IMPACT OF CLIMATIC VARIABILITY AND DROUGHTS ON CROP YIELDS IN KERALA

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MARCH 1996

To my beloved parents

DECLARATION

I do hereby declare that this thesis entitled " Impact of Climatic Variability and Drought on Crop Yields in Kerala" is a genuine record of research work carried out by me under the guidance of Dr H. S. Ram Mohan, Professor and Head of Department of Atmospheric Sciences, School of Marine Sciences, Cochin University of Science and Technology, Kochi and has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title of recognition.

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CERTIFICATE

I hereby certify that this thesis entitled " Impact of Climatic Variability and Droughts on Crop Yields in Kerala " is an authentic record of genuine and bonafide research work carried out by Ms. Haseena Raghavan during the period 1991 to 1996, under my supervision and guidance at the Department of Atmospheric Sciences, 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 I

INTRODUCTION

The State of Kerala lies in the southwest corner of India as a long and narrow strip of land lying between the Western Ghats and the Arabian Sea. Its coastal line is 580 km. long and its breadth varies from 130 km. in the central parts to 32 km. at the extreme ends. It has an area of 38,863 sq. km which represents 1.18 per cent of the total area of India. However, it supports 3.43 per cent of the total population of the country (1991 census)

The physical configuration of the State is singularly diversified. The forest-clad Western Ghats, forms the eastern boundary of the State. From the Western Ghats, the land undulates to the west presenting a series of hills and valleys intersected by numerous rivers and streams. The western portions of the State adjacent to the Arabian Sea is more or less level and numerous lakes and backwaters adorn this narrow coastal belt. These diverse characteristics of the land and consequent changes in plant growth demarcate the State into three distinct regions: the highland, the midland and the lowland.

The highlands slope down from the Western Ghats which rise to an average height of 900m, with a number of peaks well over 1,800m in height. This is the area of major plantations like tea, coffee, rubber, cardamom and other spices.

The midlands, lying between the mountains and the lowlands, is made up of undulating hills and valleys. This is an area of intensive cultivation. Cashew,coconut, arecanut, tapioca, banana, rice, ginger, pepper, sugarcane and vegetables of different varieties are grown in this area.

The lowlands or the coastal area, which is made-up of the river deltas, backwaters and the shore of the Arabian Sea, is essentially a land of coconut and rice. Fisheries and coir industry constitute the major industries of this area.

Kerala is a land of rivers and backwaters. Forty four rivers (41 west-flowing and 3 east-flowing) cut across Kerala with their innumerable tributaries and branches, but these rivers are comparatively small and being entirely monsoon-fed, practically turn into rivulets in the dry months, especially in the upper reaches.

Paddy, coconut, arecanut, tapioca, pepper and rubber are the most important crops of the State. Owing to historical and climatic reasons, the State has developed commercial agriculture more than food crops. Consequently, the State is short of food grains, especially rice which is the staple food of the people.

Kerala has a unique cropping pattern. It accounts for 92 percent of India's rubber, 70 percent of coconut, 60 percent of tapioca and almost 100 percent of lemon grass oil. Kerala is the single largest producer of a number of other crops such as banana and ginger, besides tea and coffee in abundance.

Though rubber was originally cultivated in the lower highland region, it has made deep inroads into the midland region also. Now-a-days, rubber is the most flourishing crop of the

State. Paddy being a seasonal crop, is cultivated on the wet lands during the three seasons The high cost of cultivation and comparatively low return on rice now-a-days has adversely affected both area and productivity of paddy Though rice is the staple food of the people of the State, they have to depend upon the Central government and the neighbouring States for their food needs as the rice produced in the State is less than half of the quantity required. In the present context, a detailed discussion on the land-use pattern of the State seems to be quite relevant. Information regarding the area and productivity of major crops, would give a vivid picture of the agricultural status of the State.

