is observed in the 22nd week and the AAR is 93 cm. For most of the weeks during the growing period, MAI exceeds 0.9 and hence there will be soil moisture storage at the end of rainy season to augment the growing period. Double cropping can be done here at this probability level with one moderately long duration crop and one short duration crop having high moisture demand.

At 75% level, MAI becomes greater than 0.3 from 25th to 45th week (mid-June to mid-November), comprising a growing period of 16 weeks. But a water stress period of 3 consecutive weeks (36th - 38th) occurs during this period. Hence crop planning should be done with care so that sensitive phases of the crops do not coincide with this water stress period. One moderately long duration crop can be grown here at this probability level.

Masulipatnam:

Masulipatnam also comes under the sub-division of the region as that of Cuddalore and Madras with coastal alluvium soils. Figure 4.9g gives the details of MAI variations at Masulipatnam at various probability levels. At 50% level, here, the growing period consists of 20 weeks and AAR during this period is 56 cm. Double cropping of short duration crops of drought-hardy variety will be suitable for this place. It can be seen from the Figure that it is difficult to raise crops at this place with 75% chance of success.

Khammam:

At this place medium black and red loam soils are found. From Figure 4.9h it is seen that for this station at 50% level, the growing period begins from 23rd week and lasts till 42nd week (June to mid-October), comprising of 20 weeks. AAR is 62 cm at this probability level. The MAI values are high (> 0.9) mostly during the first half of the growing period but in the second half, it undergoes large fluctuations. Here also double cropping of short duration varieties which can withstand the fluctuations in moisture availability can be cultivated.

At 75% level MAI exceeds 0.3 from 26th to 35th week (last week of June to last week of August) with one week of water stress period occurring twice (28th and 34th). MAI never exceeds 0.9, and is greater than 0.7 only once. Drought-resistant crop of moderately long duration can be raised here with 75% chance of success.

Mahabaleshwar:

At Mahabaleshwar both costal alluvium and lateritic soils are found. At this place (Figure 4.9i), in almost all weeks during the growing season at all the probability levels MAI is greater than 0.9. Mid season water stress is observed only once at 25% level. At 50% level, AAR is 49 cm and growing period is of 20 weeks duration. The growing periods at all the levels will be longer because of the stored soil moisture available for use after the cessation of the rain. Double cropping is possible at this place with short duration crops, but care should be taken while selecting the crop varieties, so that the abundant moisture will not adversely affect the crops. Water storage is also possible.

At 75% level too there exists a growing period of length 16 weeks (mid-June to September last) and MAI is constantly above 0.9. One moderately long duration crop can be suggested for this place.

Even at 95% level, high water availability exists for 10 weeks which is a sufficiently long period for raising a moderately long duration crop.

From Figure 4.8 it is seen that among the stations of I type agroclimate, at 50% level, Mahabaleshwar which is on the windward side of the Ghats has the highest AAR while Mysore has the least value. Among the east coast stations Cuddalore has the highest AAR. Out of the 9 stations of I type of agroclimate, Mysore has the longest growing period. However, it is to be pointed out that this station has the least AAR among the selected stations of this agroclimatic type. The station which receives the highest AAR is on the windward side of the Western Ghats and hence the major rainy season is linked to the SW monsoon. Because of this fact, its growing period also comprises of only a few weeks. Generally, south interior Karnataka experiences longer growing periods; along the east coast, Madras has the longest growing period. The earliest commencement of growing period is observed at Mysore and the latest at Madras and Masulipatnam. The earliest cessation of growing periods is observed at Belgaum, Khammam and Mahabaleshwar while the latest occurs at Cuddalore and Madras.

The maximum number of breaks in the growing periods at 50% level is observed at Mysore. Among the stations of I category of agroclimate 95% probability of cultivation exists only at Karwar and Mahabaleshwar; for Cuddalore, Mysore and Masulipatnam it is possible at 50% level only.

H Type:

This agroclimatic zone extends from southwest extreme part of Maharashtra through Karnataka into Tamil Nadu as a narrow belt and also exists in the northeast sector of the study region (Figure 4.5). The soils of this zone comprises mainly of red loam, laterites, coastal alluvium, medium black, mixed red and black and deep black soils which make a separate sub-division of this agroclimatic region (Figure 4.6).

At 75% probability level, the AAR of this zone (Figure 4.1a) varies between 5 cm and 10 cm in the southern portion of Tamil Nadu and in the portion in northeast sector of the study region; it is between 50 cm and 100 cm in the northwest portion of the region. The growing period varies from 5-10 weeks in the southern and the northeastern portions and 15-20 weeks in the coastal northwestern portions (Figure 4.2a). At 50% level, the AAR of this zone ranges from nearly 50 cm in the southern part and northeastern part to around 200 cm in the northwestern part (Figure 4.1b). The growing period at this probability level ranges between 15 and 25 weeks throughout the region (Figure 4.3). The AAR of this zone at 25% level is around 200 cm in the southern part and northeastern parts while it is between 400 cm and 500 cm in the northwest part (Figure 4.1c). Growing period at this probability level is 30-35 weeks in the southern region and in the central part and around 25 in the northwestern and northeastern parts of the zone (Figure 4.4a).

Crop Potential at individual stations:

Table 4.4 gives the summary of the results for the individual stations of H type of agroclimate.

Salem:

At Salem, generally red loam soils are found. At 50% level (Figure 4.10a), MAI exceeds 0.3 from 20th to 45th week (mid-May to mid-November) at this station. The AAR is 56 cm during this period and water stress periods of 1 week duration occurs thrice (23rd, 26th and 28th weeks) in between. Crops with low water requirement and drought-resistant varieties can be raised during the first half of the period. During the second part of the growing period, crops having high water demand can be raised under rainfed condition. Thus double cropping can be done with one moderately long duration crop and one short duration crop.

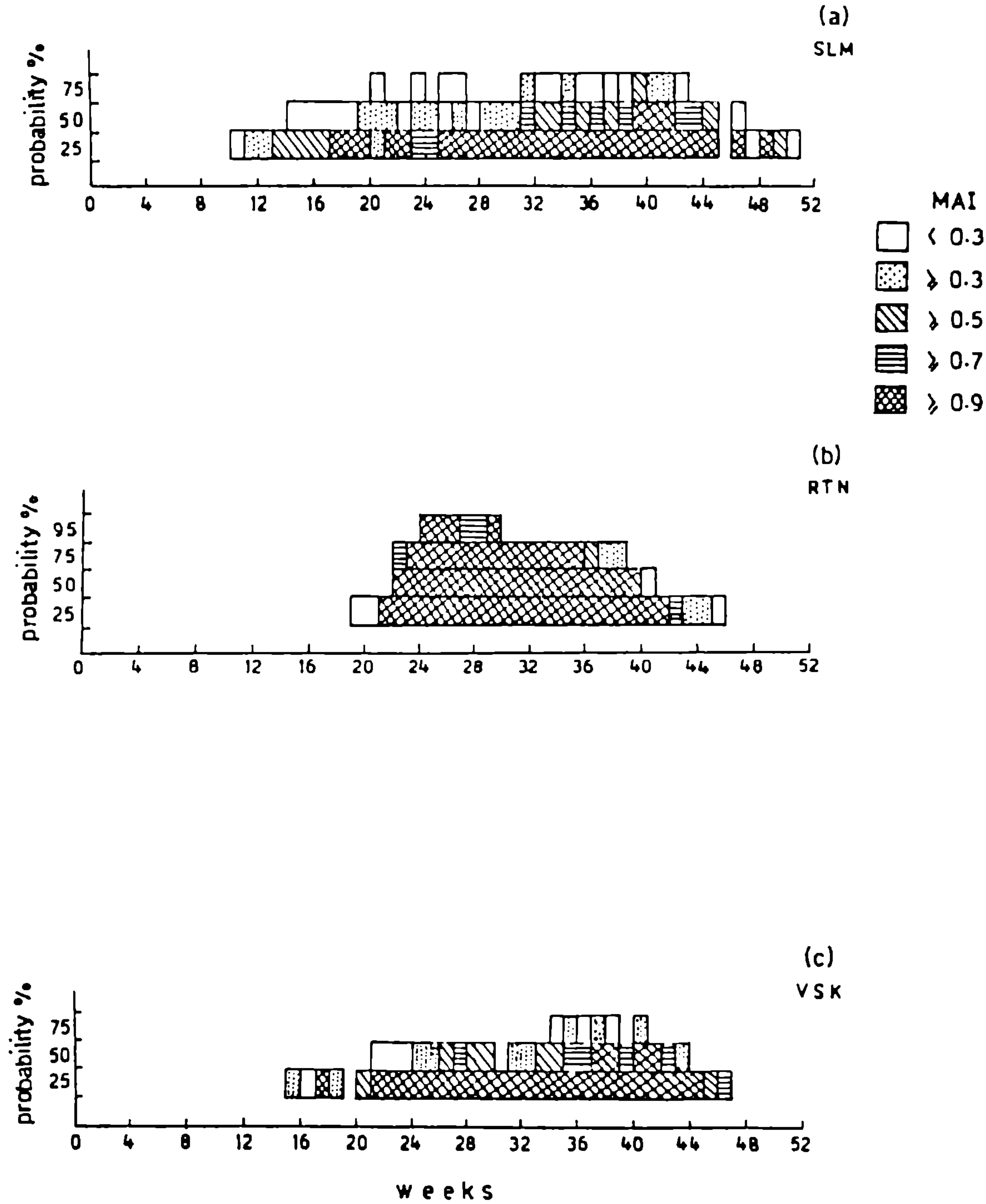


Figure 4.10 Magnitude and duration of MAI at different probability levels for stations of H type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)	No. of breaks
SLM	25	37	34	29	27	175	12-50 (39)	2
	50	23	14	9	3	56	20-45 (26)	3
	75	6	1	-	-	9	- -	-
	95	-	-	-	-	-	- -	-
RTN	25	24	22	22	21	460	22-45 (24)	-
	50	18	18	18	18	221	23-40 (18)	-
	75	17	15	14	13	111	23-39 (17)	-
	95	6	6	6	4	27	25-30 (6)	-
VSK	25	29	27	25	24	176	16-47 (32)	2
	50	19	14	9	4	46	25-44 (20)	1
	75	3	-	-	-	4	- -	-
	95	-	-	-	-	-	- -	-

Table 4.4. Agroclimatic status at different probability levels for H type stations

At 75% level the MAI never exceeds 0.7 and while it is greater than 0.5 only during one week. Mid-season water stress is greater at this probability level. From these facts it becomes clear that cultivation will not have 75% chance of success at this place.

Ratnagiri:

Coastal alluvium and lateritic soils are found at Ratnagiri which forms a different sub-division of this agroclimatic type. Figure 4.10b shows that at 50% level the growing period is from 23rd to 40th week (first week of June - first week of october). During this period AAR is 221 cm and for this station no mid-season water stress is observed and MAI values exceed 0.9. Because of high water availability during the growing season, the soil moisture status will be high after the withdrawal of rainfall. Therefore, at this station, a rainfed crop of more than 18 weeks duration can be cultivated without difficulty. Otherwise, double cropping of short duration crops can be done.

At 75% level too, MAI becomes greater than 0.3 from 23rd week and it remains so till the 39th week (June - September). At this level, too, rainfed agriculture is not risky and a long duration crop of more than 17 week duration can be raised.

At 95% probability level, MAI becomes greater than 0.3 from 25th week to 30th week (mid-June to July end), a growing period of more than 6 weeks with high water availability. A short duration crop can be raised without difficulty, since stored soil moisture will be there to support crops after the rains.

Vishakhapatnam:

Coastal alluvium soils are found at this place. Moisture availability variations at Vishakhapatnam is given in Figure 4.10c. At 50% level, the growing period comprises of 19 weeks beginning from the 25th week and ending in 44th week (mid-June to first week of November) with water stress in the 31st week. The AAR of this station during this period is 46 cm. Water availability is low during the first half of the growing period. If double cropping of short duration varieties is to be carried out, during the first half of the growing period, crops with low water demand have to be selected. During the second half, water availability is comparatively high so that high water demanding crops can be cultivated.

At 75% level MAI is more than 0.3 for only 3 weeks that too are not consecutive. Agriculture is not possible at this level of probability.

Among these stations which fall in H type of agroclimate, at 50% level, Salem has the longest growing period but the AAR is highest at Ratnagiri (Figure 4.8). At Salem, though the rainfall is less it is spread among a larger number of weeks since it receives NE monsoon rainfall too. But Ratnagiri, the place with highest AAR, is on the windward side of the Ghats where the major rainy season is the SW monsoon period. The earliest commencement of growing period is at Salem.

The number of breaks observed during the growing season is more at Salem whereas Ratnagiri experiences none at any probability level.

G Type:

From Figure 4.5, it can be seen that this agroclimatic zone exists in a narrow circular strip in the central part of the study region comprising parts of North Interior Karnataka, Rayalaseema, South Coastal Andhra Pradesh, Telangana and adjoining parts of Maharashtra. In south Tamil Nadu too, this climatic type exists as a circular strip outside Kodaikanal mountain area. The soil varieties found in this region are mainly medium black, deep black, mixed red and black, red loam and in a few places red gravel soils, lateritic soils and coastal alluvium. These soil classes categorize the climatic type into 7 sub-divisions (Figure 4.6).

At 75% probability level, the AAR is below 10 cm in this zone (Figure 4.1a): in northern Tamil Nadu it is almost negligible. The growing period (Figure 4.2a) at this probability level is less than 10 weeks and there exists no growing period in northern Tamil Nadu and part of east coast region of this zone. At 50% probability level, AAR is below 50 cm except in the northeast part where it is between 50 cm and 100 cm (Figure 4.1b). At this probability level growing period varies between 15 and 20 weeks except northern Tamil Nadu where it is between 20 and 25 weeks (Figure 4.3a). At 25% level (Figure 4.1c), AAR generally ranges from 100 cm to 200 cm in almost all parts except in northern Tamil Nadu where it is greater than 200 cm. The growing period (Figure 4.4a) at this probability level is between 20 and 25 weeks in the northern parts and varies between 30 and 35 weeks in Tamil Nadu.

Crop Potential at individual stations:

Table 4.5 gives the summary of the results for the individual stations of G type agroclimate.

Tiruchirappalli:

This station represents the sub-division of the zone with red loam soils. The variation of MAI at this station for the different probability levels are given in Figure 4.11a. It can be seen that at 50% probability level, MAI is greater than 0.3 from 35th to 50th week (last week of August - last week of December) giving a growing period of 16 weeks with no water

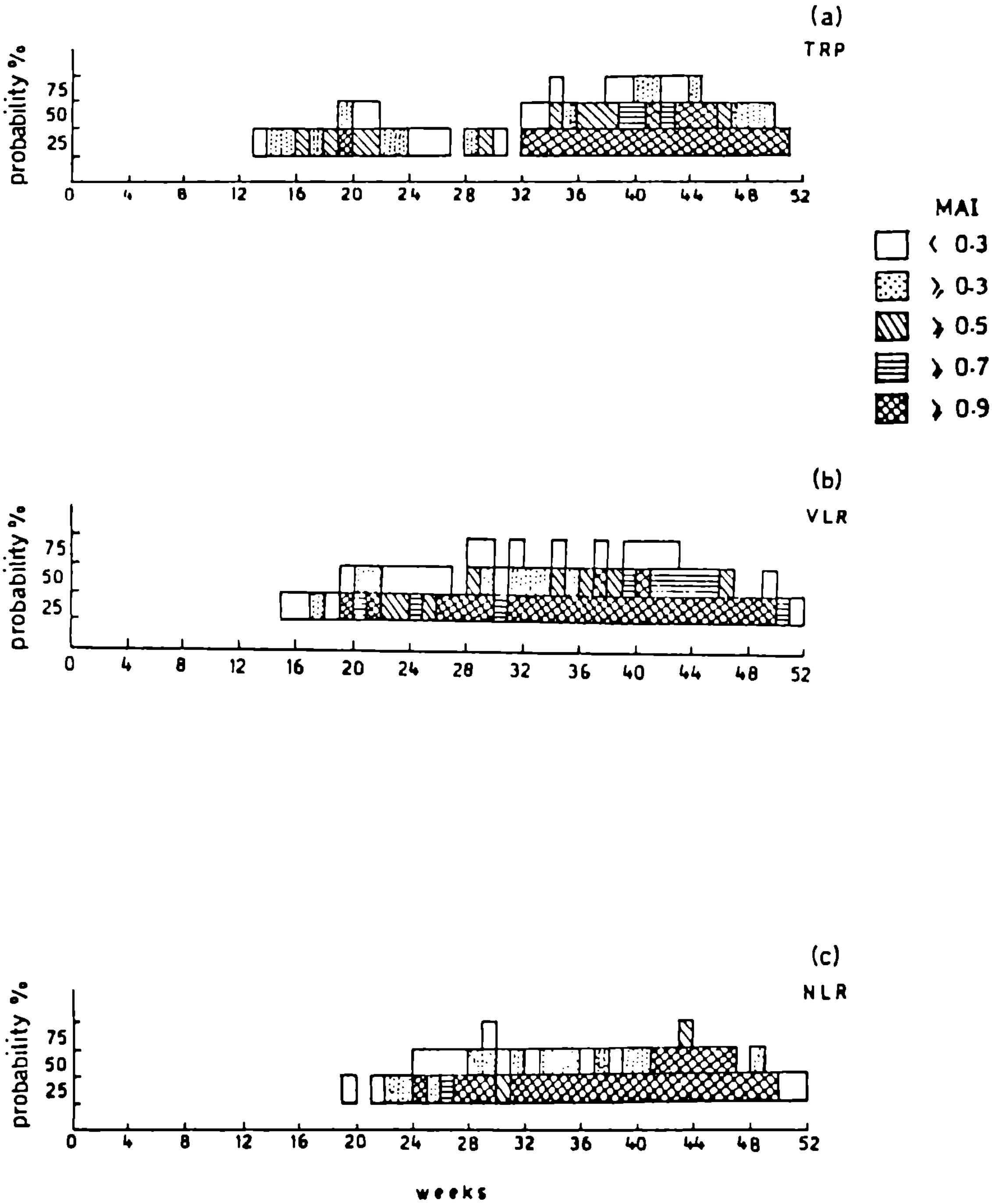


Figure 4.11 Magnitude and duration of MAI at different probability levels for stations of G type agroclimate

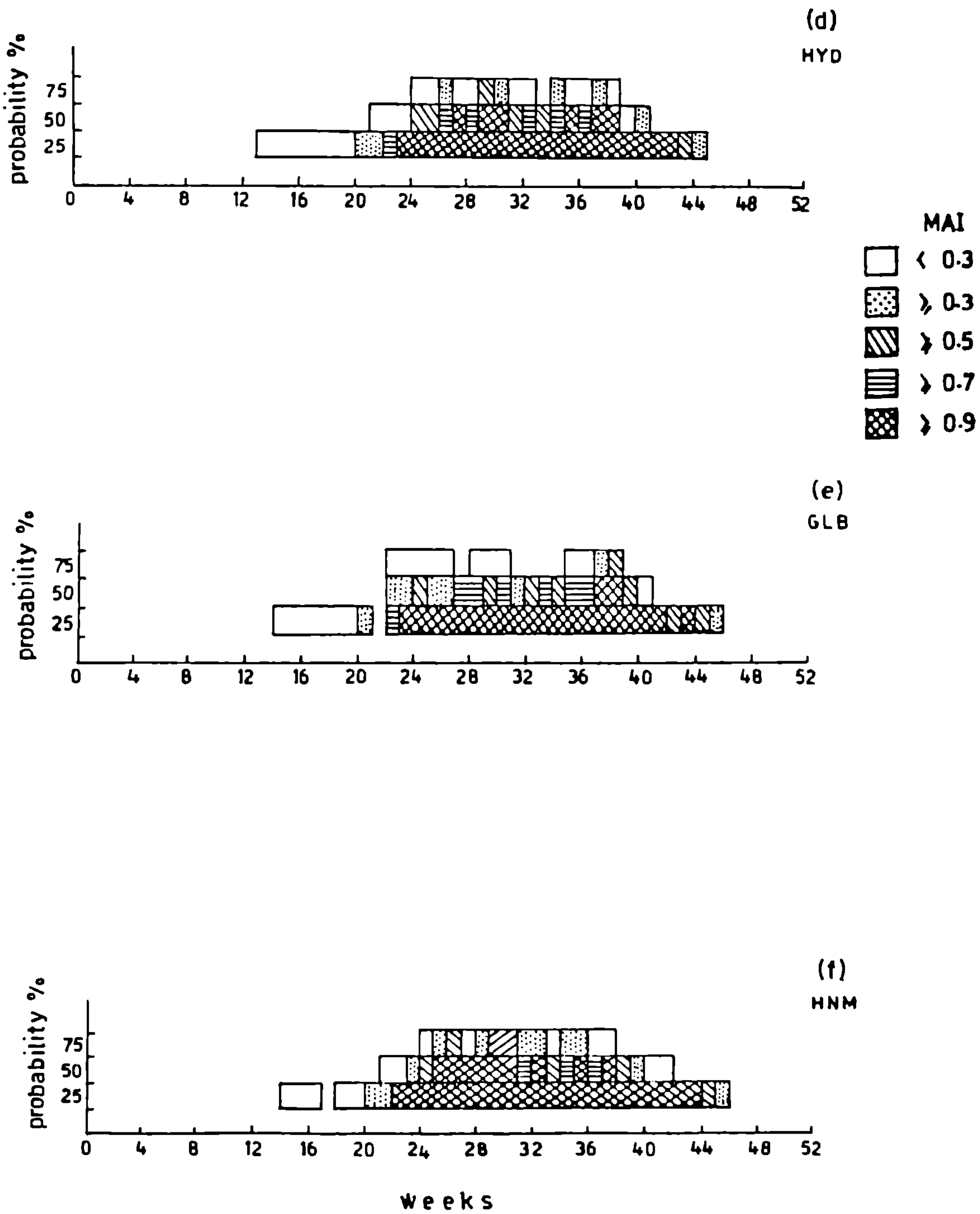


Figure 4.11 (contd.) Magnitude and duration of MAI at different probability levels for stations of G type agroclimate