The State is blessed with a salubrious tropical climate, with heavy rainfall, high humidity and fairly uniform temperature throughout the year. Agriculture in Kerala is primarily rain dependent. Every year its fate oscillates with the onset, progress and spatial distribution of the south west monsoon rainfall and spatial distribution of post-monsoon and pre-monsoon rainfall. Even for the crops grown in irrigated areas, the quantum of irrigation requirement depends upon the distribution of rainfall during the rainy season. As droughts and floods are a consequence of variabilities in the quantum and distribution of rainfall, it is necessary to have a detailed knowledge of the rainfall statistics. The State receives an average annual rainfall of 294.3 cm. ranging from 175 cm. in the extreme south to 350 cm. in the north. The spatial and temporal variability in rainfall occurs due to differences in physiography, temperature, air pressure, proximity to sea etc.

besides several other factors global, regional and local

Severe and disastrous droughts often play havoc with the economy of the State. One of the common natural hazards faced by many countries in the world, sometime or other, is drought which can occur in any climatic region. In this context, a detailed study of the occurrence of droughts in the State seems to be very relevant and necessary The Index of Moisture Adequacy, which is the percentage ratio of actual evapotranspiration to potential evapotranspiration on an annual or monthly basis gives very essential information useful for various agricultural activities, such as choosing the variety of crops, adjusting the farming operations, assessing the irrigation potential of the region and scheduling the irrigation operations.

Lack of rainfall or soil moisture is not the only parameter which influences the growth and development of a crop. Any crop has its own optimal requirements of environmental factors such as rainfall, temperature, soil moisture supply, soil warmth, duration of darkness, light intensity etc. Crops are often influenced significantly by one or two atmospheric parameters that are more crucial for their growth and development than others. Therefore, a thorough understanding of crop weather interactions and thereby the development of crop weather models for yield prediction is essential.

In the present investigation, the impacts of the variability of the climatic parameters on the yields of major crops grown in the State are analysed. In particular, the effects of rainfall variability on the water balances of the different regions in the State have been studied. Through this analysis the drought climatology of the region has been studied along with an overview of the climatic shifts involved in individual years. The relationship between weather parameters and crop yields over the State have been analysed with case studies of two crops- coconut and paddy. Crop-weather models for forecasting coconut and paddy yields have been developed, which could be used for planning purposes.

The thesis consists of six Chapters including the Introduction. The first section of the second Chapter gives a detailed review of rainfall variability, and droughts. Thornthwaite's book-keeping procedure of water balance, various methods of analyzing and categorizing droughts and crop weather models for predicting crop yields have been discussed alongwith various methods of analyzing crop- weather relationships in Section Two. The methodology followed in the present study for analyzing droughts and investigating crop- weather relationships is presented in Section Three of this Chapter. Statistical techniques such as correlations, Principal Component Analysis and multiple regression models are discussed in detail. Details concerning meteorological data used in the present study are also furnished in this Section,

The Third Chapter consists of a discussion of the important physico-climatic features and agricultural status of Kerala State. A detailed picture of the location and extent, physiography, drainage and soil type over the State is given in Section One. Section Two consists of a review of the distribution of climate types over the State, while Section Three discusses its agricultural status.

Studies previously carried out on variability of rainfall over Kerala State are referred to in the first Section of the fourth Chapter. The drought climatology of the State such as occurrence of droughts, categorization of droughts and the spatial coherence have been presented in the Second section. An analysis of the climatic shifts that occurred during the study period is also presented.

The fifth Chapter deals with case studies of crop- weather relationships. Two crops - coconut, a perennial crop and paddy an annual crop - that are most important for the State have been chosen for this purpose. The different stages of coconut development and its relationship with weather parameters during its development is presented in Section One. A crop-weather model for forecasting coconut yields, is developed and presented. Section Two deals with the different phenological stages of the paddy crop and their relationships with weather parameters during the growth period. This Section also discusses the development of a crop-weather model for forecasting paddy yields.

The sixth Chapter comprises the summary of the study, and conclusions drawn from the investigations and the recommendations based on the results.

CHAPTER II

LITERATURE REVIEW , MATERIALS AND METHODS

An exhaustive and relevant review of literature on the various aspects of study in the present investigation is presented in this Chapter The first section reviews the available literature on climatic change and variability. The concept of droughts and the different methods of analysis are presented in section Two. This section also includes a review of various crop weather models. The data employed and the methods used in the thesis are discussed in section Three.

2.1 Climatic change and climatic variability

The term 'climate' usually brings to mind an average regime of weather. However the mechanisms that create the earth's climate and its variations are part of an enormously complex physical system, which includes the relatively well known behaviour of the world's ocean and ice masses, together with the variations occurring at the earth's surface.