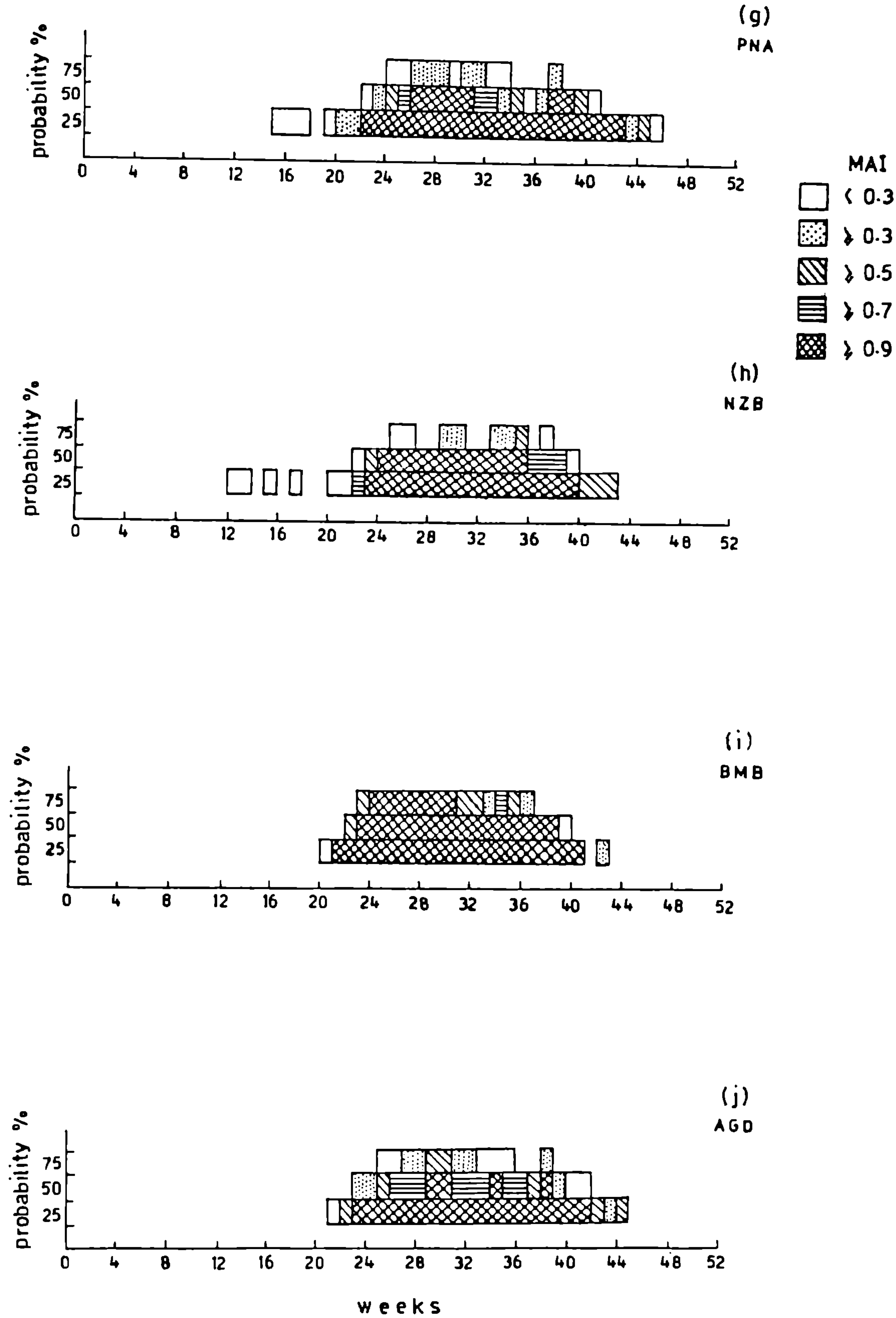


Figure 4.11 (contd.) Magnitude and duration of MAI at different probability levels for stations of G type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ⩾0.3	⩾0.5	⩾0.7	⩾0.9	AAR (cm)	Growing period (weeks)	No. of breaks
TRP	25	30	24	19	19	154	15-51 (36)	2
	50	16	12	7	4	35	35-50 (16)	-
	75	3	-	-	-	5	41-45 (5)	1
	95	-	-	-	-	-	- -	-
VLR	25	33	32	29	25	216	18-15 (34)	1
	50	18	13	8	2	27	29-47 (19)	1
	75	-	-	-	-	-	- -	-
	95	-	-	-	-	-	- -	-
NLR	25	28	25	24	23	209	23-50 (28)	-
	50	12	6	6	6	35	30-49 (20)	5
	75	1	1	-	-	2	- -	-
	95	-	-	-	-	-	- -	-
HYD	25	25	22	21	20	138	21-45 (25)	-
	50	16	15	11	6	41	25-41 (17)	1
	75	5	1	-	-	6	- -	-
	95	-	-	-	-	-	- -	-
GLB	25	25	23	21	20	146	21-46 (26)	1
	50	18	13	8	2	44	23-40 (18)	-
	75	2	1	-	-	3	- -	-
	95	-	-	-	-	-	- -	-
HNM	25	26	23	22	22	161	21-46 (26)	-
	50	17	15	12	9	54	24-40 (17)	-
	75	9	3	-	-	15	26-36 (11)	2
	95	-	-	-	-	-	- -	-
PNA	25	25	22	21	21	137	21-45 (25)	-
	50	16	13	10	7	37	24-40 (17)	1
	75	6	-	-	-	6	27-32 (6)	1
	95	-	-	-	-	-	- -	-
NZB	25	21	21	18	17	177	23-43 (21)	-
	50	16	16	15	12	70	24-39 (16)	-
	75	4	1	-	-	12	29-36) (7)	1
	95	-	-	-	-	-	- -	-
BMB	25	21	20	20	20	419	22-43 (22)	1
	50	17	17	16	16	153	23-40 (18)	-
	75	14	12	8	7	54	24-37 (14)	-
	95	-	-	-	-	-	- -	-
AGD	25	23	22	19	19	122	23-45 (23)	-
	50	17	14	12	4	39	24-40 (17)	-
	75	7	2	-	-	8	28-33 (6)	-
	95	-	-	-	-	-	- -	-

Table 4.5. Agroclimatic status at different probability levels for G type stations

scarcity in between. At this station, AAR is 35 cm. It can be understood that either long duration crops can be grown here under rainfed conditions or double cropping of two short duration varieties can be resorted to.

At 75% level, MAI never exceeds 0.5 and is greater than 0.3 for only three non-consecutive weeks. Hence at this level of probability agriculture is not practicable.

Vellore:

Vellore also comes under the same sub-division (red loam) as that of Tiruchirappalli. From Figure 4.11b, it is clear that at this station at 50% level of probability, the growing period commences in the 29th week and lasts 19 weeks till the 47th week (mid-July to mid-November). Only 1 week (31st) of water stress is observed during this period, but MAI is greater than 0.9 only for 2 weeks. AAR at this station is 27 cm. Double cropping can be done with short duration crops of drought hardy-variety.

At 75% level MAI is always less than 0.3: hence cropping is not practicable at this level without irrigation.

Nellore:

At this place both coastal alluvium and red loam are found. Figure 4.11c makes clear that at Nellore the growing period at 50% level is from 29th to 49th week (mid-July to first week of December) resulting in a 21 week duration with AAR value of 35 cm. Water shortage occurring five times, each of one week duration. High MAI values during the growing period point to the abundance of moisture and hence the probability of enriched soil moisture storage. Hence, crops can survive for some more time even when MAI becomes less than 0.3 and thus the growing period is longer than 21 weeks. Either single cropping with a long duration crop or double cropping with one moderate and one short duration crop can be carried out with 50% chances of success.

From the figure, it is clear that agriculture is not at all possible at 75% level.

Hyderabad:

Generally, medium black soils and in a few areas lateritic soils are found here. From Figure 4.11d, it is seen that at 50% level MAI exceeds 0.3 from 25th to 41st week (mid-June to mid-October) giving a growing period of 17 weeks, with a break during the 40th week. The AAR during the growing period is found to be 41 cm. From the large fluctuations of MAI it is understood that the crop varieties have to be so selected that their sensitive phases are not affected by these variations. A long duration crop or two short duration crops can be suggested for this place.

At 75% level, MAI is greater than 0.3 for 5 non-consecutive weeks. Water stress periods of more than 2 weeks occur in between. Hence it can be concluded that agriculture at this place will not have a 75% chance of success.

Gulbarga:

This station represents the sub-division with medium black and deep black soils. Variation of MAI for this station is given in Figure 4.11e. It is clear from the figure that at 50% level the growing period commences in 23rd week and ends at 40th week (first week of June - to first week of October). During this 18-week period no water stress is observed. The AAR for this station is 44 cm. Here one long duration crop or two short duration crops can be raised under rainfed conditions.

At 75% level rainfed cultivation is not possible.

Hanamkonda:

This station also comes under the same sub-division as that of Gulbarga (medium black and deep black soils). Figure 4.11f represents the magnitude and duration of MAI at different probability levels for this station. MAI at 50% level is greater than 0.3 from 24th to 40th week (11th June -7th October), which enables crop cultivation for a 17-week period without any water stress period. During the first half of this period, water availability is larger compared to the second half. Hence, high water demanding crops can be cultivated during the first half. It is evident from the figure that one long duration crop or two short duration crops can be grown here under rainfed conditions with a 50% chance of success.

From the variations in magnitude and duration of MAI at 75% level, it can be understood that the growing period begins from the 26th week and ceases in the 36th week (last week of June -

first week of September) giving a duration of 11 weeks. But water stress periods of one week duration occur twice (28th and 34th week) in between. At this level MAI is never greater than 0.9. Hence high water demanding crops are not advisable at this probability level. A short duration crop of low water demand can be selected for this place.

Pune:

Medium black soil is the major soil type at this place. Figure 4.11g reveals that for Pune, at 50% level, the growing period begins from 24th week lasting for 17 weeks upto 40th week (11th June - 7th October) with one week of water stress period. At this station, too, the water availability is higher during the first half of the growing period. At this station, double cropping can be carried out with two short duration crops if planned properly such that during the second cropping the selected crop varieties are of comparatively lower water requirement. Single cropping of a long duration crop is also possible.

At 75% level, MAI values are never greater than 0.5 and the growing period is from 27th - 32nd week (first week of July - first week of August, 6 weeks). This indicates that crops with shorter life span and less water demand can be grown here.

Nizamabad:

At this place, too, the soil types are of medium black and deep black category. At 50% level, MAI exceeds 0.3 (Figure

4.11h) from 24th to 39th week (11th June -30th September) thus making 16 weeks suitable for cultivation. Water availability is high during the entire growing period and therefore crops can thrive on stored soil moisture for some more time even when MAI less than 0.3. Hence double cropping can be carried out with two short duration crops under rainfed conditions, or a single cropping of long duration variety.

At 75% level, there are only 7 weeks suitable for crop growing, with a two week's water stress in between. MAI is always less than 0.7 and hence any short duration crop of drought-resistant variety will have a 75% success.

Bombay:

Coastal alluvium soils are found at Bombay which forms another sub-division of this agroclimatic type. Figure 4.11i represents the magnitude and duration of MAI at different probability levels for Bombay. Here at 50% level, MAI exceeds 0.3 from 23rd to 40th week (first week of June - first week of October) thus giving a growing period of 18 weeks duration. At this probability level, moisture status is so high that MAI decrease to below 0.7 only for two weeks in the growing period. No water stress is observed in between while AAR is 153 cm. Since MAI is high throughout the season there will be sufficient soil moisture available for plants and hence crops can survive even after the withdrawal of the rainy season. Thus, at this probability level, double cropping can be done with short duration crops.

At 75% level too, during the growing season moisture status is high: 7 weeks with MAI greater than 0.9 among 14 weeks of growing period. A moderately long duration crop of high water requirement can be grown at this risk level too.

At 95% level, this station has a growing period during 24th to 37th week (11th June - 16th September). During this 14-week period, a moderately long duration crop can be cultivated with a 95% chance of success.

Aurangabad:

Aurangabad also represents the same sub-division as that of Gulbarga, Hanamkonda and Nizamabad (medium black and deep black). At this station (Figure 4.11j), at 50% level, a growing period of 17 weeks begins from 24th week and ends in 40th week (11th June - 7th October) with AAR of 39 cm. During the first stage of the growing period, MAI increases steadily and then shows fluctuations. Since moisture availability is not so high there will not be much stored soil moisture after the rainy season: hence either one long duration crop or two short duration crops having low water demand is advised at 50% level.

At 75% level MAI exceeds 0.3 for 6 weeks and hence a short duration crop of drought-hardy variety can be grown with a 75% chance of success.

From Figure 4.8, it can be pointed out that, among the 10 stations of G type of agroclimate, Bombay has the highest AAR; the least is at Vellore. It can be noted that at 50% level, the longest growing period is experienced at Vellore though it has the least AAR. This is due to the fact that, at this station rainfall is received during NE monsoon also. Hence for this station, moisture availability period is spread among larger number of weeks. Among these stations the earliest commencement of growing period is observed at Gulbarga and Bombay - the latest at Tiruchirappalli. Generally, Tamil Nadu regions have late commencement of growing periods. The earliest cessation of growing period is at Nizamabad.

The maximum number of breaks are 5 at Nellore. Among these 10 stations, 95% chance of successful agriculture is there only at Bombay. Among the other stations, there is a 75% chance of success at Hanamkonda, Pune, Nizamabad and Aurangabad.

F Type:

This climatic type is found to exist mainly in the central part of the study region as a circular strip consisting of parts of North Interior Karnataka, Rayalaseema and South Coastal Andhra Pradesh, and in Tamil Nadu, around the Kodaikanal hills (Figure 4.5). The varied soil types found in the zone in the central region are deep black, medium black, mixed red and black, red loam and red gravel. In the Tamil Nadu portion of this zone, the major soil types are red loams, laterites, coastal alluvium and medium black. Within this same agroclimatic zone, these soil varieties form individual sub-divisions (Figure 4.6).

At 75% of probability level, the AAR (Figure 4.1a) of this zone in the central sector is less than 5 cm. In the Tamil Nadu sector it is slightly greater, around 10 cm. The growing period at this probability level (Figure 4.1b) is less than 5 weeks in this zone in the central part and it is around 5 weeks in the eastern part. At 50% level the AAR of this zone varies between 10 cm and 50 cm everywhere (Figure 4.1b). The growing period (Figure 4.3a) at this probability level is around 15 weeks in the central part but slightly less in the northern part. At 25% level AAR varies between 100 and 200 cm in the entire zone (Figure 4.1c). The growing period (Figure 4.4a) is around 30 weeks in the central part of the zone but is slightly lesser in the coastal region of Tamil Nadu.

Crop Potential at individual stations:

Table 4.6 gives the summary of the results for the individual stations of F type of agroclimate.

Pamban:

This place has coastal alluvium soils. Figure 4.12a gives the detailed picture of MAI variations at this place for different probability levels. At 50% level, MAI exceeds 0.3 between 42nd and 52nd week (mid-October to last week of December) comprising a growing period of 11 weeks without any break in between. AAR observed at this station is 44 cm. During the growing period, moisture status is high and hence there will be sufficient stored soil moisture after the rainy season. Thus, a moderately long duration crop having slightly more than 11 weeks

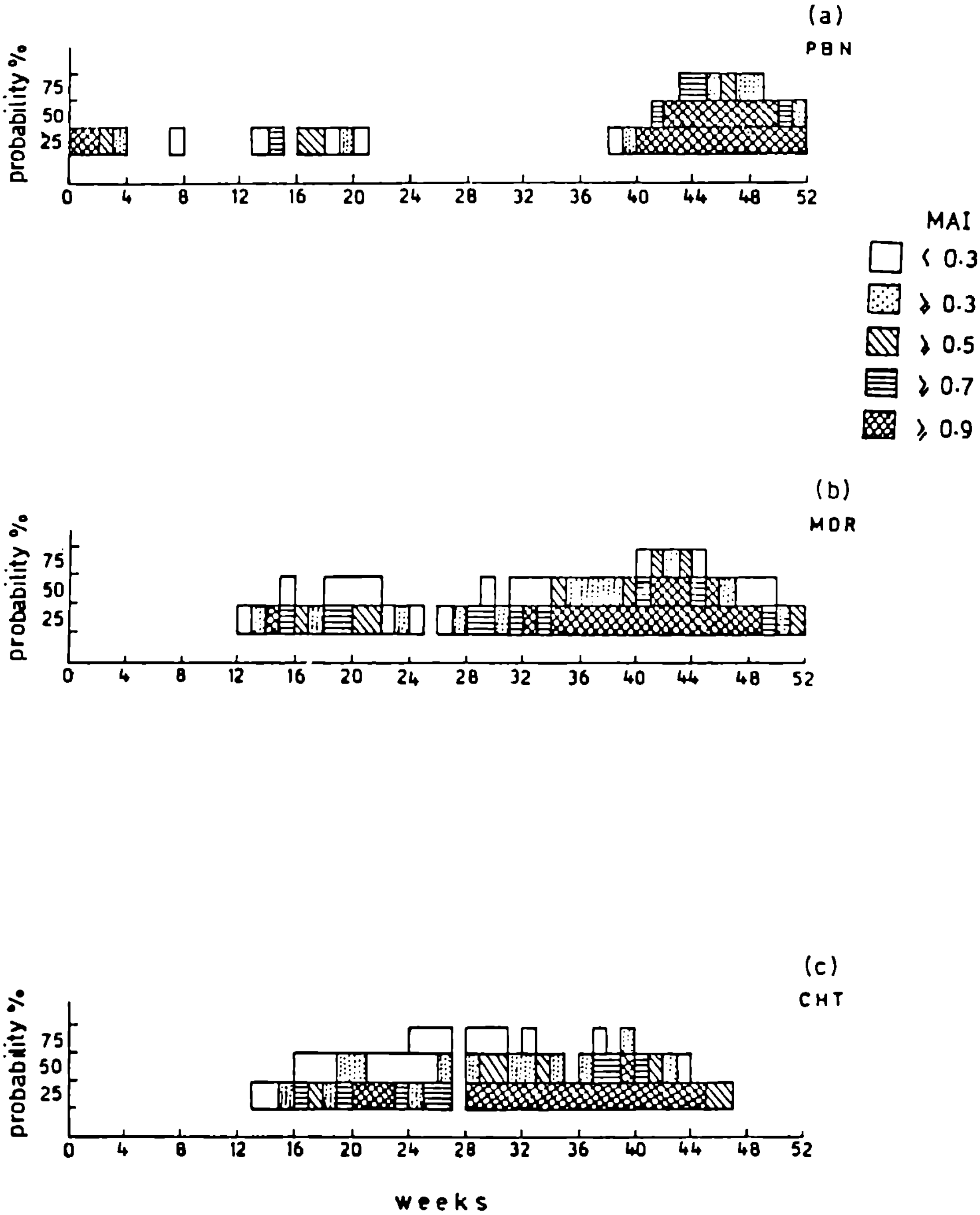


Figure 4.12 Magnitude and duration of MAI at different probability levels for stations of F type agroclimate

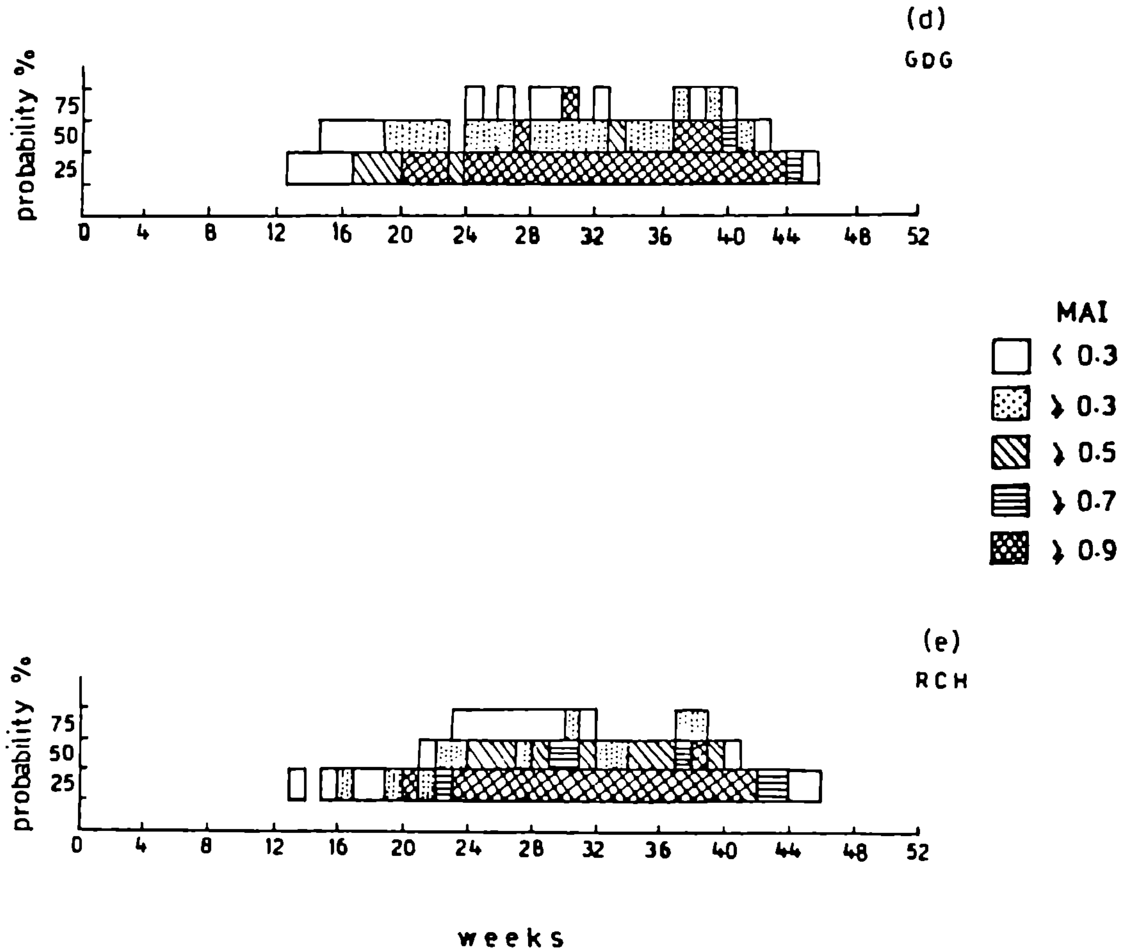


Figure 4.12 (contd.) Magnitude and duration of MAI at different probability levels for stations of F type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)		No. of breaks
PBN	25	21	18	15	14	154	15-20	(6)	-
							40-04	(17)	2
	50	11	10	10	8	44	42-52	(11)	-
	75	6	3	2	-	10	44-49	(6)	-
	95	-	-	-	-	-	-	-	-
MDR	25	35	29	25	17	160	14-52	(39)	2
	50	13	8	6	4	33	35-47	(13)	-
	75	3	2	-	-	5	42-44	(3)	-
	95	-	-	-	-	-	-	-	-
CHT	25	31	28	25	20	115	16-47	(32)	1
	50	15	8	4	1	24	27-43	(17)	2
	75	1	-	-	-	1	-	-	-
	95	-	-	-	-	-	-	-	-
GDG	25	28	28	24	23	117	18-45	(28)	-
	50	22	6	5	4	35	20-42	(23)	2
	75	3	1	1	1	3	-	-	-
	95	-	-	-	-	-	-	-	-
RCH	25	26	23	23	20	143	17-44	(28)	1
	50	18	13	4	1	37	23-40	(18)	-
	75	3	-	-	-	1	-	-	-
	95	-	-	-	-	-	-	-	-

Table 4.6. Agroclimatic status at different probability levels for F type stations

duration can be grown here under rainfed conditions, because when MAI falls below 0.3 crops can thrive on stored soil moisture for some more time.

At 75% level, the growing period is from 44th week to 49th week (last week of October - first week of December) comprising of 6 weeks without any water shortage. But since MAI values are less than 0.9 always,only a short duration crop with low water demand can be cultivated with 75% of success.

Madurai:

Madurai represents the sub-division of this agroclimatic zone with red loam soils. Figure 4.12b shows that at this station at 50% level, MAI is high enough to enable cropping from 35th - 47th weeks (last week of August - last week of November). Within this period of 13 weeks, AAR is 33 cm only, though no water stress is observed at this probability level. A moderately long duration crop of low water demand can be grown here.

At 75% level, MAI shows values greater than 0.3 only during 3 weeks and hence successful cropping is not possible.

Chitradurga:

Mixed red and black soils characterize this station. Figure 4.12c shows that at this station the growing period at 50% level consists of 17 weeks beginning from 27th week and ending in 43rd week (first week of July - last week of October) with water stress periods of one week occurring twice (28th and 36th week) and with an AAR of 24 cm. Since the water availability is not that high (MAI exceeds 0.9 only once) there will not be any stored soil moisture for the use of crops after the rainy season. Under rainfed conditions, cultivation of crops with high water requirement is difficult. Either a single cropping of long duration variety or double cropping of two short duration varieties can be carried out provided the crops have low water demand.

At 75% level crop prospects are nil.

Gadag:

The medium black soils of this place form another sub-division of F agroclimatic type. From Figure 4.12d it is understood that at this place the growing period commences in the 20th week and exists till 42nd week (mid-May to mid-October, total 23 weeks) with water stress period of one week (24th). AAR is 35 cm during this period. During the first half of the growing period, MAI values are low and hence only crops having low water demand can be grown. But during, the second part, MAI values are sufficiently high to support crops with moderate water requirement under rainfed conditions. This indicates that double cropping of moderately long duration varieties can be planned with a 50% probability of success.

At 75% level, MAI exceeds 0.3 for 3 non-consecutive weeks. Hence at this place crop cultivation does not have a 75% assurance of success.

Raichur:

Raichur represents the sub-division with deep black soils. At this place (Figure 4.12e) at 50% level, MAI values are high enough to enable cropping from 23rd week to 40th week (first week of June - first week of October, 18 weeks). No break is observed during this period and AAR is found to be 37 cm. However as MAI values are not that high, it is advisable to have double cropping of short duration variety having low water demand.

At 75% level, MAI is greater than 0.3 for 3 non consecutive weeks and hence crop cultivation will not have a 75% chance of success.

Among the stations of F agroclimatic category stations, Pamban experiences the highest AAR at 50% level (Figure 4.8) while least value is observed at Chitradurga. The growing period is longest at Gadag. Among the five stations of this agroclimatic type, Pamban has the shortest growing period. The earliest commencement of growing period is observed at Gadag and the latest at Pamban. The earliest cessation of growing period is at Raichur but the latest cessation is found to occur at Pamban and Madurai.

The maximum number of breaks observed are at Chitradurga and Gadag. None of these stations have 95% chance of successful dryland agriculture; even at 75% probability level,there is a chance of success only at Pamban.

E Type:

This type of agroclimate is observed inside the region of F type agroclimate in the central part of the study region comprising parts of North Interior Karnataka, Rayalaseema and Telangana and in the south in region around Coimbatore (Figure 4.5). Major soil types are deep black, medium black, red loams, mixed red and black resulting in 4 sub-divisions of this zone (Figure 4.6).

The AAR at 75% level for this entire region varies between 0 and 5 cm (Figure 4.1a). Growing period (Figure 4.2a) at this probability level ranges from 0 to 5 weeks. At 50% level, AAR of this zone ranges between 10-50 cm (Figure 4.1b) and the growing period (Figure 4.3a) between 10-20 weeks except in the south where it is less than 10 weeks. At 25% level AAR has values ranging from 100 cm to 200 cm (Figure 4.1c). The growing period at this probability level ranges from 25-30 weeks, but in the southern portion, it is slightly greater than 30 weeks (Figure 4.4a).

Crop Potential at individual stations:

Table 4.7 gives the summary of the results for the individual stations of E type of agroclimate.

Coimbatore:

Coimbatore is of the sub-division with red loams and medium black soil categories. Figure 4.13a represents the moisture status of this station. At 50% level of probability, the growing period begins from the 40th week and ends in the 46th week (first week of October to mid-November) giving a duration of 7 weeks without any break. Water availability during this period is sufficient only for raising a low water demanding crop of short duration. Single cropping of short duration variety is possible during the year under rainfed conditions.

At 75% level, MAI exceeds 0.3 but less than 0.5 only, for 3 consecutive weeks. Agriculture is not possible at this level of probability.

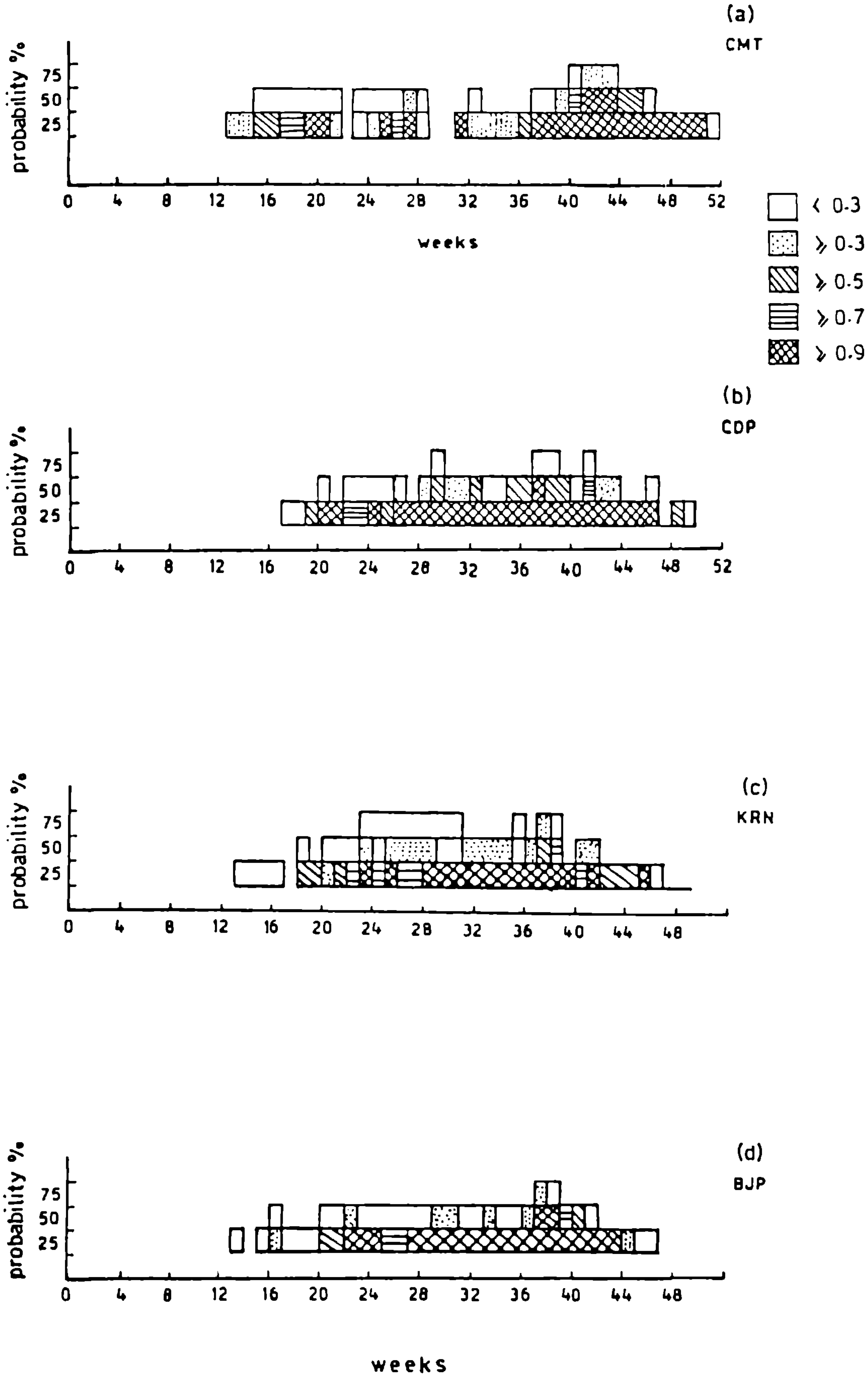


Figure 4.13 Magnitude and duration of MAI at different probability levels for stations of E type agroclimate

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)		No. of breaks
CMT	25	33	25	22	19	110	14-51	(38)	2
	50	7	6	4	3	16	40-46	(7)	-
	75	3	-	-	-	3	-	-	-
	95	-	-	-	-	-	-	-	-
CDP	25	29	29	26	24	158	20-49	(30)	1
	50	17	8	2	1	32	27-44	(18)	3
	75	-	-	-	-	-	-	-	-
	95	-	-	-	-	-	-	-	-
KRN	25	28	27	21	16	128	19-46	(28)	-
	50	14	2	1	-	32	24-42	(19)	4
	75	1	-	-	-	1	-	-	-
	95	-	-	-	-	-	-	-	-
BJP	25	25	24	21	20	116	17-44	(28)	1
	50	5	4	3	2	17	37-41	(5)	-
	75	1	-	-	-	1	-	-	-
	95	-	-	-	-	-	-	-	-

Table 4.7. Agroclimatic status at different probability levels for E type stations

At 25% level, growing period is between 14th and 51st week (April to mid-December) with two breaks occurring in between (23rd to 24th and 29th to 31st weeks). At this station, MAI has high values for long duration at this low probability level: hence it is obvious that high water demanding, long duration crops have only a 25% chance of success.

Cuddapah:

At Cuddapah (Figure 4.13b), mainly mixed red and black and red loam soils are found. At this station at 50% level, the MAI values exceed 0.3 from 27th to 44th week (July -October) enabling 18 weeks of agriculture. But within this period, breaks occur thrice (28th, 34th to 35th and 41st weeks) while AAR is found to be only 32 cm. Two single crops of short duration with low water requirement can be carried out here at this level of probability. At 25% level, the growing period begins from the 20th week and extends in the 40th week (mid-May to first week of October) with one week of water stress. Moisture availability is high only at this level of probability: thus for high water demanding and long duration crops, the chance of success is only 25%.

Kurnool:

Generally, medium black and red loam soils are found at Kurnool. Figure 4.13c shows that the growing period begins from the 24th week and ceases in the 42nd week giving a growing period of 19 weeks (mid-June to mid-October). But during this period, four times (25th, 30th to 31st, 36th and 40th weeks) water scarcity occurs and MAI exceeds 0.7 only once. Even though AAR is 32 cm, the moisture availability is low because of the high water need of this place. Here too, one long duration crop of drought-hardy variety is advisable.

At 75% level, MAI is greater than 0.3 for only two weeks and hence no agriculture is possible here.

At 25% level the moisture status is high from the 19th to the 46th week (second week of May to mid-November) without any break: only this probability level has high moisture availability. Hence at this place with a 25% chance of success cultivation of high moisture demanding, long duration crops can be done.

Bijapur

Here medium and deep black soil varieties exist. MAI variations at this station (Figure 4.13d) show that at 50% probability level it has consecutive values for 5 weeks. Only a short duration crop of low water requirement can be suggested for this place.

At 75% level no cultivation is possible.

The MAI values at 25% level become greater than 0.3 from 17th to 46th week (last week of April to mid-November) with one water stress period of two weeks duration (18th to 19th). At this level only, MAI have high values for long durations: hence probability of successful rainfed agriculture is only 25%.

Among these 4 stations of E type of agroclimate, the highest value of AAR at 50% level is observed at Cuddapah (Figure 4.8). The least value of AAR is at Coimbatore. The longest growing period at this probability level is found to occur at Kurnool but it has the maximum number of breaks too. The shortest growing period among these stations is found to occur at Coimbatore. The earliest onset of growing period is found to occur at Kurnool and the latest at Coimbatore. The earliest cessation of growing period is again at Kurnool and the latest at Coimbatore.

No station has 75% chance of rainfed agriculture and at Bijapur, it is not possible even at 50% level.

At 25% level, too, highest AAR is observed at Cuddapah and the least at Coimbatore. But at this probability level, Coimbatore has the longest growing period. The shortest growing period is observed at Kurnool and Bijapur. The earliest commencement of growing period is observed at Coimbatore and the latest at Cuddapah. The earliest cessation is found to be at Bijapur and the latest at Coimbatore.

D Type :

This climatic type exists in the central sector of the study region around Bellary and Anantapur (Figure 4.5). The soil is mainly of medium black variety, but small areas of deep black soils, mixed red and black soils and red loams are also found. The different characteristics of these soils lead to the formation of different sub-divisions of the zone (Figure 4.6).

At 75 % level, the AAR of this zone is very low (Figure 4.1a). The growing period at this probability level is practically non existent (Figure 4.2a). At 50% level, the AAR values are around 10 cm (Figure 4.1b) and the growing period varies between 5 and 10 weeks (Figure 4.3a). At 25% level the AAR of this zone (Figure 4.1c) shows values around 100 cm and the growing period ranges from 25-30 weeks (Figure 4.4a).

Crop Potential at individual stations:

Table 4.8 gives the summary of the results for the individual stations of D type of agroclimate.

Station	Prob. lev. (%)	No. of weeks with MAI ≥0.3	≥0.5	≥0.7	≥0.9	AAR (cm)	Growing period (weeks)		No. of breaks
ANT	25	26	21	16	9	86	20-48	(29)	3
	50	5	2	1	1	10	38-43	(6)	1
	75	1	-	-	-	1	-	-	-
	95	-	-	-	-	-	-	-	-
BLY	25	30	23	18	14	99	17-46	(30)	-
	50	5	3	1	1	10	38-42	(5)	-
	75	-	-	-	-	-	-	-	-
	95	-	-	-	-	-	-	-	-

Table 4.8. Agroclimatic status at different probability levels for D type stations

Anantapur:

Medium black, mixed red and black and red loam soils are found at Anantapur. From the Figure 4.14a showing the MAI variations of this place, it can be seen that at 50% level, MAI becomes greater than 0.3 from 38th week to 43rd week (mid-September to last week of October) enabling crop growth during 5 weeks with one break (42nd week). During this 5-week period, MAI is greater than 0.9 only for 1 week and AAR is only 10 cm. Hence it is clear that under rainfed conditions at this probability level, single cropping of short duration varieties of low water demand is possible.

At 75% level there is no chance of successful agriculture.

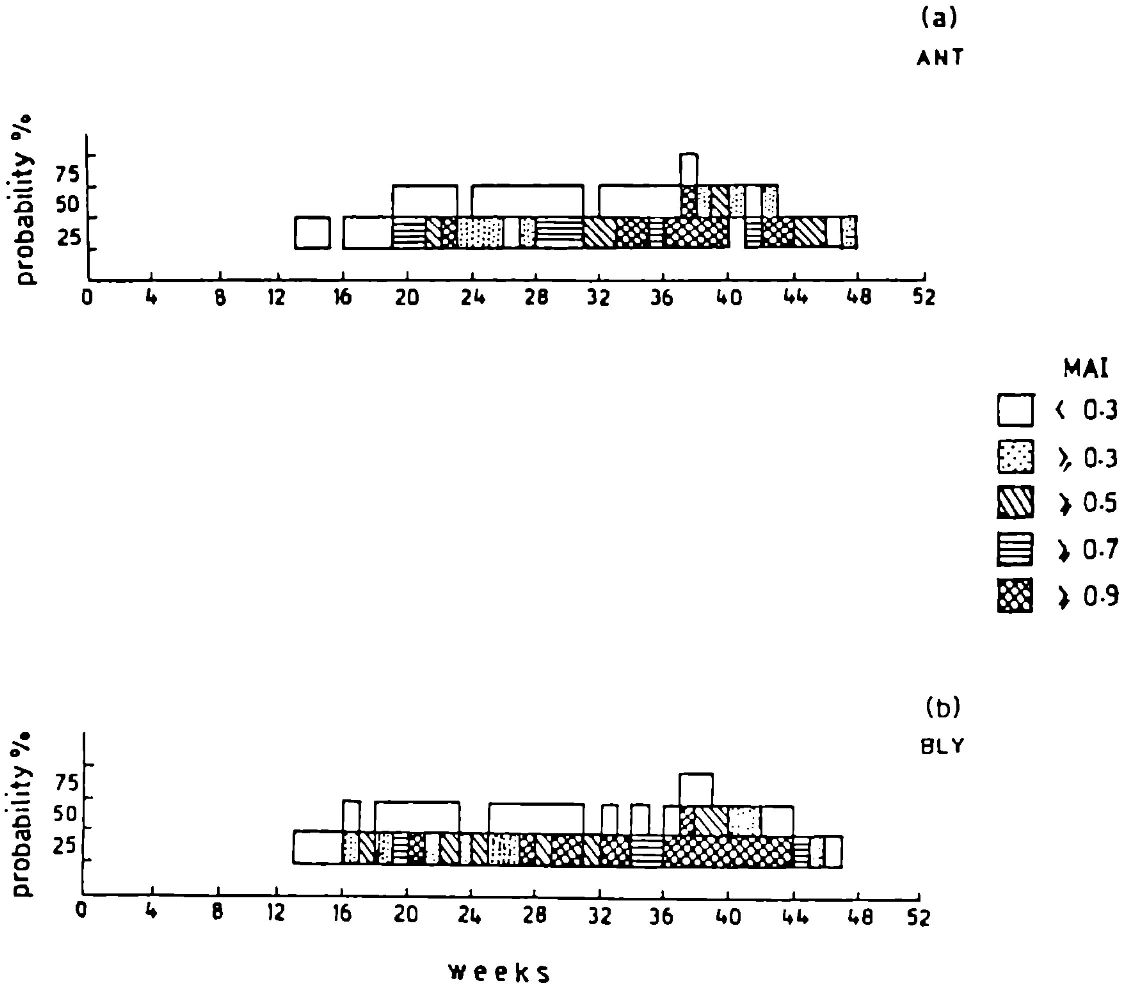


Figure 4.14 Magnitude and duration of MAI at different probability levels for stations of D type agroclimate

At 25% level, MAI shows values exceeding 0.3 from 20th to 48th week (mid-May to first week of November) with 3 breaks (27th 41st and 47th weeks) in between and with wide fluctuations too. Only this level has high values of MAI and thus high water demanding long duration crops have only a 25% chance of success under rainfed conditions. But care has to be taken about the moisture fluctuations at this low probability level too.

Bellary:

Generally, medium black, mixed red and black varieties of soils are found at this place. At this station at 50% level (Figure 4.14b) MAI is greater than 0.3 from 38th to 42nd week (mid-September to last week of October) giving a growing period of 5 weeks without any break. But MAI values are greater than 0.9 only during 1 week and AAR is only 10 cm indicating that under rainfed conditions, only a short duration crop having low water demand can be successfully cultivated at this probability.

At 75% probability level no chances of rainfed agriculture.

At 25% level, MAI values exceed 0.3 from 17th to 46th week (last week of April to mid-November) without any break, but it shows fluctuations. Taking care of this fluctuations, high water demanding crops can be cultivated with 25% probability of success under rainfed conditions.

Among these two stations in the D type of agroclimate, Bellary has higher AAR at 50% level (Figure 4.8). The growing period is longer at Anantapur, but it experiences one week of water stress within this period. At both these stations, the growing period at this probability level begins in the 38th week.

At 25% level, Bellary has higher AAR and longer growing period. At this probability too the maximum number of breaks are observed at Anantapur. In this case, the earliest commencement of growing period occurs at Bellary and the earliest cessation is also observed at this station.

It can be seen from Figure 4.8 that for the most arid type D, AAR is only around 10 cm while for the most humid type J it is about 300 cm. The growing period is around 5 weeks among the D type stations but is more than 30 weeks among J type stations. The gradual gradation in both these parameters are very much visual among the agroclimatic groups as evident from the figure. Similarly the probability of successful rainfed agriculture also decreases from J type to D type agroclimates.

Any discussion about the crop growth potential of a region using MAI values cannot be complete without a complementary study of the wet and dry spells in rainfall patterns. Results from such a study are discussed in the next Chapter.

CHAPTER 5

ASSESSMENT OF WET AND DRY SPELLS AND EFFICIENCY OF GROWING PERIODS

Rainfall over the South Indian region, being monsoonal in nature, occurs in definite spells lasting for a few days followed by brief dry spells. Studies on the sequence of wet and dry spells are important to understand the dependability or otherwise of the rainfall. If the probabilities of the wet spells and their persistence are high during the growing period, the period could be deemed to be very favourable: crops with high water demand can be grown. If on the other hand, the probabilities are low during the cropping season, crops with low water demand can be successfully grown. Hence the analysis presented below would *supplement the results obtained in the previous Chapter.

The weekly rainfall data of all the stations discussed in previous Chapter for the same period have been analysed using Markov chain model to estimate probability of a wet week [P(W)] and probability of a wet week followed by a wet week [P(WW)]. Results have been discussed below for individual stations in each agroclimatic zones separately.

J type:

The important characteristics of probability curves [P(W) and P(WW)] for the selected stations of J type of agroclimate are discussed here.

The results for Trivandrum are depicted in Figure 5.1a. The nature of increments in P(W) indicates an abrupt beginning of the growing period. Within the growing period, a fairly dependable commencement of kharif cropping season is observed around mid-May. During the kharif and rabi seasons, both the probabilities rise above 75%, but never reach 100%. The withdrawal of monsoon is associated with an erratic nature of these probabilities. Again, during the first week of September, these probabilities show increments associated with post-monsoonal activities. The values of this probability are not altogether zero at any time of the year. The probability of occurrence of wet weeks during January to March shows a maximum value of 35% (8th week).

P(WW) values show that some random weeks during this period have a 35% probability of persistence if they are wet. It is evident from this analysis that at Trivandrum the growing period is from the last week of March to last week of November (13th to 47th week), including the three rainfall seasons. During the period August to mid-October, these probability values are low (below 75%) and among the three parts of the growing period, corresponding to the three rainfall seasons, the monsoon cropping season is the most favourable and of longest duration. For this place, one could select drought-sensitive crops during kharif

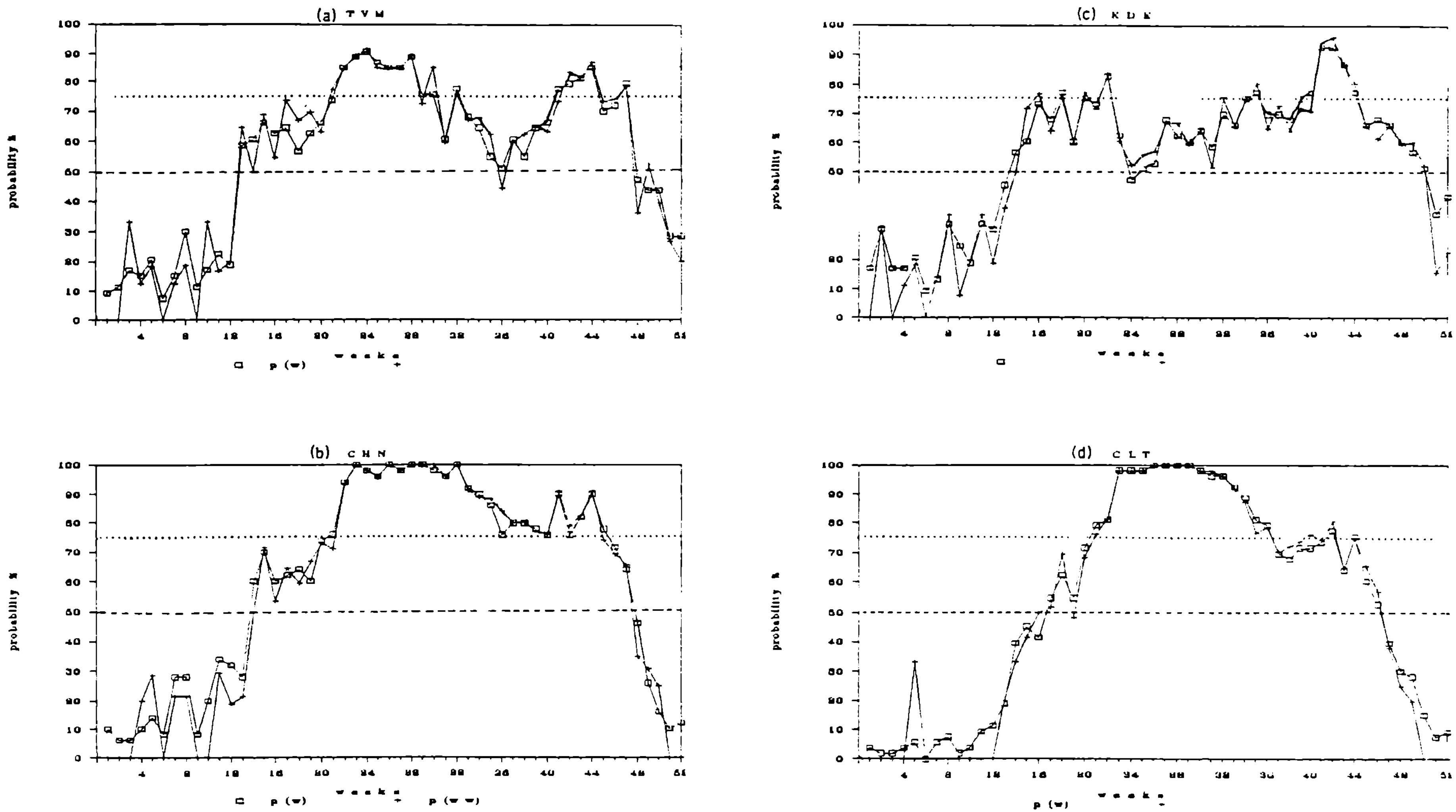
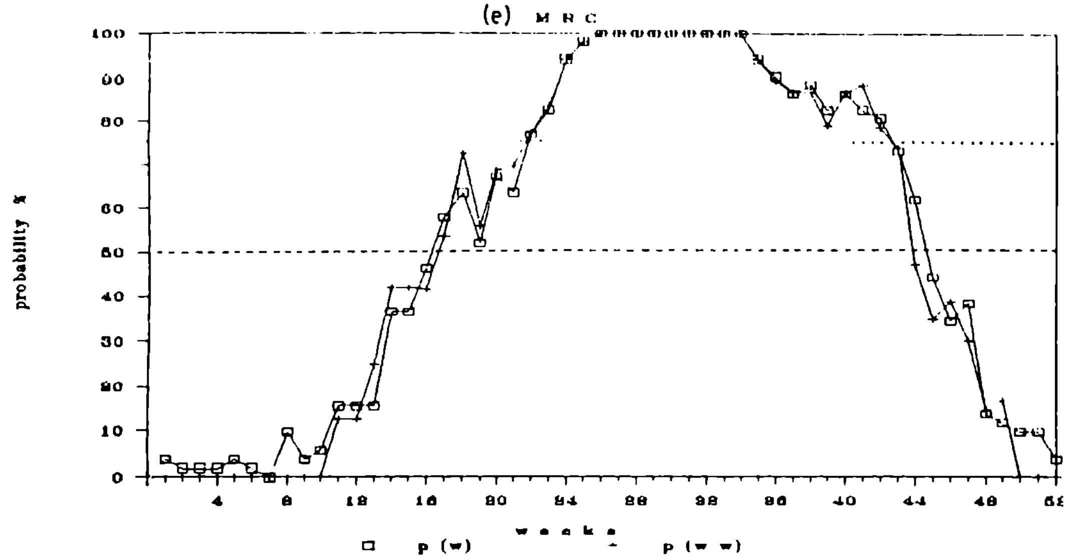


Figure 5.1 Patterns of probability curves in J type agroclimatic region



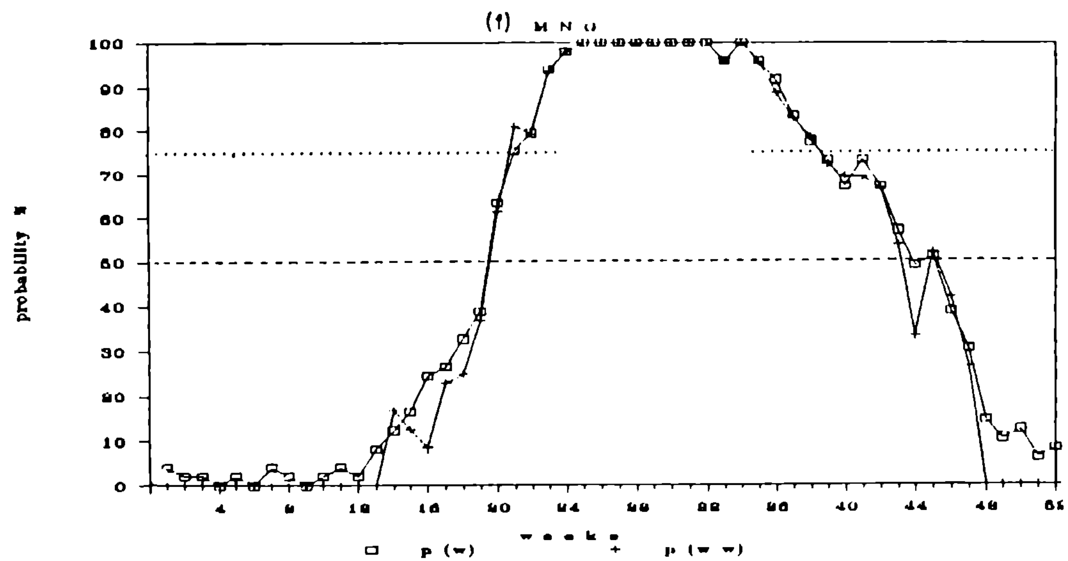


Figure 5.1 (contd.) Patterns of probability curves in J type agroclimatic region

season, but care should be taken so that the crop phases sensitive to moisture aberrations do not occur during the period August to mid-October.

At Cochin (Figure 5.1b), the main difference in the probability pattern from that at Trivandrum is that the kharif season is longer and also the reduction in probabilities found at Trivandrum during August to October is not that significant here. The growing period at Cochin is found to be distributed between the 14th and 47th week (first week of April to mid-November). Here, too, a sudden increase in wetness probabilities is observed at the beginning of the growing period. Again, during the monsoon season, these probabilities increase steadily denoting a dependable commencement of kharif cropping season. During the pre-monsoon part of the growing period, the wetness probabilities are less than 75%, but during the entire monsoon season, these probabilities remain close to 100%. The withdrawal of monsoon is associated with a steady decrease in these probabilities. The P(W) and P(WW) values indicate that the rains occur during December to March months in about 3 out of 10 years and some random weeks in this period, if wet, have about 30% chance to continue to be so over the next two weeks. For this station, too, the kharif cropping season is the longest and most reliable. Obviously, one could select a drought-sensitive crop for this station, especially in the kharif season.

The pattern of probability distribution for Kodaikanal is entirely different from that of the other stations of the same agroclimatic group (Figure 5.1c). This station has its growing period between 14th and 50th week (first week of April to second week of December). The values of P(W) indicates that this station has a dependable commencement of the growing season. During the pre-monsoon season, both P(W) and P(WW) rise upto 75% but they are of widely fluctuating nature. One significant point is that, during the monsoon season, these probabilities get reduced and also show large fluctuations throughout. There is an increase again in these probabilities to about 75% associated with post-monsoonal activity. Rains occur between January and March too, but only on an average of about in 3 out of 10 years with a persistency around 35%. It becomes quite obvious that, for this station pre-monsoon and post-monsoon cropping seasons will be more efficient than the monsoon cropping period. In general, crops which are sensitive to moisture variations should not be selected for this region.

The patterns of the probability curves are of similar nature for Calicut and Mercara. At Calicut (Figure 5.1d), the growing period is from 17th to 46th week (last week of April to mid-November) and from 17th to 44th week (last week of April to first week of November) at Mercara (Figure 5.1e). The steady increases in P(W) indicate that at both these stations, the commencement of growing period is quite dependable. Increases in these probabilities associated with pre-monsoon and post-monsoon activities are observed only as very small peaks. But at both the places, the kharif season commencement is significant and

P(W) and P(WW) remain to be 100% for a fairly long period without fluctuations; these probabilities remain high for a longer time at Mercara. The nature of P(WW) curves implies that once the post-monsoon rainfall decreases, it has a tendency to withdraw completely; no persistency is observed, except in the 5th week at Calicut (first week of February). No doubt the kharif season will be an efficient part of the crop growing period at these stations. Raising drought-sensitive crops will not face any risk at these stations especially in the kharif season.

At Mangalore (Figure 5.1f), the picture is slightly different in the sense that it does not have any marked peak in these probabilities associated with the pre-monsoon rainfall. The growing period is between 20th and 45th week (mid-May to mid-November) and its commencement is dependable. During the pre-monsoon season persistence of wet weeks is low but during kharif season, the wetness probabilities [P(W) and P(WW)] remain 100% for a long period without fluctuations. The decrease of post-monsoon rainfall also is steady; once the monsoon rains withdraw, there is a high probability for the season being dry in the post-monsoon period. Before and after the growing period, tendency of rainfall to occur is very low. A drought-sensitive crop will be suitable at this place under rainfed conditions.

The results for the stations discussed above are summarised in Table 5.1.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
TVM	13th - 47th	kharif	nil	dependable
CHN	14th - 47th	kharif	nil	dependable
KDK	14th - 50th	rabi	nil	dependable
CLT	17th - 46th	kharif	nil	dependable
MRC	17th - 47th	kharif	nil	dependable
MNG	24th 45th	kharif	nil	dependable

Table 5.1 Characteristics of growing periods at stations of J type agroclimate

I Type:

For the I type of agroclimatic stations, generally 5 varieties of probability patterns [P(W) and P(WW)] exist. Cuddalore and Madras are more or less of the same pattern. Similarly, Bangalore and Mysore, Khammam and Masulipatnam, Karwar and Mahabaleshwar show similar patterns while Belgaum exhibits a different one.

At Cuddalore (Figure 5.2a), the growing period commences from 29th week and ceases during 50th week (mid-July to mid-December), whereas it is between 25th and 50th week (mid-June to mid-December) at Madras. The steady increase in P(W) implies that the commencement of the growing period is dependable at Madras. At Cuddalore, right at the beginning of the growing period, in the 31st week (first week of August) there is a probability for dryness to occur in 6 out of 10 years. Again, in the 37th week (mid-September), there is a likelihood of dryness in 5 out of 10 years and the persistence probability also becomes low for the next few weeks. In general, the probability curves

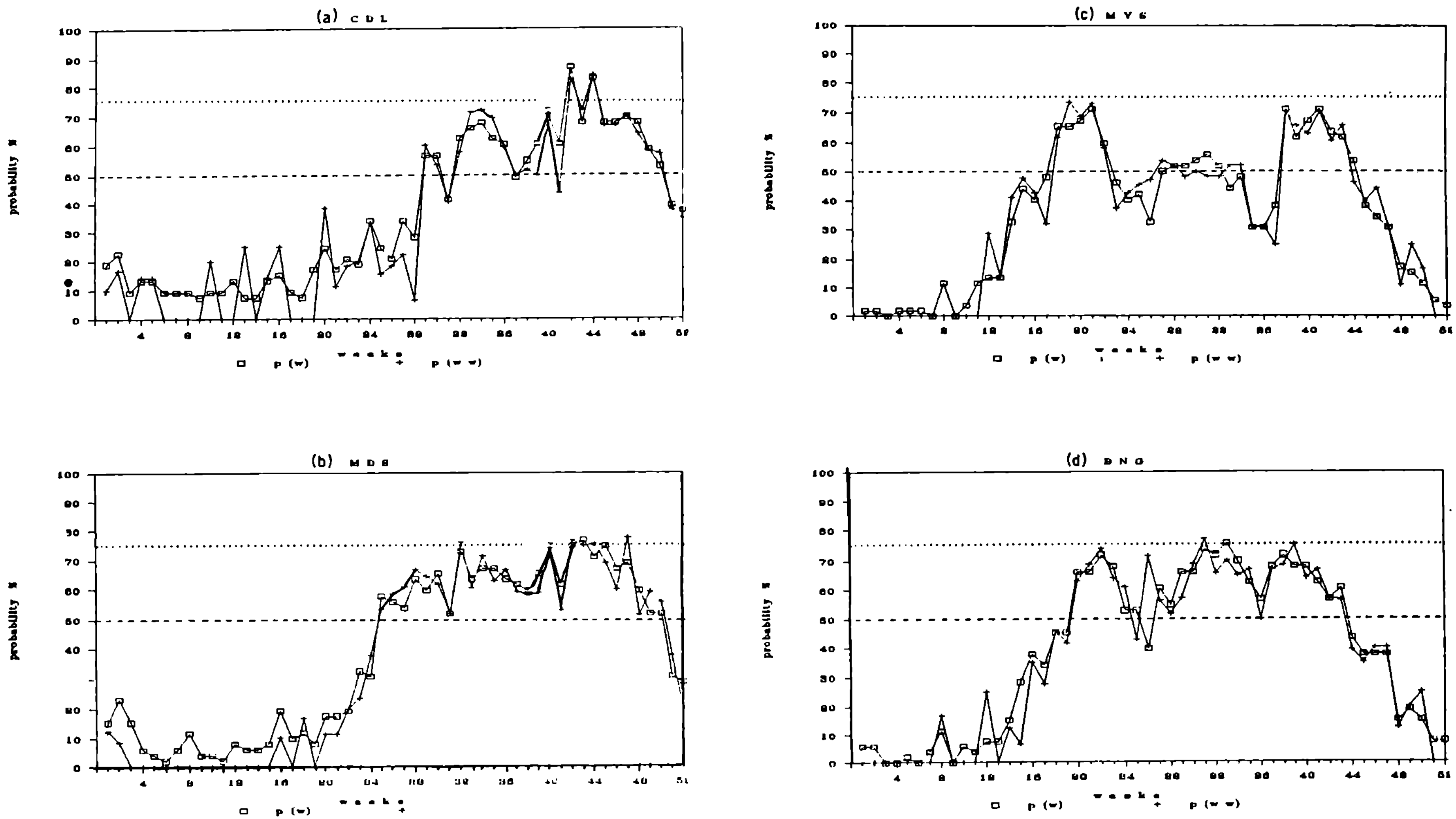


Figure 5.2 Patterns of probability curves in I type agroclimatic region

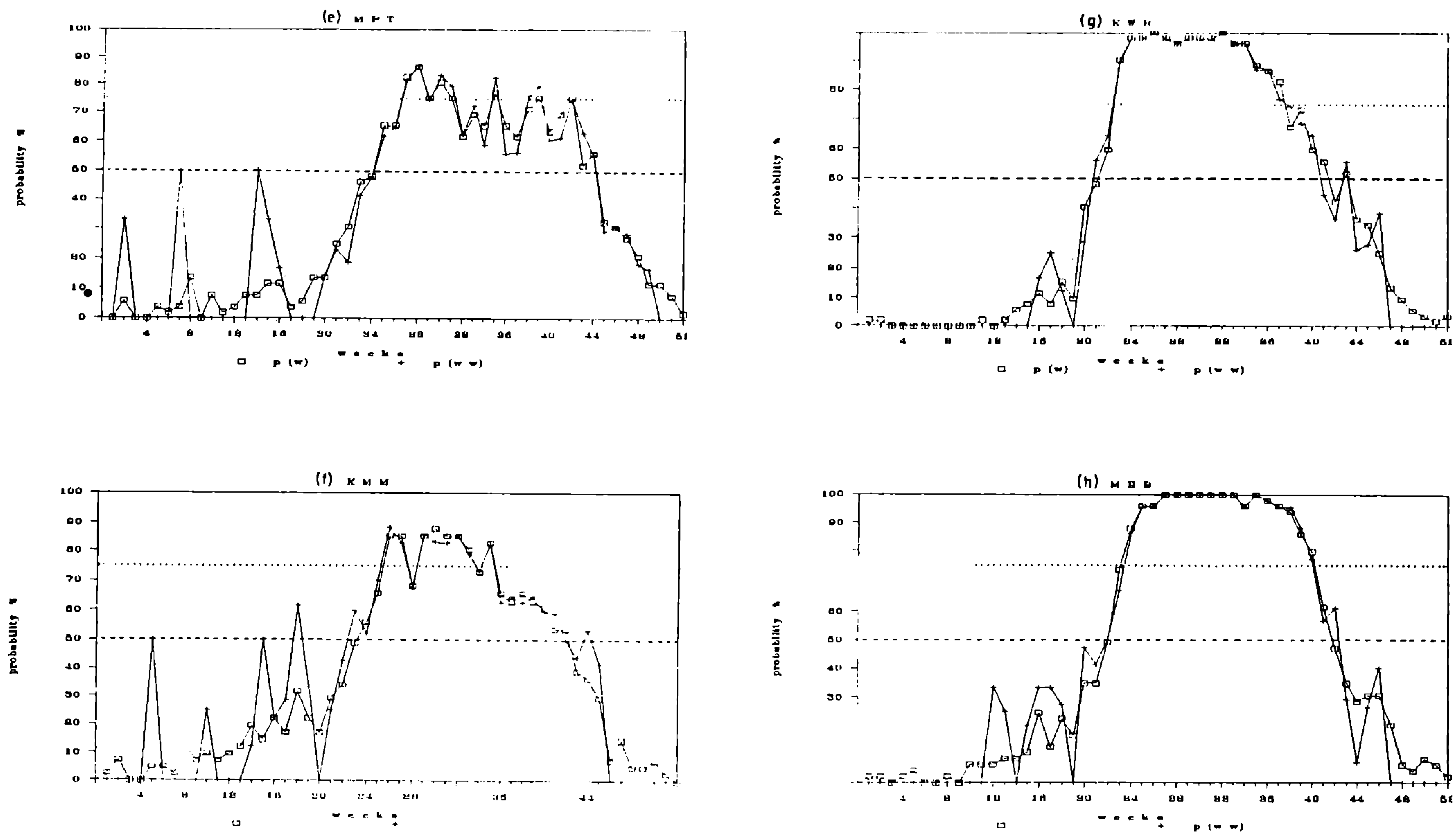


Figure 5.2 (contd.) Patterns of probability curves in I type agroclimatic region

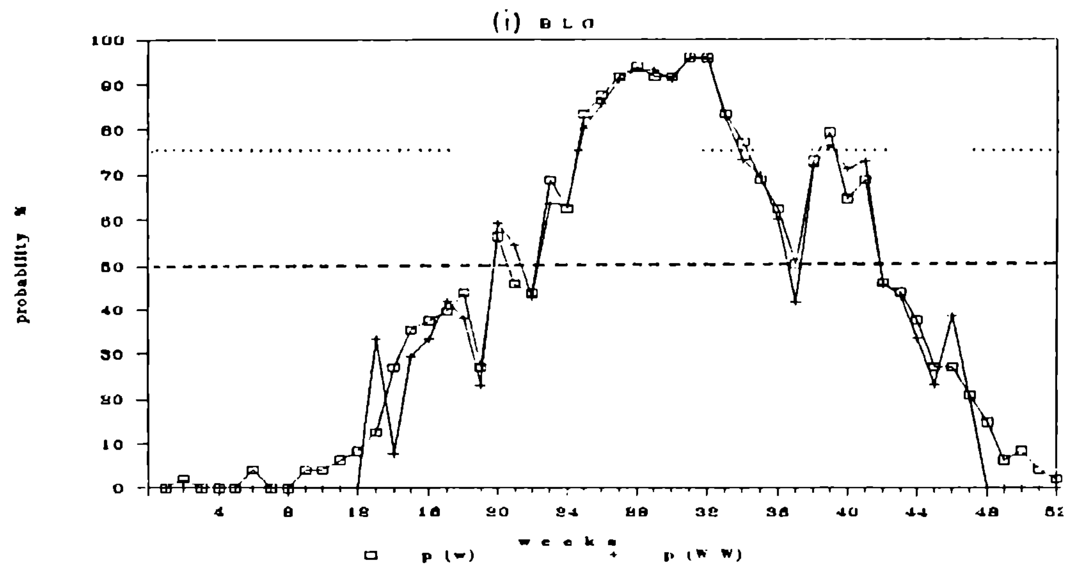


Figure 5.2 (contd.) Patterns of probability curves in I type agroclimatic region

are of erratic nature and the values cross 75% only during a couple of dispersed weeks. The withdrawal of rains is steady and once it takes place, there is the risk for this season to be completely dry. Before the onset of growing period, some randomly distributed weeks have high persistence of wetness and the maximum is 40% in the 20th week (mid-May). Since the probabilities are low, whole of September and first half of October are not suitable for cropping. Only crops having moderate water requirements and whose maturity phases are not sensitive to moisture variations can be suggested for this place.

At Madras (Figure 5.2b), during the growing period, the probability curves are more or less of orderly nature except during a few weeks where they show some sharp drops: the probabilities never cross 75% at this station. There is a chance for the 31st week (first week of August) to be dry in approximately 5 out of 10 years. The withdrawal of rains is steady and the season becomes dry altogether. The chances of rain to occur during pre-monsoon months and the beginning of monsoon are very low (less than 20%); the persistency of wet weeks, if any, is also very low. The entire growing period is uniformly dependable, except at one or two weeks when the chances of dry weeks are more. Only crops having moderate water requirements can be selected for this station too.

Mysore and Bangalore have P(W) and P(WW) curves (Figures 5.2c and 5.2d) of similar patterns except that at Mysore, the peak in the probabilities associated with the monsoonal activity is not conspicuous (values are below the threshold value of 50%): at both the places, these probabilities never exceed 75%. P(W) and P(WW) values indicate that the commencement of growing period is more dependable at Bangalore than at Mysore, where the growing period is not a continuous one. The growing period at Mysore is between 17th week and 44th week (last week of April to first week of November), and within this period from 23rd to 26th week (whole of June), P(W) is below the threshold value of 50% indicating more than 50% probability for dryness to occur (for 26th week it is nearly 70%). Similarly, from 35th to 37th week (last week of August to mid September) probability of dryness is 70%. The withdrawal of rainfall is steady and the nature of P(WW) indicates that if there occurs a wet week in November and December, there is a tendency for further wetness. Probability of wetness in January and February are negligible, but if a wet week occurs in mid-March it has a tendency to continue over to the next week. It is felt that at Mysore rainfed agriculture is risky and only crops with moderate water requirement can be suggested. Cropping during pre-monsoon season and during rabi season will be comparatively efficient at this place.

At Bangalore, crop cultivation under rainfed conditions is possible for more number of weeks than at Mysore from 20th to 43rd week (mid-May to mid-October). During the 26th week, there is a 60% chance of dryness, but P(WW) for this week indicates that if it is wet it continues to be so in the next week in 7 out of 10 years. However, entire June and first week of July have low values of wetness probabilities. As in the case of Mysore, Bangalore also experiences low probability of wetness during the 36th week (first week of September). The withdrawal of rainfall is not altogether abrupt during the post-monsoon season; values of P(WW) show that if it rains during the 50th week (mid-December), there is a 30% chance for it to continue over to the next week. Chances of wet weeks in January and February are negligible but if they occur, some weeks have nearly 30% probability of persistence. Here, the last part of the monsoon season and the post-monsoon season are found to be favourable for cropping but crops with moderate water requirements only can be grown here. Care should be taken so that the crop phases sensitive to moisture variations do not occur between June and mid-July.

The difference in patterns of P(W) and P(WW) for Masulipatnam and Khammam (Figures 5.2e and 5.2f) is that at Masulipatnam the growing period is found to comprise of more weeks and at Khammam higher probability of wetness is observed. At both the stations, the increments in P(W) associated with the commencement of growing period is fairly dependable and are never less than 50%.

At Masulipatnam, the growing period is spread between 25th and 44th week (mid-June to first week of November). Even though the wetness probabilities are of erratic nature, during 28th week (second week of July) these probability values rise above 75%.

The cessation of rainfall after the monsoon season is not that abrupt at this station. The probability of wet weeks during January to April is very low (less than 20%). But once it rains a few dispersed weeks have a 50% chance of persistence during the following week. The efficiency of the entire growing period is uniform, apart from a slight increment in wetness during the period from second half of June to first half of July. Crops having moderate water requirements and whose maturity phases are not moisture-sensitive can be grown here.

At Khammam, the growing period is from 23rd week to 42nd week (first week of June to mid-october). The cessation of rains after mid-October occurs more rapidly at this place, but during the 44th week, there is a 50% probability that it extends from the normal date of withdrawal and continues over to the next week. Probability of rains during the months November to May is very low, but during these months some weeks have a tendency to continue to be so in the following weeks in 5 to 6 years out of 10. The first half of the growing period (kharif cropping) is more efficient: drought-sensitive crops can be grown during this period.

Karwar and Mahabaleshwar are the stations among this agroclimatic type for which, during the growing period, the wetness probabilities reach 100% value (Figures 5.2g and 5.2h). Both these stations have a fairly dependable commencement of growing period and no fluctuations are observed in the probability values during this period. For Mahabaleshwar, the withdrawal of rains is more abrupt than at Karwar.

At Karwar, the growing period begins in the 22nd week (first week of June) and ends around 41st week (mid-October). Chances of wetness during December to mid-May are very low. The entire growing period is equally efficient (kharif and rabi) and drought-sensitive crops can be grown here without any risk.

Mahabaleshwar, too has, its growing period between first week of June and mid-October. At this station, a few weeks in March to April and in November if become wet, have a 30% probability to continue over in the following weeks. Here, too, both kharif and rabi cropping seasons are efficient and drought-sensitive crops can be suggested here too.

At Belgaum (Figure 5.2i), the growing period is found to be between mid-May and mid-October but its commencement is not dependable. Just after the beginning of the growing period (21st or 22nd week), P(W) becomes less than the threshold value and about 60% probability exists for these weeks to be dry. Probabilities of wet weeks in June and July are above 75% but during August, probabilities are very low. Chances of wet weeks during December to April are again very low. A drought-sensitive crop can be cultivated during the first half of the growing period (kharif cropping) which is more efficient than the second half.

The summary of results for all the stations discussed under I type agroclimate are presented in Table 5.2.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
CDL	29th - 50th	rabi	31st	not dependable
MDS	25th - 50th	rabi	nil	dependable
MYS	17th - 44th	rabi	23rd - 26th, 35th - 37th	not dependable
BNG	20th - 43rd	rabi	26th	not dependable
MPT	25th - 40th	kharif	nil	dependable
KMM	23rd - 42nd	kharif	nil	dependable
KWR	22nd - 41st	kharif	nil	dependable
MHB	23rd - 41st	kharif	nil	dependable
BLG	20th - 41st	kharif	21st - 22nd	not dependable

Table 5.2. Characteristics of growing periods at stations of I type agroclimate

H Type:

All the selected stations of H type agroclimate show different distribution patterns for P(W) and P(WW).

At Salem (Figure 5.3a), the growing period can be considered to begin from the 3rd week of May and end during first week of November (20th to 45th week). From the values of P(W) and P(WW), it can be seen clearly that the commencement of growing period for this station is not dependable. During the first half of the growing period, these probabilities are of more erratic nature and fluctuate around 50%; in the 23rd week (first week of June) probability of dryness is 55%. The withdrawal of rainfall after the end of monsoon season is steady and the probability of wet weeks during December to April is very low. The rabi cropping season is found to be more efficient than kharif and during

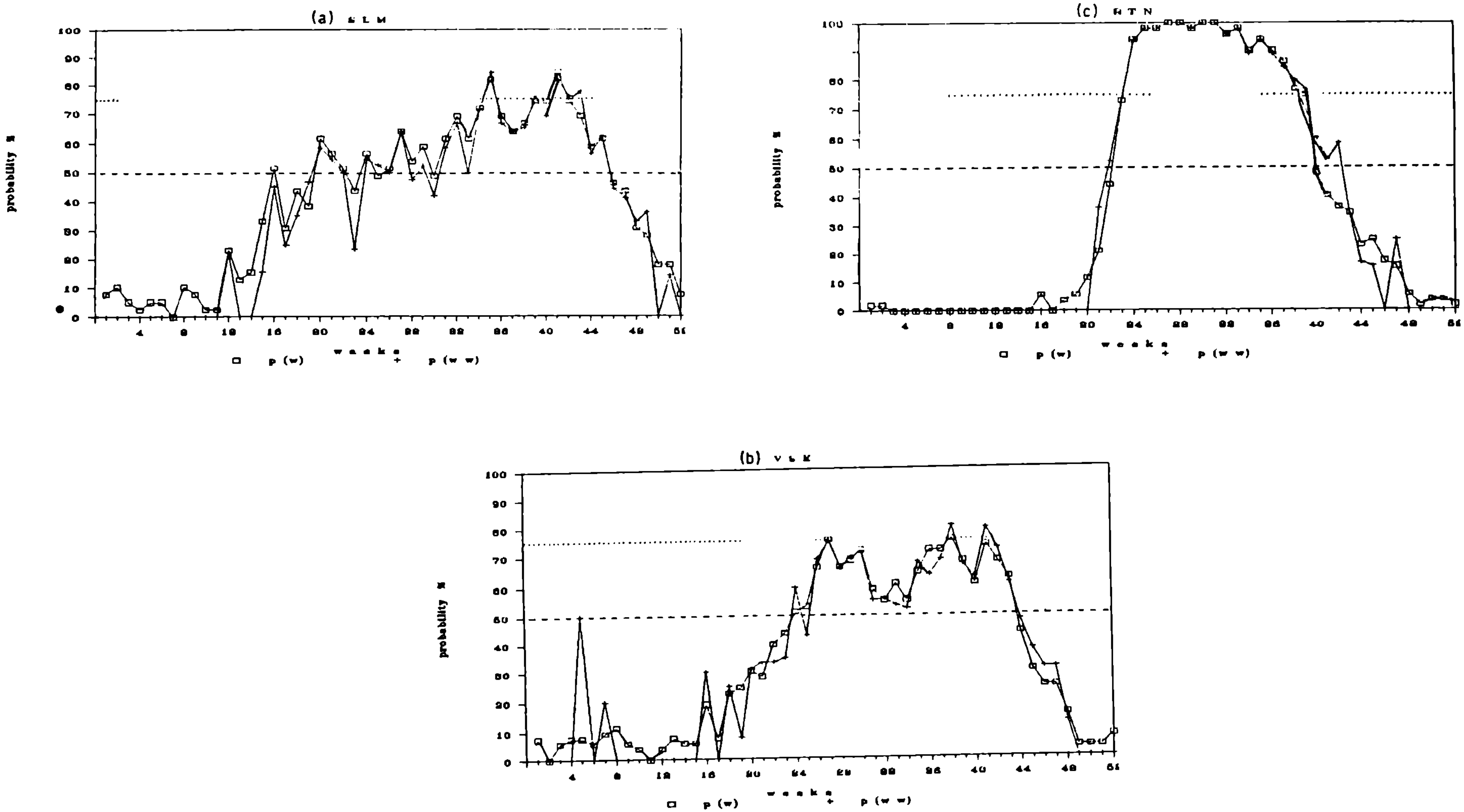


Figure 5.3 Patterns of probability curves in H type agroclimatic region

kharif season, a drought-hardy variety can be grown. Generally, crops having low water demand will be suitable for this place.

At Vishakhapatnam (Figure 5.3b) cultivation under rainfed conditions will be possible during 24th to 43rd week (mid-June to last week of October). At this place, too, the commencement of the growing period is not dependable and during this period, P(W) never crosses 75%. During the growing period, these probabilities fluctuate widely and in August low values are observed. During the withdrawal of rainfall, P(W) decreases steadily and the probabilities of wet weeks during December to April is very low (less than 20%). But if it becomes wet during 5th week, the wetness will continue to the following week also on 50% of occasions. It is clear that the rabi season is more efficient than kharif at this place; it should be noted while selecting crops that, the moisture-sensitive phases should not occur in August. Crops with moderate water requirements alone can be selected for this place.

The pattern of P(W) and P(WW) for Ratnagiri (Figure 5.3c) are entirely different from that of the other two stations of the same category of agroclimate. The growing period at this station is between June and September (23rd to 40th week) and most of the weeks during this period have P(W) of 100%. Ratnagiri experiences a steady increase in probabilities of wet weeks indicating a fairly dependable commencement of growing period and a gradual decrease in P(W) associated with the withdrawal of rainfall during the post-monsoon phase. If the

42nd week (mid-October) becomes wet, there is about 55% probability for the next week also to be wet. One interesting point is that probability of a wet week is almost nil from December to mid-May. At this station, therefore, only the kharif season is suitable for cropping; a drought- sensitive crop can be grown without any risk.

The summary of results for the stations discussed above are presented in Table 5.3.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
SLM	20th - 45th	rabi	23rd	not dependable
RTN	23rd - 40th	kharif	nil	dependable
VSK	24th - 43rd	rabi	nil	not dependable

Table 5.3. Characteristics of growing periods at stations of H type agroclimate

G Type:

Generally, the P(W) and P(WW) distribution pattern for stations of G type agroclimatic region fall under 4 varieties. Tiruchirappalli, Vellore and Nellore have similar patterns. Hyderabad, Gulbarga, Pune and Aurangabad are of another type, Hanamkonda and Nizamabad are again of similar type while Bombay has a fourth type of pattern.

At Tiruchirappalli (Figure 5.4a), crop-growing under rainfed conditions is possible between 35th and 47th week (last week of August to mid-November). However, during this period only for a couple of weeks P(W) and P(WW) values reach 75%. The

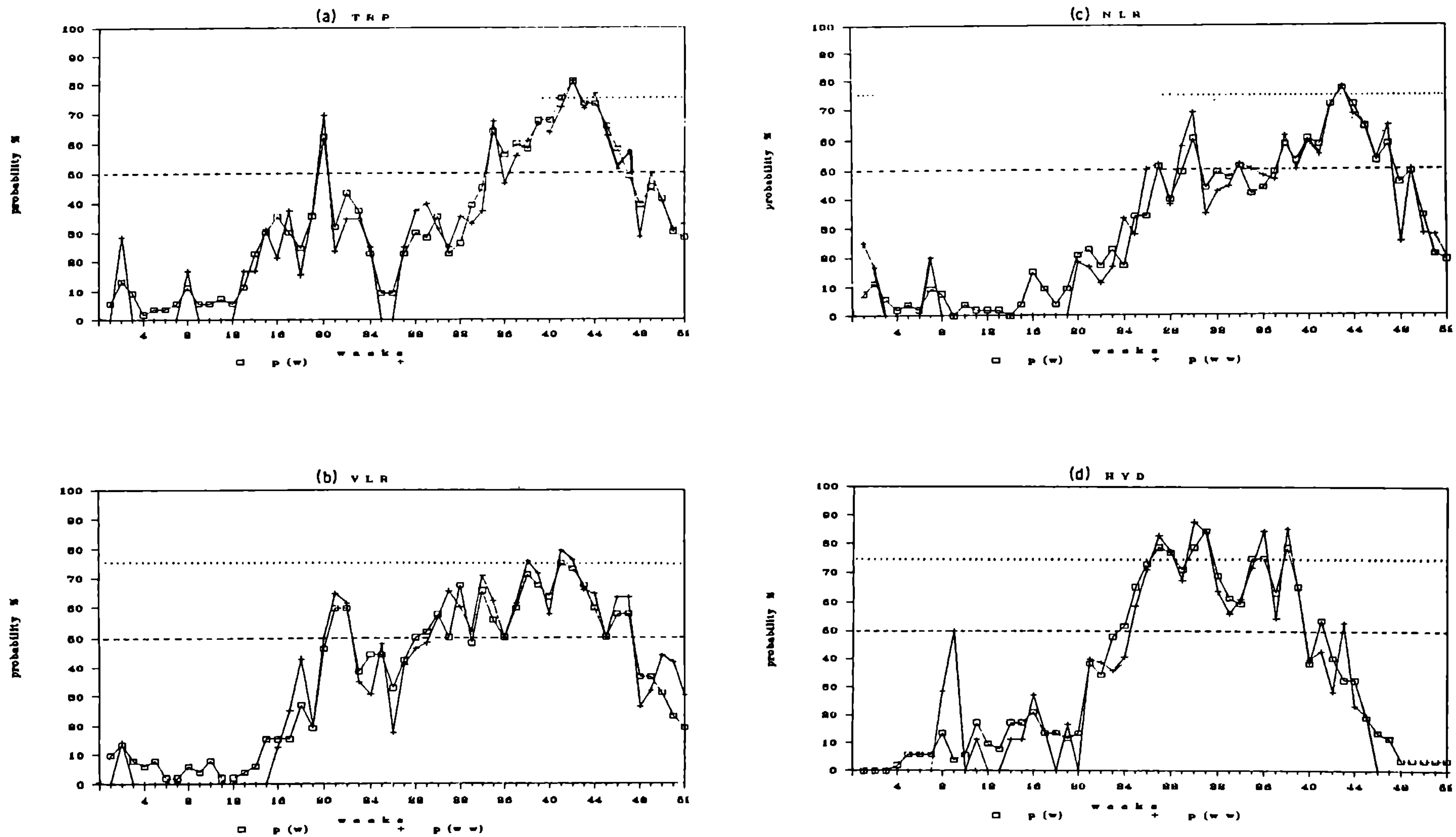


Figure 5.4 Patterns of probability curves in G type agroclimatic region

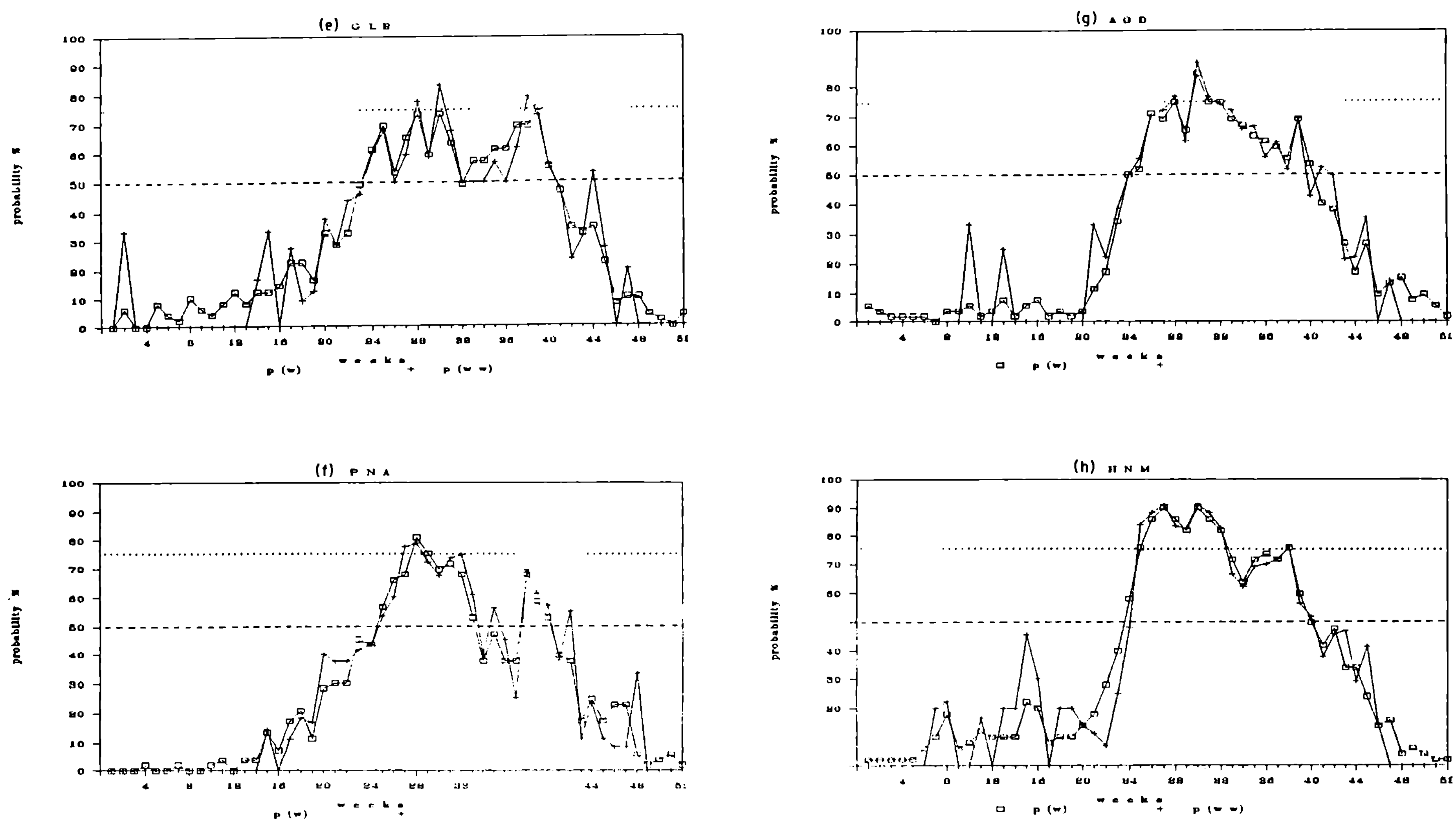


Figure 5.4 (contd.) Patterns of probability curves in G type agroclimatic region

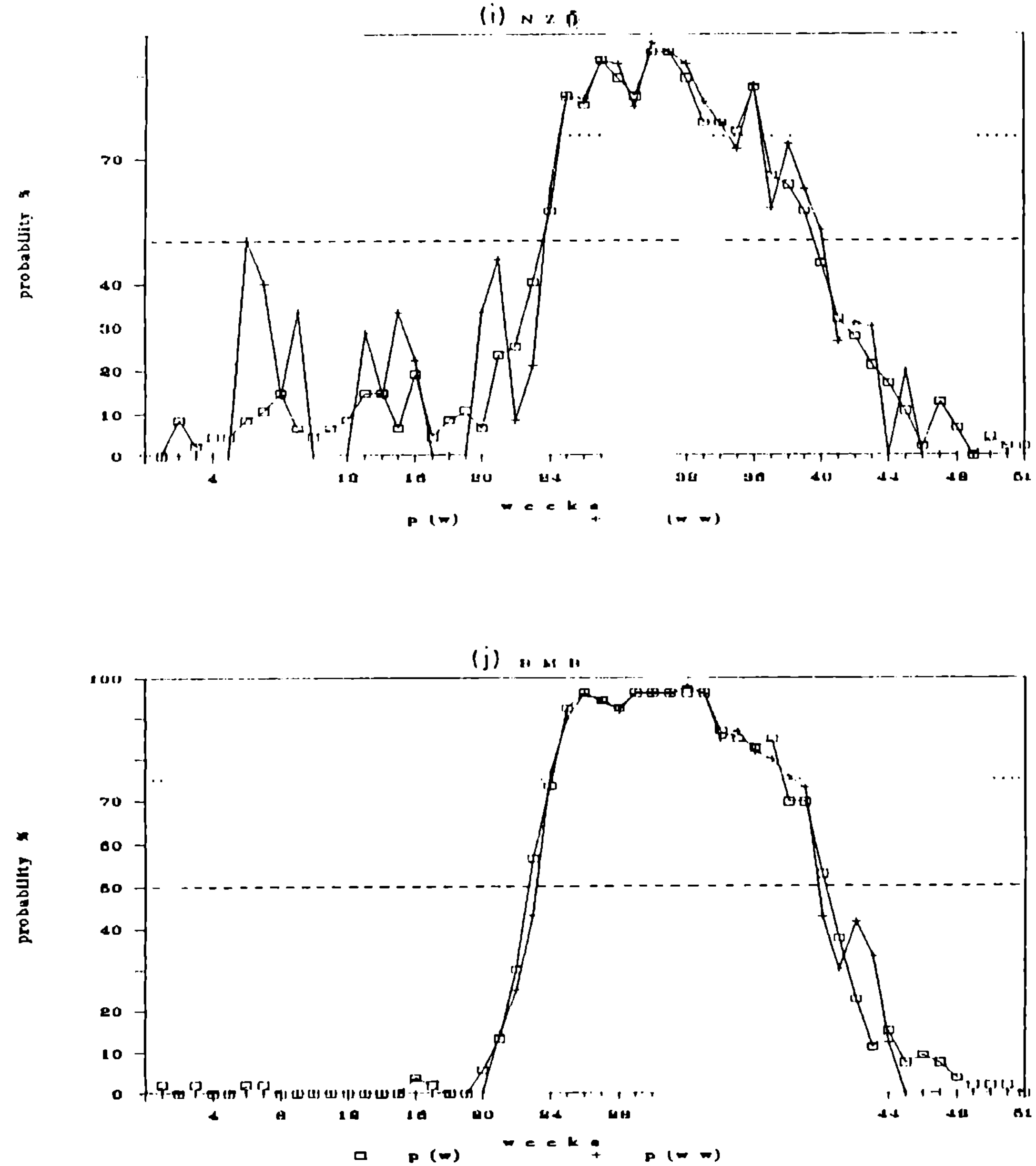


Figure 5.4 (contd.) Patterns of probability curves in G type agroclimatic region

reduction in probabilities of wet weeks during the withdrawal of rainfall is not sudden. The probability of wet weeks to occur in December is above 30% and from January to April it is less than 15%. But once it becomes wet, the 2nd week of January has a 30% probability to persist. A sharp dip in these probabilities is observed around 24th and 25th weeks (mid-June). At this place, only rabi cropping is possible: only a drought-resistant crop can be cultivated.

At Vellore (Figure 5.4b), rainfed cropping is possible between 28th and 47th week (mid-July to mid-November). Here, the increase in the probability of wet weeks in the beginning of the growing period is significant. The fluctuations in P(W) and P(WW) values are more during the growing season, though, during this period P(W) never crosses 75%. The reduction in probability of wet weeks is not that rapid during the post-monsoon season; P(WW) values during December indicate that the persistence of wet weeks in this month is nearly 45%. P(W) during January - March is very low while P(WW) is nil. Here, too, a dip in wetness probabilities is observed around 26th week. At this place, only rabi cropping with a drought-hardy variety will be possible.

Distribution pattern of P(W) and P(WW) for Nellore (Figure 5.4c) is similar to that at Tiruchirappalli and Vellore, except that at this station, the small peak in probabilities before the commencement of growing period is not observed. Here, the growing period is between last week of July and first week of November (30th week to 49th week) but during this period, the

31st week has 55% probability of dryness and for 35th and 36th week the probability of dryness is around 60%. At this station, the commencement of growing period is not characterised by a sharp increase in P(W) and P(WW). The probability of wet weeks during January to May is very low. At this station, too, the rabi season will have more efficiency for cropping than kharif. Crops requiring less moisture can only be suggested for this place.

At Hyderabad (Figure 5.4d), the cultivation under rainfed conditions is feasible from mid-June to mid-October (24th to 41st week). The increase in probability of wet weeks indicating the beginning of growing period is steady; similarly, the reduction in P(W) associated with the withdrawal of rainfall during post-monsoon phase is also steady. During the growing period, these probabilities fluctuate widely and cross 75% only during certain weeks. A sharp reduction in P(W) and P(WW) is observed between 1st and 3rd week of August and again around first week of September. During the 40th week, there is a 60% probability of dryness. But P(WW) indicates that if the 43rd week becomes wet it will have 50% probability of persistence in the next week. The probability of a wet week during November to mid-May is very low (less than 20%). P(WW) values indicate that during this period some randomly distributed weeks have nearly 50% persistence. At Hyderabad, kharif cropping will be suitable with crops having moderate water requirements, but moisture-sensitive phases should not occur during the first three weeks of August.

At Gulbarga (Figure 5.4e), the favourable period for cropping is from first week of June to first week of October (23rd to 40th week). The increments in P(W) associated with the commencement of growing period is steady except during some weeks but the reduction in P(W) during the withdrawal of rains is not that steady. During the entire growing period, P(W) never crosses 75% and between 31st and 36th weeks (entire August and first week of September), a noticeable reduction in P(W) occurs. From the P(WW) values, it is clear that during 33rd to 37th week the persistency of wet weeks is low. It is seen that if 44th week happens to be wet it will continue to be so in the next week on 50% of occasions. The probability of wet weeks during November to mid-April is very low, but some weeks have nearly 35% persistency. At this station both kharif and rabi cropping seasons are not that favourable though comparatively kharif season can be considered to be better for cropping. A moderate water demanding crop whose maturity phases are not sensitive to variations in moisture can be suggested for this place.

Crop growing under rainfed conditions is possible at Pune (Figure 5.4f) between 24th and 40th week (mid-June to first week of October). The increase in P(W) announcing the commencement of growing season is not steady and the reduction of P(W) values during the withdrawal of rainfall is also not abrupt. During the growing period, P(W) increases to above 75% only during mid-July but between 34th to 37th week (3rd week of August to mid-September), there is a 60% probability for dryness, roughly in 6 out of 10 years. P(WW) indicates that if the 42nd week (mid-October) becomes wet, the probability of persistence is nearly 55%. Probability of a wet week during the period from last week of November to mid-April is very low. At Pune, the kharif cropping season will be favourable as the growing period. Care should be taken while selecting crop varieties so that moisture-sensitive phases should not occur during the period mid-August to mid-September, and the crop should be of moderate water requirement.

One difference in pattern of probability curves for Aurangabad (Figure 5.4g) is that the dip found in P(W) and P(WW) values for Hyderabad, Gulbarga and Pune in August - September months is not significant at this place. The growing period is found to be during the same period as that at Pune. Here, the increase in probability of wet weeks in relation to the commencement of growing period is fairly dependable but the reduction associated with the withdrawal of monsoon rainfall is not altogether abrupt. But P(WW) values during 41st and 42nd week indicate that if these weeks are wet, the following weeks could be wet during half of the years. During the growing period wide fluctuations in these probabilities are not observed but P(W) exceeds 75% only during one week. The probability of a wet week during November to mid-June is very low. It is clear that at Aurangabad too kharif season will be efficient and crops having moderate water requirement can be grown here successfully.

At Hanamkonda and Nizamabad (Figures 5.4h and 5.4i), the values of P(W) and P(WW) rise above 75% during the growing period. A fairly dependable increase in probability of wet weeks is observed in connection with the beginning of growing period and the reduction in P(W) during the withdrawal of rainfall is also steady. The probability of wet weeks during December to January is very low. At both these stations, randomly distributed weeks in the period February to May have high persistencies of wetness (40-45%). At both the stations, a reduction is observed in P(W) and P(WW) during August.

The growing period is found to be between mid-June and first week of October (24th to 40th week) at Hanamkonda. It is seen that at Hanamkonda, too, the kharif season is more efficient than rabi season. More over during kharif season crops with high water demand can be grown.

At Nizamabad, depending on the rainfall, crop growing is feasible only during mid-June to last week of August (24th to 39th week). This station also has efficient cropping during kharif season and crops with high water demand can be grown too.

At Bombay (Figure 5.4j), the picture is somewhat different in the sense that the probability of wetness and its persistence are absolutely nil during December to mid-May and during the growing period fluctuations in these probabilities are negligible. Here the growing period is between 23rd and 40th week (June to first week of October) and a considerable number of weeks during this period have P(W) nearly 100%. Increase in P(W) declaring the commencement of growing period is very dependable and the reduction during withdrawal is also steady. At this place, too, kharif season is favourable and crops having high water demand and even which are sensitive to moisture aberrations can be suggested.

The results of the above discussion are put together in Table 5.4.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
TRP	35th - 47th	rabi	nil	dependable
VLR	28th - 47th	rabi	nil	not dependable
NLR	30th - 49th	rabi	31st, 35th - 36th	not dependable
HYD	24th - 41st	kharif	nil	dependable
GLB	23rd - 40th	kharif	nil	dependable
PNA	24th - 40th	kharif	34th - 37th	dependable
AGD	23rd - 40th	kharif	nil	dependable
HNM	24th - 40th	kharif	nil	dependable
NZB	24th - 39th	kharif	nil	dependable
BMB	23rd - 40th	kharif	nil	dependable

Table 5.4. Characteristics of growing periods at stations of G type agroclimate

<u>F Type :</u>

The patterns of probability curves [P(W) and P(WW)] for selected stations Pamban, Madurai, Raichur, Chitradurga and Gadag of F type agroclimatic region are discussed here.

The favourable period for growing crops at Pamban (Figure 5.5a) is from mid-October to last week of December (42nd to 51st

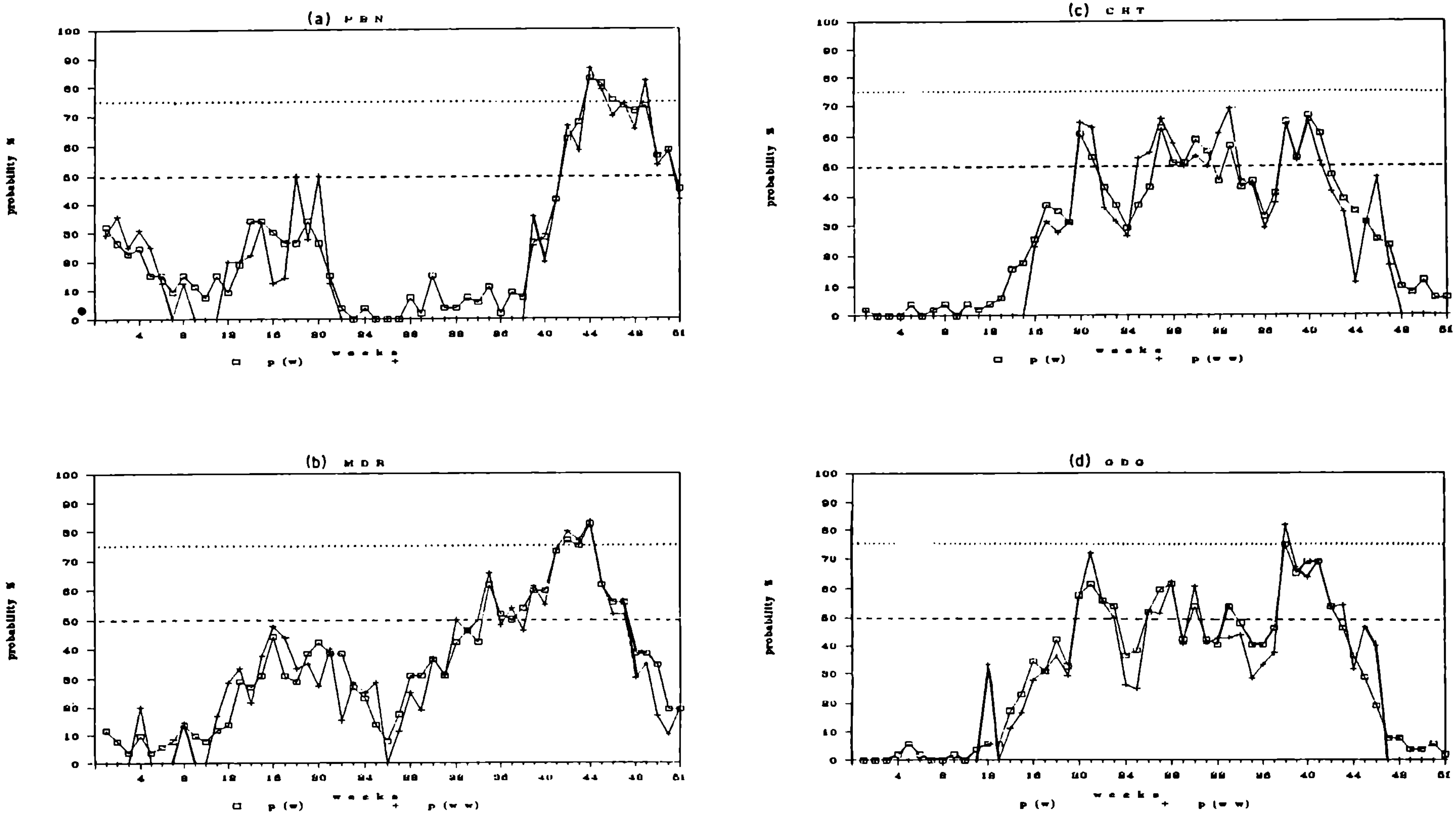


Figure 5.5 Patterns of probability curves in F type agroclimatic region

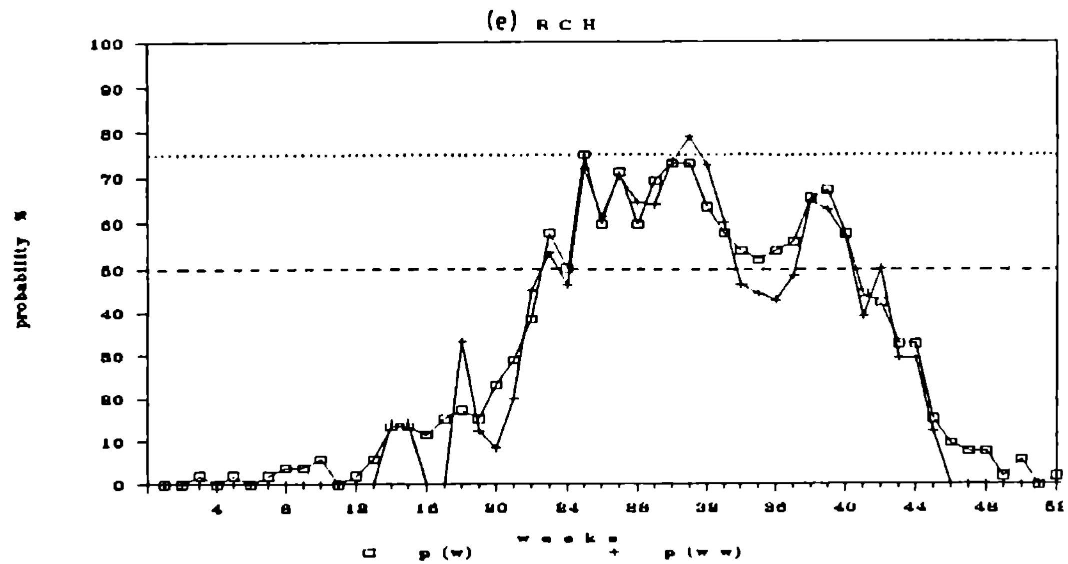


Figure 5.5 (contd.) Patterns of probability curves in F type agroclimatic region

week). Increase in P(W) related to the commencement of growing period is fairly dependable and the reduction in P(W) during the withdrawal of monsoon rainfall is also steady. During the growing period P(W) and P(WW) fluctuate widely but cross 75% only during 3 weeks. The entire monsoon season is characterised by low values (less than 20%) of P(W); P(WW) is zero indicating poor persistency. It is quite obvious that the rabi cropping season is efficient at this place and crops with moderate water demand can be grown successfully.

The crop growing period at Madurai (Figure 5.5b) is from 35th week to 47th week (last week of August to last week of October). The increment in probability of wet weeks associated with the beginning of growing period is not dependable. During the growing period P(W) crosses 75% only during 3 weeks; during the first half of this period P(W) is about 50% only. During the entire monsoon season, both the wetness probabilities are less than 50% and exhibit wide fluctuations too. Probability of wet weeks during mid-December to February is less than 50% and their persistence negligible. Only rabi cropping season is favourable at this place and only crops with low water demand are suitable.

In this agroclimatic zone, Chitradurga and Gadag have similar pattern of P(W) and P(WW) curves (Figures 5.5c and 5.5d). At both the stations, the growing period is not a continuous one and the probability of wet weeks during December to mid-March is very low and their persistency nil. The increase in P(W) in connection with the beginning of the growing period is dependable except during a few weeks. Similarly, during, the post-monsoon phase, the reduction in P(W) is also very steady. P(WW) shows that wet weeks have nearly 50% probability of persistence during November.

Chitradurga has favourable period for crop-growing between 27th week and 41st week (July to mid-October). During this period both the probabilities fluctuate widely and never reach 75%: they become less than 50% from mid-August to mid-September causing a dry spell of 4 weeks duration. Both kharif and rabi cropping seasons are not that favourable at this place. However a drought-hardy crop can be grown from July to mid-August.

At Gadag, crop cultivation is feasible during mid-May to mid-October (20th - 42nd weeks). During this period P(W) and P(WW) fluctuate and reach 75% value only during one week. On an average, there is a 60% probability for water stress period of more than one week to occur thrice during the growing season (24th to 25th week, 32nd to 33rd week, 35th to 37th week) and another dry period of one week (29th) duration with 55% probability during the 29th week. Kharif and rabi cropping seasons are not efficient and hence only a drought-resistant crop will be suitable at this place.

For Raichur (Figure 5.5e), the growing period begins from first week of June and ends in the first week of October (23rd to 40th week). The increase in P(W) in connection with the commencement of growing period is dependable but during the growing period P(W) and P(WW) have wide fluctuations. These probabilities reach 75% only during a few weeks and from August to mid-September generally a reduction in P(W) is observed. During November to mid-April, P(W) is low (less than 20%). At this place kharif cropping will be efficient and a moderate water demanding crop can be grown. But care should be taken while selecting crops so that its moisture demanding phases do not occur during August to mid-September.

Results of the F type stations are given in Table 5.5.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
PBN	42nd - 51st	rabi	nil	dependable
MDR	35th - 47th	rabi	nil	not dependable
CHT	27th - 41st	nil	34th - 37th	not dependable
GDG	20th - 42nd	nil	24th - 25th, 32nd - 33rd, 35th, 37th	not dependable
RCH	23rd - 40th	kharif	nil	dependable

Table 5.5. Characteristics of growing periods at stations of F type agroclimate

E Type:

The four selected stations of E type agroclimate discussed below have different patterns of P(W) and P(WW) curves.

At Coimbatore (Figure 5.6a), the period 40th to 47th week (October to mid-November) is suitable for crop cultivation. The increase in P(W) related to the commencement of growing period is dependable; similarly, the reduction in probability of wet weeks during the withdrawal phase is also steady. During the growing

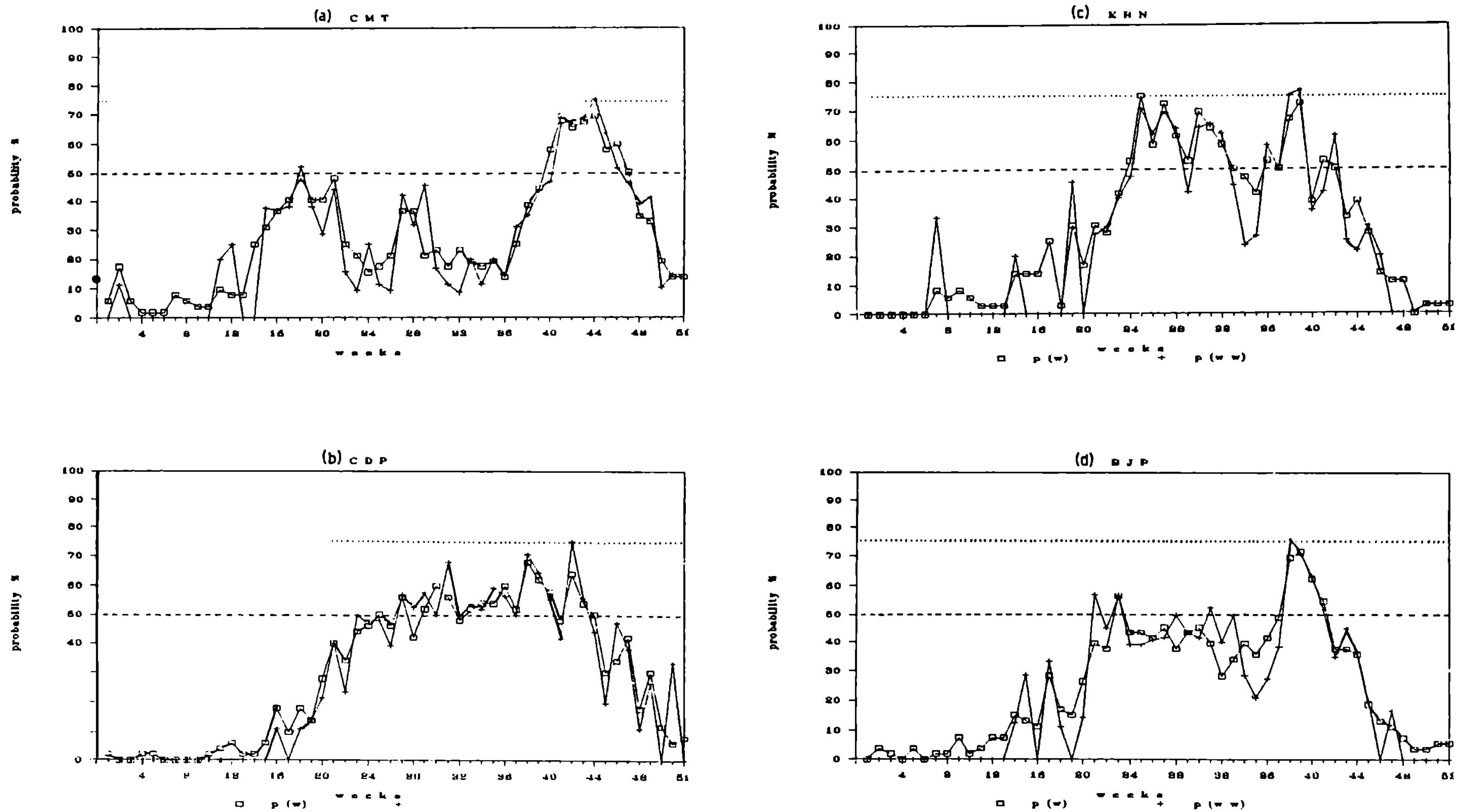


Figure 5.6 Patterns of probability curves in
E type agroclimatic region

period these probabilities do not show much fluctuations but never reach 75%. Probability of wet weeks during December to March is very low but shows increments in connection with pre-monsoonal activity even though the values are less than 50%. During the entire monsoon season, P(W) and P(WW) are very low except during the first and second weeks of July. Only rabi cropping season exists at Coimbatore and crops with moderate water demand will be suitable.

Cuddapah (Figure 5.6b) has its growing period between July and October (27th to 44th week). The increase in P(W) indicating the commencement of growing period is not dependable and cessation of rainfall is also not steady. The probability of wet weeks during January to mid-April is negligible. During the growing period P(W) and P(WW) fluctuate widely, seldom cross 50% and never reach 75%. During the growing season, in the 28th week there is a chance for dryness in nearly 55% of occasions. At Cuddapah, the entire growing period is not that efficient; only drought-hardy varieties will survive at this place.

At Kurnool (Figure 5.6c), favourable period for crop growing is between 24th and 42nd week (mid-June to mid-October). At this place the increment in P(W) associated with the commencement of growing period is steady and dependable but the reduction of P(W) during cessation of rainfall is not steady. During the growing period P(W) and P(WW) fluctuate widely and reach 75% only during a few weeks; during the 34th and 35th weeks (August) P(W) is below the threshold value of 50%. Thus a dry spell of two weeks duration occurs in 6 out of 10 years during this period. Again, during the 39th week, P(W) shows a dip and a 60% probability exists for the week to be dry. The probability of wet weeks during November to April is low and its persistence nil. At Kurnool, therefore, kharif cropping season will be suitable and a drought-resistant crop can be grown here: care should be taken so that the sensitive phases of the crops do not occur in August and first week of September.

Crop-growing under rainfed conditions is possible at Bijapur (Figure 5.6d) only during 37th to 41st week (mid-September to mid-October). Here the increase in P(W) associated with the commencement of growing period is not dependable but the reduction in P(W) in relation to the withdrawal of rainfall in September is steady. During the five weeks of growing period significant fluctuations in P(W) and P(WW) are not observed. The probability of wet weeks during November to mid-April months is low and the persistence nil. It is obvious that only rabi cropping is possible here with moderate water requirement crops.

The summary of the above discussions are presented in Table 5.6.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
CMT	40th - 47th	rabi	nil	dependable
CDP	27th - 44th	nil	28th	not dependable
KRN	24th - 42nd	kharif	34th - 35th	dependable
BJP	37th - 41st	rabi	nil	not dependable

Table 5.6. Characteristics of growing periods at stations of E type agroclimate

D Type:

At Anantapur and Bellary (Figures 5.7a and 5.7b), the selected stations of D type agroclimate have similar patterns of P(W) and P(WW) curves. At both these stations, the increase in probability of wet weeks in connection with the commencement of crop growth period is not dependable but the reduction in P(W) during the withdrawal of monsoon rainfall is quite steady. Both the stations have only four weeks suitable for crop growth from 38th to 41st week (mid-September to mid-October). The probability of wet weeks during December to mid-April is very low (less than 20%) and its persistence nil. At these stations, cropping is not feasible under rainfed conditions.

The results for this two stations are summarised in Table 5.7.

Station	Duration (weeks)	Efficient season	Dry spells (weeks)	Nature of commencement
ANT	38th - 41st	nil	nil	not dependable
BLY	38th - 41st	nil	nil	not dependable

Table 5.7. Characteristics of growing periods at stations of D type agroclimate

Success of dry seeding practice depends upon the dependability of the commencement of growing period. Based on the results obtained from this study, regions having low risk for dry seeding is demarcated in Figure 5.8. It is found that the whole of the west coast and the south east coast are suitable for dry seeding. Generally in the interior parts of Karnataka, Rayalaseema and south Tamil Nadu dry seeding will be risky.

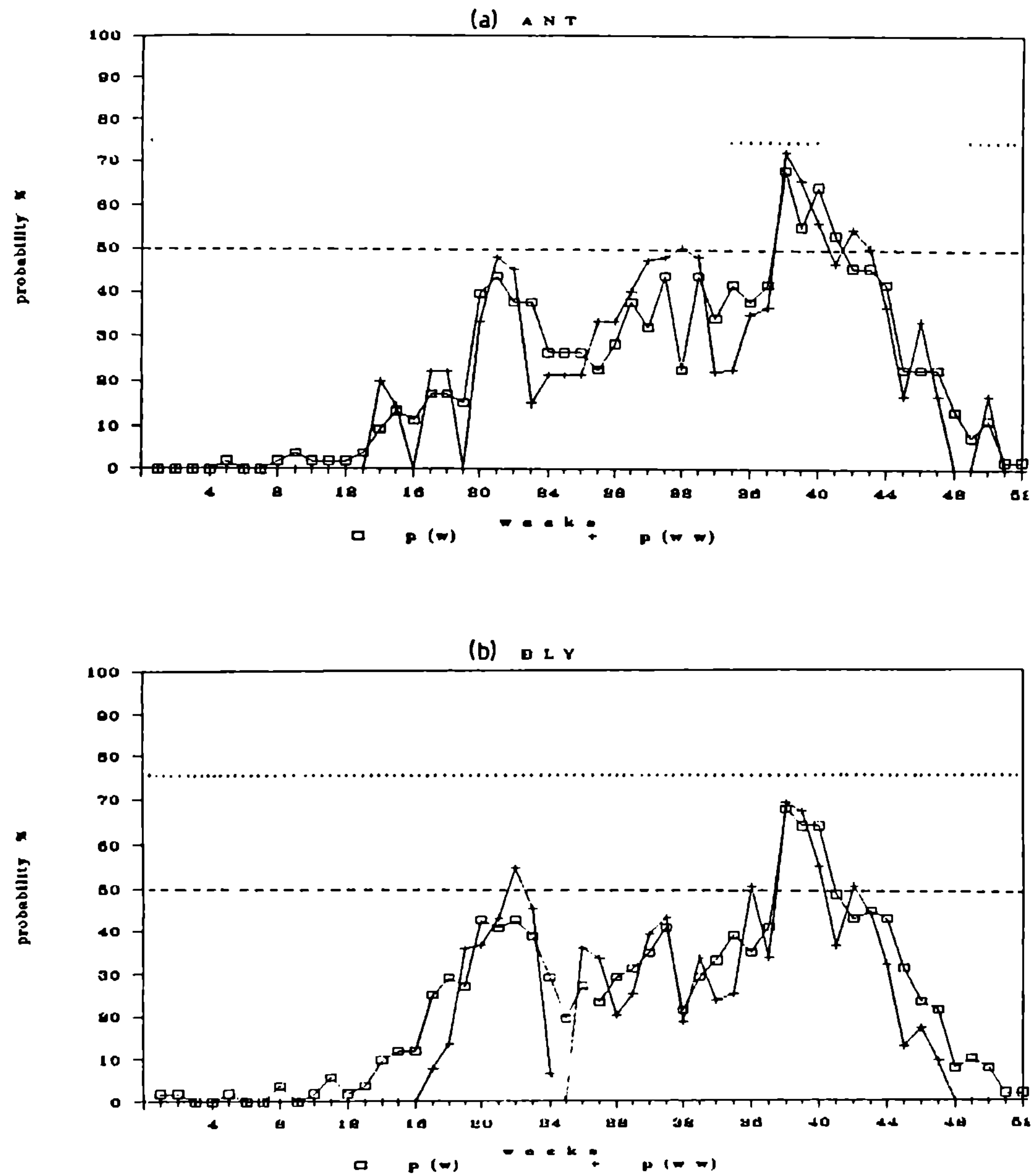


Figure 5.7 Patterns of probability curves in D type agroclimatic region

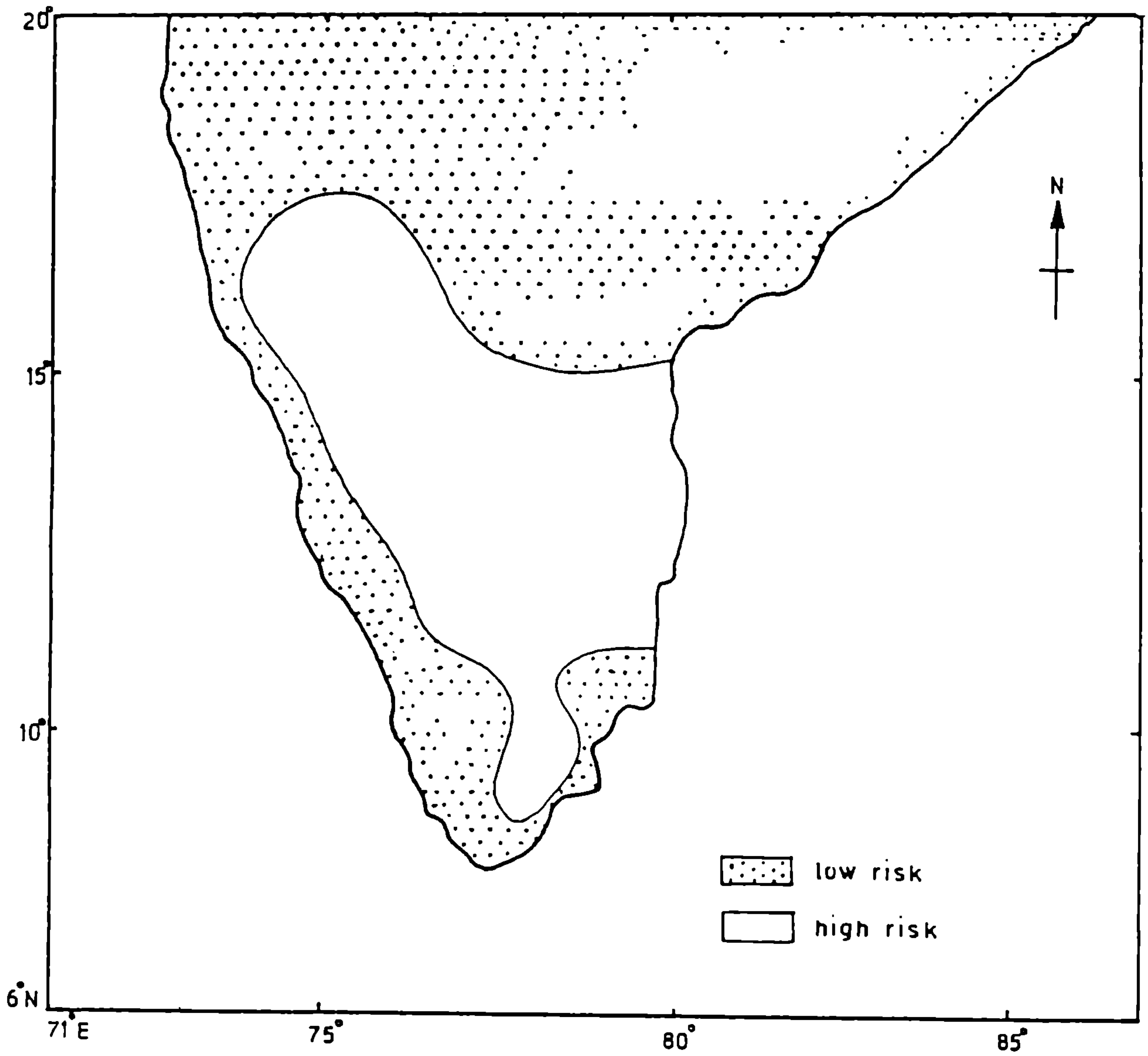


Figure 5.8 Areas favourable for dry seeding

The spatial distribution of P(W) over the region for representative weeks are given in Figures 5.9 to 5.12. The changes in the spatial pattern during different seasons are clearly seen from these figures.

Figure 5.9 depicts the spatial distribution of P(W) for representative weeks in winter months. The maximum value of probability of wet weeks during this season varies between 20% and 30% and the region of maxima is confined to South Kerala and South Tamil Nadu coasts and to parts of Telangana. P(W) is less than 10% elsewhere in the region with zero values at many places. With the advancement of the season, the region of maximum shifts from South Tamil Nadu coast to South Kerala coast. The hill station of Kodaikanal is an exception to the general pattern.

During the pre-monsoon season, a gradual and steady increase of P(W) values is observed over the region (Figure 5.10). It is seen that from South Kerala coast and from Telangana the probability values spreads towards the central parts of the region as the season progresses. In the 11th week (mid-March) the maximum value of P(W) is between 30% and 40% but in the 20th week (mid-May) it varies between 70% and 80%. Compared to west coast, the east coast has very low values of probability of wetness. During this season too, P(W) becomes less than 10% for North Tamil Nadu, Karnataka, Andhra Pradesh (except parts of Telangana) and for southwestern parts of Maharashtra.

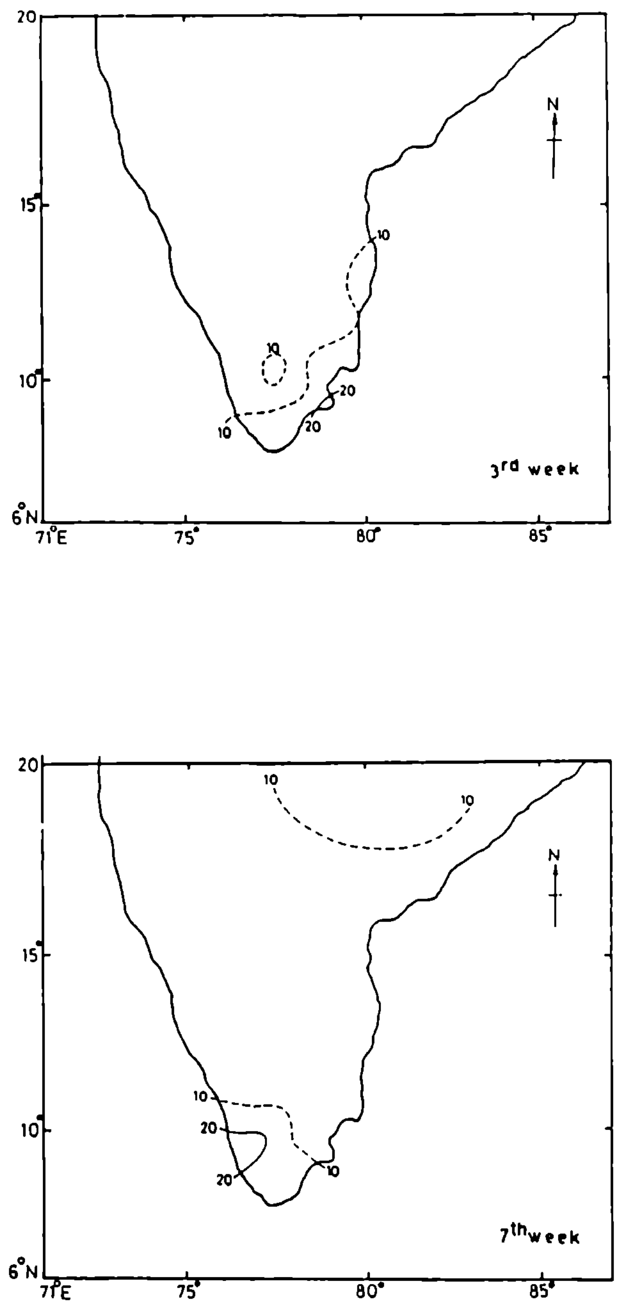


Figure 5.9 Spatial distributions of P(W) for representative weeks in winter months (%)

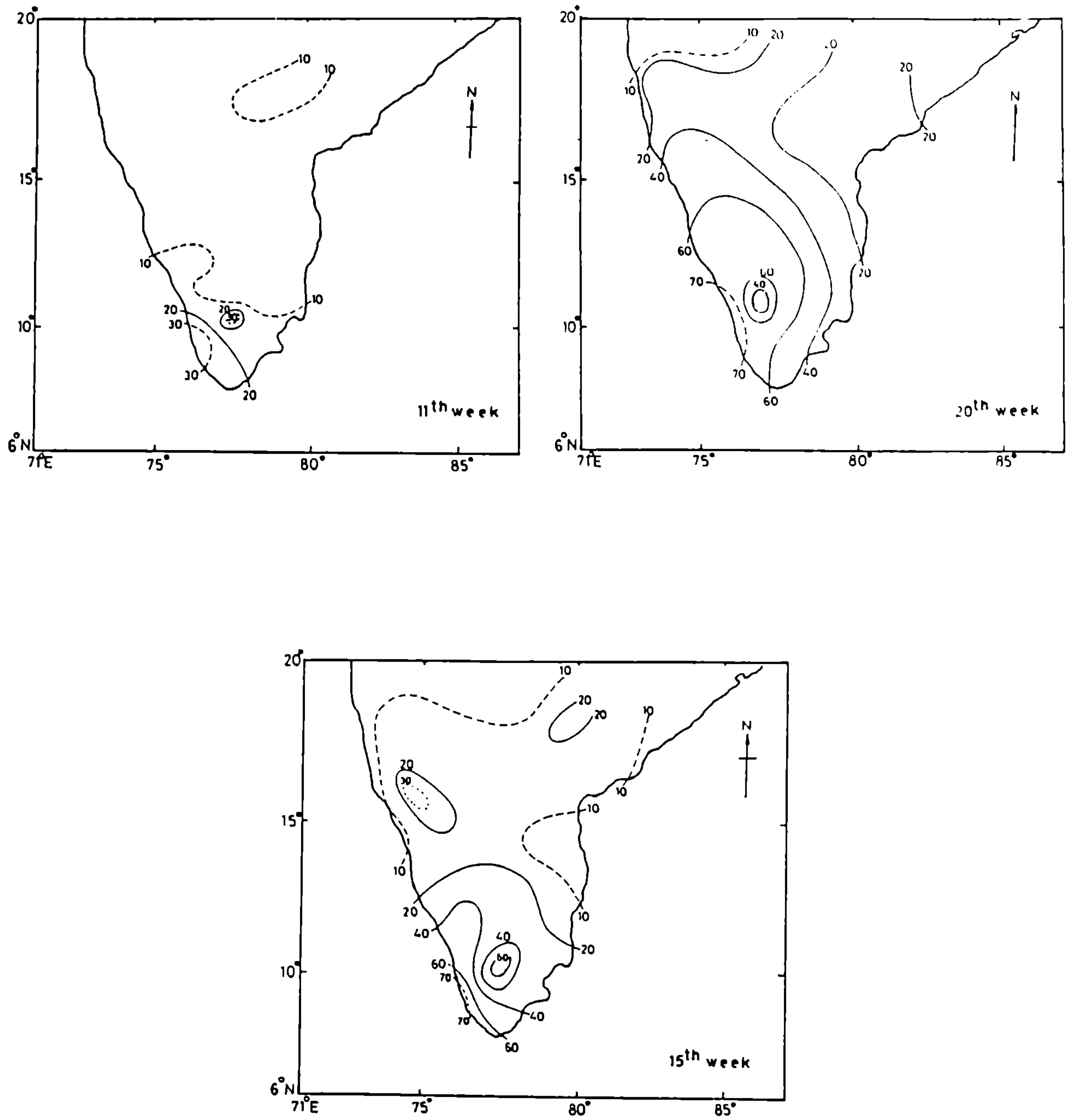


Figure 5.10 Spatial distributions of P(W) for representative weeks in pre-monsoon months (%)

Figure 5.11 represents the variation in spatial pattern of P(W) for representative weeks during the four monsoon months. The alignment of isolines with the topography of Western Ghats is the marked feature of this season. In the 20th week (mid-July) P(W) becomes 100% along west coast. Generally, the values vary between 100% (mid-July) in the windward side of the Ghats to less than 10% (mid-September) around Pamban on the east coast: the gradient of values from windward side to leeward side of the Ghats is clearly seen. In this season, too, the east coast has lower values than the west coast.

A significant change in pattern of isolines is seen for post - monsoon season from the previous season (Figure 5.12). Generally a reduction in P(W) values is observed along the west coast and in Telangana but along the east coast an increase can be clearly noticed. In the 42nd week (mid-October) along the east coast, around Cuddalore, the value rises to more than 80%; around Pamban it becomes greater than 60% whereas it was less than 10% in 37th week (mid-November). By the 50th week, the maximum value drops to about 40% along the west coast while on the Tamil Nadu coast it is greater than 50%. During this season too the minimum value drops to below 10% around Nizamabad and Gulbarga.

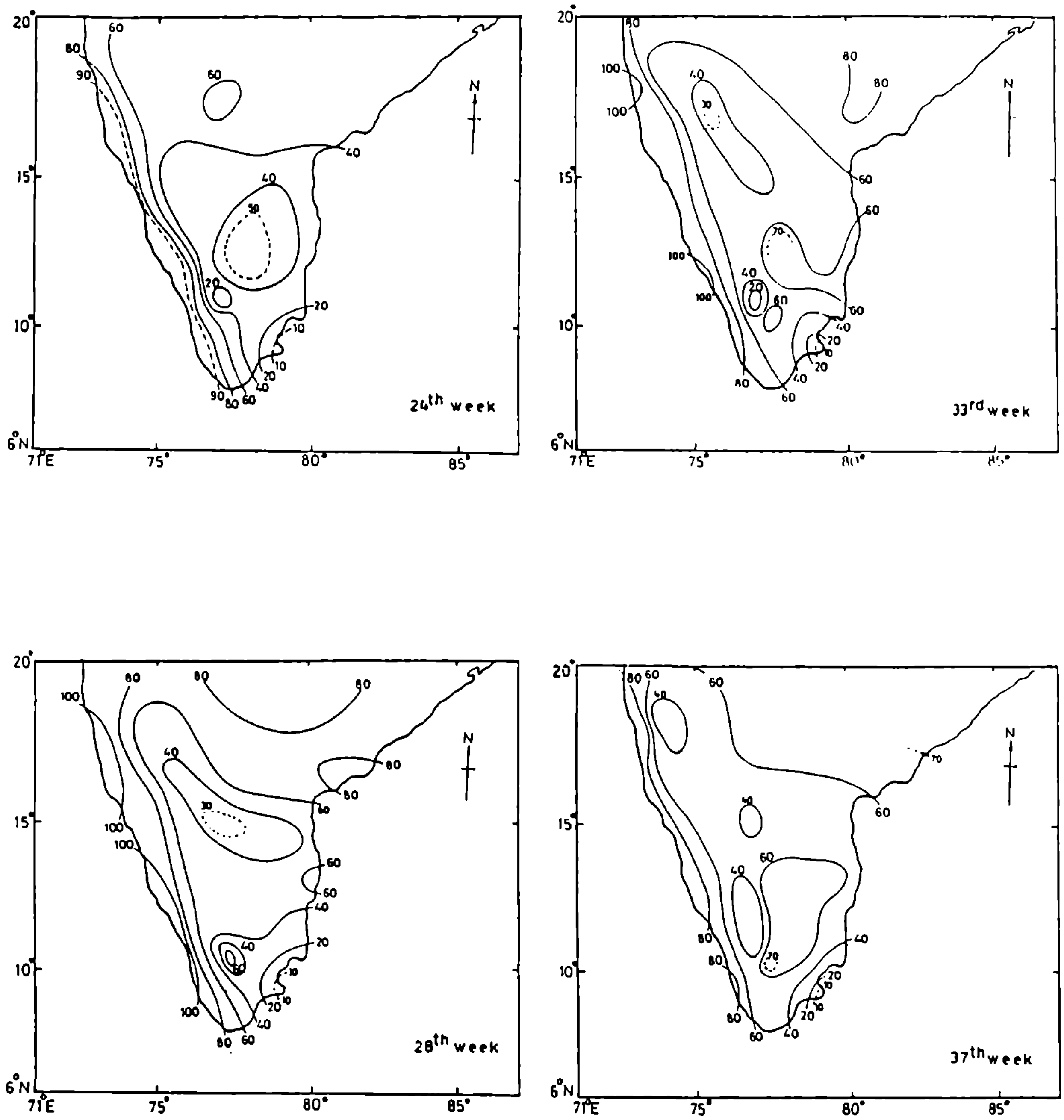


Figure 5.11 Spatial distributions of P(W) for representative weeks in monsoon months (%)

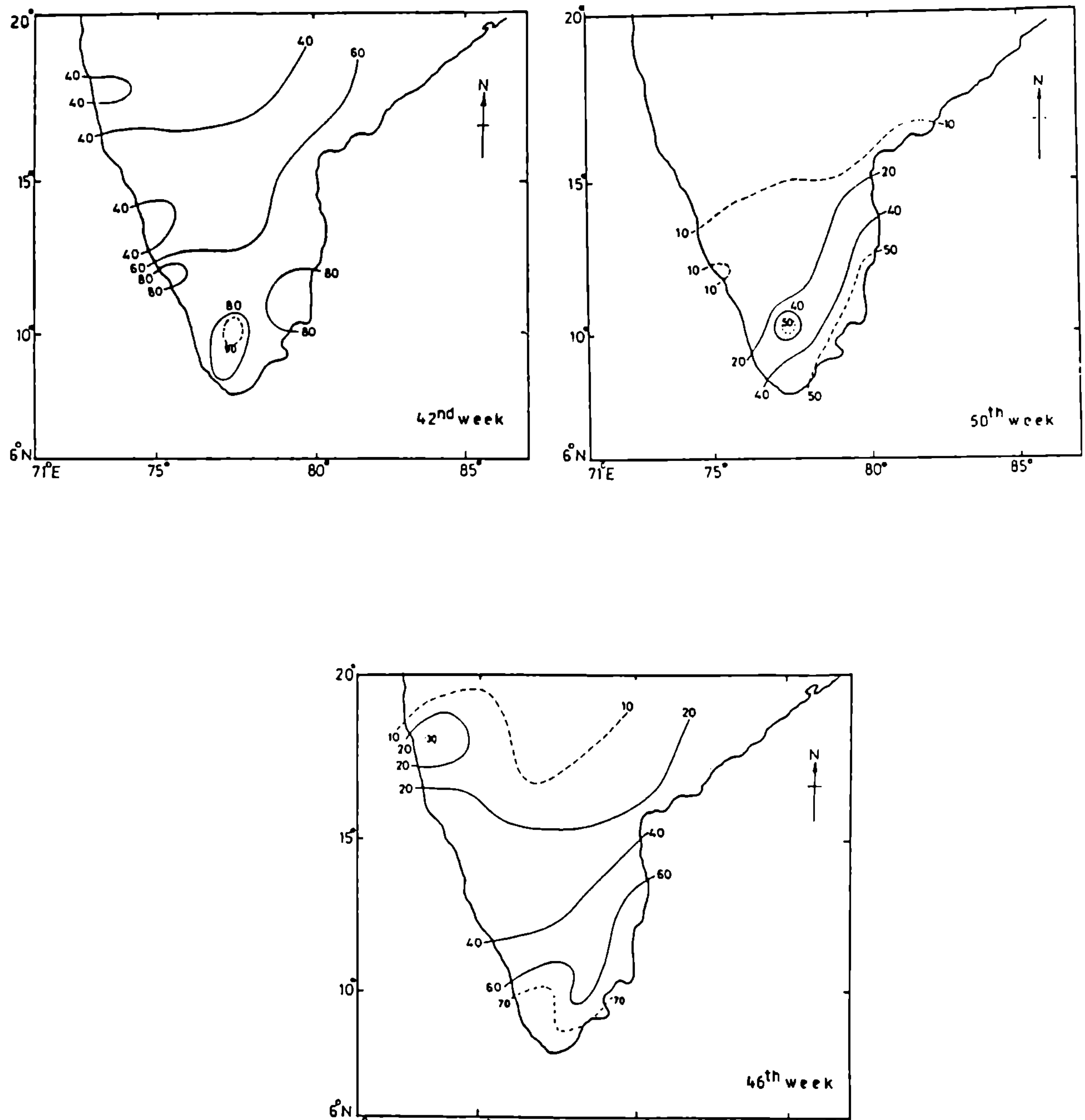


Figure 5.12 Spatial distributions of P(W) for representative weeks in post-monsoon months (%)

CHAPTER 6

SUMMARY AND CONCLUSIONS

The South Indian region selected for this study comprises of a spectrum of climates from the most humid type of climate on the windward side of the Western Ghats to the arid climates on the leeward side. This unique set of climatic conditions are mainly due to the diverse physiographic features of the region caused mainly by the Western Ghats. Within the Ghats region, from the windward to the leeward side, a sharp decline in the degree of humidity in the climates are seen.

In the low rainfall areas on the leeward side of the Ghats, moisture is the limiting factor in agriculture. In recent years, there has been a growing appreciation of these climatic constraints and attempts are being made to increase the length of growing period by improving soil and water management.

The identification of different agroclimatic zones, studies on the variation of accumulated assured rainfall, analysis of commencement, duration and cessation of the growing period, and the appraisal of the probability of successful rainfed agriculture dealt with in this study are very relevant to the region for proper crop planning and management.

The thesis consists of six Chapters of which the first Chapter gives the introduction to the problem and also the scope of the study. In the first Section of the second Chapter, relevant literature on water balance studies, estimation of potential evapotranspiration, studies on rainfall distributions, climatic classifications in general and agroclimatic classifications, in particular has been reviewed. The review also includes literature on evaluation of crop growth potentials and analysis of wet and dry spells over different climatic regimes. The second Section of this chapter explains the method of estimation of potential evapotranspiration, water balance computations, and techniques used for the rainfall analysis (Gamma distribution method) in the investigation. The criteria employed for agroclimatic classification and the method of rainfall analysis to assess wet and dry spells using Markov chain model have also been given in detail.

The third Chapter comprises of a discussion of physical and climatic features of the study region. The first Section gives details about the location and extent, physiography, drainage, soil types, natural vegetation, land-use and the major crops grown in the region. The second Section concerns itself with the rainfall, temperature, and humidity characteristics of the region. The distributions of water balance parameters, namely potential evapotranspiration, actual evapotranspiration, water deficit and water surplus are also mapped and discussed in this Section.

Analysis of weekly rainfall using Gamma distribution method and the agroclimatic classification based on moisture availability index has been dealt with in Chapter 4. Spatial distributions of accumulated assured rainfall at different probability levels have been mapped and discussed. Similarly, the spatial distributions of duration of MAI of different magnitudes at different probability levels have also been presented and discussed. The crop potentials of individual stations of each agroclimatic type have been separately discussed in detail in this Chapter. The salient results are given below:-

The accumulated assured rainfall (AAR) over South India at 75% probability level varies from more than 150 cm around Mangalore coast to zero around Bellary, Cuddapah and Vellore. From this region of maximum value, it decreases in both northward and southward directions along the coast. Along the east coast the values are less than 10 cm except around Pamban; in Telangana the values are greater than 10 cm.

The distribution pattern of AAR at 75%, 50% and 25% probabilities have the following general features. Along the west coast and in the Ghats region, the isohytes follow the topography and a sharp gradient is seen from the windward side to the leeward side. The hill stations generally have high values.

At 50% level, the AAR over the region ranges from more than 250 cm along Karnataka coast to less than 10 cm around Bellary and Anantapur. It is found to be more than 50 cm along the north

Tamil Nadu coast, the region around Bangalore and Salem, in Telangana and along North Andhra Coast.

At 25% probability level, the AAR values vary between 500 cm along Karnataka and North Kerala coast and less than 100 cm around Bellary and Anantapur region. Along the north Tamil Nadu coast, the values are greater than 200 cm.

The duration of MAI values of different magnitudes at 75% probability level for the region is more than 20 weeks (for MAI $\geq$ 0.3) along Karnataka and Kerala coast and decreases towards the leeward side of the Ghats. In Rayalaseema, North Interior Karnataka, Telangana and along North Tamil Nadu coast, it is nil everywhere. Along the east coast, some isolated regions have more than 5 weeks duration of MAI greater than 0.3.

At 50% level, MAI exceeds 0.3 for periods longer than 35 weeks along Kerala and South Karnataka coasts. In this case, too, the core of low values (less than 5 weeks) are found in Bellary and Anantapur regions but Telangana region shows a slight increase in the values.

The duration of MAI at 25% level varies from greater than 35 weeks (MAI greater than 0.3) along South Kerala coast to around 10 weeks at Bellary.

The agroclimatic types of the study region consists of 7 major zones, from J type to D type. The region around Bellary and Anantapur is the driest part, namely D type. Aridity decreases in all directions from this zone, but the gradient is more towards the southwest compared to the other directions. The most humid type J is observed along the west coast and in the mountain regions of Kodaikanal. The alignment of climatic types in the western sector is parallel to the Ghats. The classification when superimposed on the soil map of the region forms 36 soil agroclimatic sub-divisions out of which 7 sub-zones are under G type, 6 sub-divisions under I, H and F types. E and D types have 4 sub-divisions each and J type has the minimum number of 3.

The J type agroclimatic zone is confined to a narrow strip along the west coast extending north upto Mangalore and to the Kodaikanal hill region. The varied soil types of this zone brings forth 3 different sub-divisions in the zone.

At 75% level, the AAR of this zone varies from 50 cm to 150 cm in the coastal region but in the hilly regions, it is around 30 cm only. The growing period in this zone varies generally between 20 and 25 weeks, but in the high altitude region it is found to be slightly greater than 25 weeks. It is to be noted that though the AAR of the hilly area is less than that of the coastal stations, its growing period is larger.

At 50% level, the AAR of this zone varies from 250 cm in the northern sector to 150 cm in the extreme southern sector along the coast. The high altitude regions have AAR less than that of the coasts. The growing period at this probability level is found to vary from 25 to 35 weeks along the coast and it is around 40 weeks in the hilly regions.

The AAR of J type zone varies from around 400 cm to 500 cm in the coastal region and around 300 cm in the hilly region at 25% level. The growing period at this probability level is found to vary between 30 and 45 weeks along the coast where as in the mountain region, it is found to be more than 45 weeks.

Among the six stations whose agroclimates are of J type, Mangalore has the highest AAR at 50% level. Though the AAR of Kodaikanal is less, it has the longest growing period. Among the other five stations a northward decrease in the growing period is observed. The commencement of growing period gets delayed for the stations in the northern part of the region, except at Kodaikanal. Apart from Trivandrum and Kodaikanal, all other stations in this zone have 95% chance of cropping under rainfed conditions. At 50% probability level, the prospects of soil moisture storage after the withdrawal of rains is high for all these stations.

The I type agroclimatic zone lies adjacent to the J type region parallel to the Ghats along the west coast. In the north, it begins from extreme southwest parts of Maharashtra, and in the central region, found to protrude into the south interior parts of Karnataka and then restricts to a narrow strip parallel to the Ghats. The hill station of Mahabaleshwar also comes under this zone. Along the east coast, it is confined to a narrow belt around Madras and Cuddalore region and to a small region further north around Masulipatnam. The soil type of this zone generates six sub-divisions.

The AAR of the I zone at 75% level varies between 150 cm and 200 cm in the northern parts of the west coast and it decreases to below 10 cm in the South Interior Karnataka and varies from 5-10 cm in the extreme south. Along the east coast it varies between 5 cm and 10 cm only. But in the hilly region of Mahabaleshwar, it is found to be greater than 200 cm. The growing period at this probability level along the west coast varies from 15 -20 weeks in the northern part and 10-25 weeks in the south. But in the central sector of Karnataka and in the east coast region, the growing periods are around 5 weeks only.

At 50% level, the AAR in this agroclimatic region ranges from 200-250 cm in the north and to 100-150 cm in the south. Along the east coast and in South Interior Karnataka it is only 50 cm. The growing period of this zone at 50% level ranges between 20 and 25 weeks.

At 25% level, the AAR of this zone is found to be between 450 cm and 500 cm in the north and between 200 and 300 cm in the south along the west coast and along the east coast, but it is less than 200cm in Karnataka region. The growing period generally varies between 25 and 30 weeks in the northern part of the region along the west coast, 30 and 35 weeks in Karnataka and in part along east coast.

Among the nine stations of I type agroclimate, at 50% level, Mahabaleshwar has the highest AAR, and Mysore the least. Among the east coast stations, Cuddalore has the highest AAR. The longest growing period is observed at Mysore. Generally, South Interior Karnataka experiences longer growing periods but along the east coast, Madras has the longest growing period. The earliest commencement of growing period is observed at Mysore and the latest at Madras and Masulipatnam. The earliest cessation of the growing period is observed at Belgaum, Khammam and Mahabaleshwar while the latest at Cuddalore and Mysore. At Mysore, maximum number of breaks in the growing period is observed at 50% level. Among the stations of I category of agroclimate, probability of dryland agriculture at 95% level exists only at Karwar and Mahabaleshwar whereas at Cuddalore, Mysore and at Madras successful agriculture is possible at 50% level.

The H type of agroclimate is found to extend from the extreme southwest part of Maharashtra through Karnataka into Tamil Nadu as a narrow strip and also in the northeastern sector of the study region. The different soil types form six sub-divisions within the zone.

At 75% probability level, the AAR of this zone varies between 50 cm and 100 cm in the northwestern part of Maharashtra and varies between 5 cm and 10 cm in the southern portion in Tamil Nadu and in northeastern parts of the zone. The growing period within the zone is found to vary from 15-20 weeks in the northwestern part of Maharashtra and from 5-10 weeks in Tamil Nadu and the northeastern sector.

At 50% level, the AAR of this zone ranges from 50 cm to 200 cm. The growing period at this probability level ranges between 15-25 weeks for the entire zone.

At 25% level, the AAR varies between 200 cm and 500 cm and then growing periods vary from 25 to 35 weeks.

Among the stations of H type agroclimate, at 50% level, Salem has the longest growing period but AAR is highest at Ratnagiri. The earliest commencement of growing period is at Salem. The number of breaks observed during the growing season is most at Salem whereas Ratnagiri experiences none at any probability level.

In the study region, the G type agroclimatic zone is found to exist as a narrow circular strip in the central part comprising of parts of North Interior Karnataka, Rayalaseema, South Coastal Andhra Pradesh, Telangana and adjoining parts of Maharashtra. In South Tamil Nadu too, this climatic type exists as a circular strip outside Kodaikanal mountain area. The soil classes categorizes the climatic type into seven sub-divisions.

The AAR of this zone at 75% probability level is less than 10 cm. While the growing period is less than 10 weeks: there exists no growing season in Tamil Nadu region.

At 50% probability level, the AAR of this zone is below 50 cm everywhere except in parts of Telangana where it varies between 50 cm and 100 cm. At this probability level, the growing period ranges between 15 and 20 weeks except in Tamil Nadu where it is 20 and 25 weeks.

The AAR at 25% probability level varies from 100 cm to 200 cm except in Tamil Nadu where it is greater than 200 cm. The growing period at this probability level is found to vary from 20-25 weeks in the northern parts and varies between 30 and 35 weeks in Tamil Nadu.

Among the ten stations of this agroclimatic type, at 50% level, Bombay has the highest AAR and the least at Vellore though it experiences the longest growing period. The earliest commencement of growing period is observed at Gulbarga and Bombay while the latest is at Tiruchirappalli. Generally, the Tamil Nadu region has late commencement of growing period. The earliest cessation of growing period is at Nizamabad. The maximum number of breaks is observed at Nellore and among this group of stations there is a 95% chance of successful rainfed agriculture at Bombay and 75% chance of success at Hanamkonda, Pune, Nizamabad and Aurangabad.

The F type agroclimatic zone in the study region is found in the central parts as a circular strip consisting of parts of North Interior Karnataka, Rayalaseema and South Coastal Andhra Pradesh and in the south outside Kodaikanal region. Within this agroclimatic zone, the soil varieties form six sub-divisions.

The AAR of this zone at 75% level is less than 5 cm in the central parts but in Tamil Nadu portion of this zone it is around 10 cm. The growing period at this probability level is around 5 weeks in this zone.

At 50% probability level, AAR of this zone varies between 10 cm and 50 cm and the growing period is around 15 weeks.

At 25% probability level, the AAR varies between 100 and 200 cm in the entire zone and the growing period is around 30 weeks in the central portion of this study region but is slightly less in the coastal regions of Tamil Nadu part.

Among the five stations of F type agroclimatic group, Pamban experiences the highest AAR at 50% probability level whereas the least value is observed at Chitradurga. The growing period is longest at Gadag; the shortest at Pamban. The commencement of the growing period at Gadag is the earliest one and that at Pamban the latest. The earliest cessation of growing period is at Raichur, and the latest at Pamban and Madurai. The maximum number of breaks observed are at Chitradurga and Gadag. None of these stations has 95% chance of successful rainfed agriculture. Even at 75% probability level, there is the chance only at Pamban.

In the study region, the E type agroclimatic zone exists inside the region of F type in the central parts of the study region comprising parts of North Interior Karnataka, Rayalaseema and Telangana and in Tamil Nadu, the region around Coimbatore. As a result of varying soil type, 4 sub-divisions form within this zone.

The AAR for this entire region at 75% level varies between zero and 5 cm and growing period ranges from 0 to 5 weeks.

At 50% level, the AAR of this zone varies between 10 and 50 cm and the growing period between 10 and 20 weeks except in Tamil Nadu, where it is less than 10 weeks.

At 25% level AAR has values between 100 cm and 200 cm, the growing period between 25 and 30 weeks, but in the southern portion, it is slightly greater than 30 weeks.

Among the four stations in the E type agroclimate, the highest value of AAR at 50% level is experienced at Cuddapah, whereas the least value is experienced at Coimbatore. At this probability level, the longest growing periods is observed at Kurnool and the shortest at Coimbatore. Among this group of stations, the earliest onset and cessation of growing period are also found to occur at Kurnool and latest at Coimbatore. In this agroclimatic zone, no station has 75% chance of success in rain-fed agriculture and at Bijapur it is not possible even at 50%.

At 25% level, too, the highest AAR is observed at Cuddapah and the least at Coimbatore. But at this probability level, Coimbatore has the longest growing period and the shortest at Kurnool and Bijapur. The earliest commencement of growing period is observed at Coimbatore while the latest is at Cuddapah. At this probability level, the earliest cessation of the growing period is found to be at Bijapur and the latest at Coimbatore.

The D type agroclimatic zone in the study region exists in the central most part around Bellary and Anantapur. In this zone too, four sub-divisions exist because of the varied soil types.

At 75% level, the AAR of this zone is negligible and there is no growing period. But at 50% level, the AAR values are around 10 cm and growing period vary from 50 to 10 weeks. At 25% level, the AAR of this zone is around 100 cm and the growing periods between 25 and 30 weeks.

Among the two stations in the D type zone, Bellary has higher AAR at 50% level where as the growing period is longer at Anantapur. At 25% level, Bellary has the longest growing period.

The reduction in magnitude of AAR and the length of growing period among the agroclimatic types with respect to its degree of humidity is clearly noticed. Generally, the AAR ranges from about 300 cm for the most humid type J to around 10 cm for the most arid type D. Similarly the growing period is found to vary from around 35 weeks in J type to as low as 5 weeks in D types. The probability of successful dry farming also decreases from 95% in J type to 25% in D type.

Using the first order Markov chain model, the weekly rainfall has been analysed in the fifth Chapter to determine the probabilities of dry and wet spells and to assess crop growth potentials of different growing seasons in the region. The results are discussed for individual agroclimatic zones. The important results brought out by this analysis are presented here.

No station in the J type agroclimatic group experiences any dry spells during the growing period. For all the stations, commencement of growing period is dependable. At all the stations, except Kodaikanal, the favourable period for crop growth is kharif season and drought-sensitive crop varieties can be grown too. At Kodaikanal, crops which are sensitive to moisture variations are not suggested.

Among the group of stations of I type agroclimate, Madras, Masulipatnam, Khammam, Karwar and Mahabaleshwar experience no dry spells during the growing season and for these five stations the commencement of growing period is quite dependable. At Cuddalore, Madras, Mysore and Bangalore the rabi season is more favourable while at Masulipatnam, Khammam, Karwar, Mahabaleshwar and Belgaum, it is the kharif season which is more favourable. At Cuddalore, Madras, Mysore, Bangalore and Masulipatnam, crops with moderate water requirement only can be grown. For the other four stations, drought-sensitive crops can be selected. At Cuddalore, during the growing period in the first week of August, there is a 60% probability for dryness to occur. At Mysore, two dry spells of more than one week duration occur in about 7 out of 10 years during the growing period. The first one is of four weeks duration, comprising entire June and the second one is of three weeks duration (from the last week of August to mid-September). At Bangalore in the 26th week, there is a 60% chance for dryness; but if the period is wet it will continue over to the next week in 7 out of 10 years. Belgaum also has a 60% probability of dryness during 21st to 22nd week.

Among the stations of H type agroclimate, only Salem has the probability of dryness. At Salem and Vishakhapatnam, the commencement of growing period is not dependable: the rabi season is more favourable than the kharif, whereas at Ratnagiri the commencement of growing period is dependable and kharif season is more favourable. The probability of dryness at Salem in the first week of June is about 55%. For Salem, only low water demanding crops can be suggested, for Vishakhapatnam moderate water demanding, while for Ratnagiri even a drought-sensitive crop will be suitable.

Among the ten stations of G agroclimatic zone, at Vellore and Nellore, the commencement of growing periods are found to be not dependable. At Tiruchirappalli, Vellore and Nellore the rabi season is found to be the favourable period for cropping while at all other stations kharif season is favourable. Among this group, at Tiruchirappalli, Vellore and Nellore, only drought-hardy varieties of crops can be grown. But at Hyderabad, Gulbarga, Pune and Aurangabad, moderate water demanding crops will be suitable. High water demanding crops will be suitable for Hanamkonda, Nizamabad and Bombay. In this climatic type, Nellore and Pune have probability of dry spells of more than one week duration. At Nellore there is a 55% probability for the 31st week to be dry. Similarly during the 35th to 36th week, there is a 60% probability of dryness. At Pune, during 34th to 37th week the probability of dryness is 60%.

Among the stations, whose agroclimates are of F type, the commencement of growing period is dependable at Pamban and Raichur. At Pamban and Madurai, the rabi season is found to be more favourable while at Raichur the kharif season is favourable; at Chitradurga and Gadag, both the seasons are not that favourable. At Pamban and Raichur moderate water demanding crops can be grown, but at other stations only drought-hardy varieties will be suitable. Chitradurga has more than 50% chance for a dry spell to occur from 34th to 37th week while at Gadag three dry spells of more than one week duration - 24th to 25th, 32nd to 33rd and 35th to 37th week - have on an average 60% probability of occurrence during the growing period and the 29th week also has nearly 55% probability of dryness.

Among the four stations of E type agroclimate, Coimbatore and Kurnool have dependable commencement of growing periods. At Coimbatore and Bijapur, rabi season is comparatively favourable for cropping and at these two stations, no dry spell is observed during the growing period. Crops of moderate water requirement can be grown too. At Cuddapah and Kurnool, only drought-hardy varieties will be suitable. At Cuddapah, the 28th week has 55%

probability for dryness and at Kurnool 34th - 35th week period has slightly more than 50% of dryness.

At both the stations - Anantapur and Bellary - of D type agroclimate, the commencement of growing period is not dependable and no part of the growing period is favourable though no dry spells are observed during the growing period: however rainfed agriculture will be risky.

The regions where dry seeding is favourable are along the west coast and south eastern coast. Generally in the interior parts of Karnataka, Rayalaseema and South Tamil Nadu, dry seeding will be risky.

It is seen that the maximum value of probability of wet weeks in South India during winter season varies between 20% and 30% and the region of high values is confined to South Kerala and South Tamil Nadu coasts and Telangana. The Kodaikanal region is an exception to the general pattern.

During the pre-monsoon season, the P(W) values are found to increase steadily over the region. It is seen that, from the South Kerala coast and from Telangana the probability values spread towards central parts of the study region. The maximum value of P(W) during this season rises upto 70% to 80% and the least value is less than 10%. Compared to the west coast, east coast stations have lower values of probability of wetness.

During the monsoon season, the alignment of isolines of P(W) with the topography of the Ghats is an important feature. Generally, the values vary between 100% on the windward side of the Ghats to less than 10% around Pamban in the east coast. The gradient of values from windward side to leeward side of the Ghats is clearly seen. In this season too, the east coast has lower values than the west coast.

Generally, a reduction in P(W) values is observed along west coast and in Telangana but along the east coast an increase can be clearly seen during post-monsoon season. The maximum value of P(W) rises upto 80% and minimum values drop to below 10% in this case.

It is clear from the above results that some parts of the South Indian region experience heavy rainfall and have more than adequate water supplies for agriculture and other purposes, whereas other parts experience meagre rainfall. Such a wide spatial variation in the rainfall characteristics is very critical too in this region which depends primarily on agriculture. The region is, however, well supplied with adequate radiant energy. As a result of high temperatures, the water need of the region (potential evapotranspiration) is high. Therefore the amount of precipitation during the growing season is the key factor influencing agriculture production.

Where the water need of the area (evaporation and transpiration by plants) is matched by the rainfall, there is no water stress for the plants. Since plants meet almost all the water requirements, through their roots, the importance of water retention and release characteristics of the soils is evident.

Where the rainfall and water requirements of the crops are not matched (in timing, amount and duration), there would be moisture stress on the plants. If these stresses affect the plant during critical phases of their growth, the yields could be much below the normal.

The present investigation has attempted to analyse in detail the agroclimatic potential of the South Indian region. The study on the accumulated assured rainfall at 75%, 50% and 25% probability levels brings out its spatial variability over the region. The quantum of the assured rainfall does not indicate the quantum of available water to plants, because the same amount of precipitation can have different effects on the plants depending up on the water need. Therefore, the moisture availability index concept has been used to classify the region.

Such an analysis supplemented by information on soil types have lead to the delineation of clear cut agroclimatic zones and sub-zones. The results of this study have delineated the growing periods at all the selected representative stations at different probability levels. The risks involved in rainfed agriculture in this region have also been quantified and suggestions have been made for selecting crops at individual stations.

However, mid-season water stress to crops may arise due to prolonged rainless dry spells. With this in view, the probabilities of runs of wet and dry spells have been worked out. The information generated from this study can help to assess the crop growth potentials of the different growing seasons in the region. Significantly, the growing periods delineated using the Gamma distribution model are the same as those generated by the Markov chain model.

It is worth repeating that all the results discussed in this investigation are valid strictly for rainfed agriculture. Where sufficient water is available for supplemental irrigation, the growing periods could be increased, the agricultural risks reduced and the crop yields improved. However, availability of water for irrigation is again dependent on the rainfall pattern of the region. In regions of heavy rainfall and consequent water surplus, proper management practices can mitigate seasonal water deficits.

The large quantity of surplus water flowing into the seas unexploited can be harnessed to a good extent by the construction of dams and reservoirs at proper locations. Inter-linked with the heavy rainfall is soil erosion which in the long run would be detrimental to agriculture. Soil conservation measures and judicious land-use practices are very important for proper soil management.

By the optimum utilisation of available water, it is possible to improve the agricultural production of dry areas in the region. The agroclimatic zoning help in transferring knowledge and experience from one place to another. Hence, growing season may be adjusted or new crops may be adopted to get higher yields. In this way agricultural development can be achieved by increasing the growing period of crops and by increasing the area of cropping.

In conclusion, it may be said that the overall development of the region is linked to its agricultural development. Therefore, it is necessary to maximise the crop yields by proper planning of agriculture in relation to climatic factors. With this in view, steps need to be taken to generate more agrometeorological data for the purpose of analysing crop-weather relationships. There is also a need to classify the agroclimates at the microlevel, so that the variations in plant growth in diverse environments may be better understood. This would also help in the transfer of information between homoclimates and enable agricultural experimentation.

Agricultural development is possible only by the proper appreciation of the climatic factor - the role of the agroclimatologist cannot be over emphasised.

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