Climatic change, variability, trends, discontinuities and fluctuations are inherent features of the climatic system. All forms of climatic inconstancy, regardless of their statistical nature (or physical causes) can be termed climatic change. It is generally slow and hence its effects are of small magnitude in the short term. Climatic discontinuity can be defined as a climatic change that consists of a rather abrupt and permanent change during the period of record from one average value to another On the other hand climatic trend is a climatic change characterized by a smooth, monotonic increase or decrease of average value in the period of record. A climatic fluctuation is a climatic inconstancy that consists of any form of systematic change, whether regular or irregular, except trend and discontinuity, and climatic variation, a fluctuation or a component thereof, whose characteristic time scale is sufficiently long to result in an appreciable inconstancy of successive 30-year averages (normal) of the variable.

Climate is not a static feature of the environment - it includes an element of continuing trend, or a discontinuity, in the average value or variability of some climatic elements. Perhaps, the first phenomenon in recent years that lent credence to the idea of changing climate was the extreme drought in the southern fringe of the Sahara, the Sahel, in the early 1970s. Next came the bad wheat harvest in the USSR in 1972, the unusual freeze in Brazil in 1974 that destroyed much of the coffee crop, very limited monsoon rains over the Indian subcontinent etc. Also, adding weight to the climatic change idea were the investigations during the 1960s which indicated that there had been a cooling of the land areas in the mid and high latitudes of the Northern Hemisphere by a few tenths of a degree beginning in the early 1940s.

Every quantifiable element of the weather, such as temperature, pressure and rainfall, varies continuously or discontinuously with time on all time scales, so that an essential aspect of climate is its variability The meteorologist's concept of climate is a dynamic one, including day-to-day changes of weather, the seasonal cycle, and small-scale variations of atmospheric conditions measurable over periods of two to 25 years. Long series of observations show something like a "beat" phenomenon, with an unevenly varying wavelength. This built-in variability of the atmosphere results from the varying time lag between any single cause and effect, from the interaction of multiple factors, and from mechanisms set in progress by one or more variables over different time scales. Climate is never stable but is subject to continuing oscillations, such as the waxing and waning of many atmospheric components over a variable period of 23 to 29 months.

The principal factors inducing spatial variability of climate are latitude, elevation, local topography, proximity of the sea and the position and size of land masses relative to oceans and other continents. The spatial variability arising from these factors produces variability in time through the motions of the atmosphere and oceans and the interactions between them. Each year the Earth experiences changes in its radiation budget, and in the distribution of heat input into the atmosphere, in the course of the seasonal migration of the zenith Sun between Tropic of Cancer and Tropic of Capricorn. The seasonal changes are accompanied by a general northward and southward movement of the subtropical anticyclone belts and other main features of the atmospheric circulation. This seasonal northward and southward migration of cyclonic activity give rise to wet and dry seasons. The seasonal migration of the wind zones and belts of cloud, rainfall and cyclonic activity is not a smooth or continuous progression, but occurs in stages. It is the end product of an alternating sequence of pulse-like advances and retreats. Occasionally, the successive pulses occur at nearly uniform time intervals, which presumably correspond to the common duration of some cyclic process in the atmosphere or involving both atmosphere and ocean. Thus, the variability of climatic elements in time may be regarded as deterministic or stochastic with some element of persistence (Mitchell, 1966) - or a combination of the two depending largely upon the time scale involved.

Large day to-day weather changes cause little trouble. But abnormalities as long as a season disrupt orderly planning, from private actions of individuals to the collective work of whole nations. Such anomalies have major impacts on crop yields, ocean fisheries, and survival of flocks and herds. World food production and energy consumption, both, in the course of rapid expansion, are seen to be especially sensitive to climatic variability.

Many methods have been used to assess past climates. For climates of the distant past, the most useful techniques are through a study of land forms, such as the evidence or absence of glaciation or the incidence of coastal or river terraces, and through deductions based on the location of the various land masses. Tectonic, topographic, and paleomagnetic observations are helpful in determining the position of the continents at various times. Another method for estimating past climate uses the uniformitarianism principle. This concept states that if a particular biological or geological situation exists under known climatic conditions at the present time, then its existence in the past predicates the idea that climatic conditions were then as they are now. Some of the most publicized methods of climatic assessment use this technique: pollen studies (palynology) dendroclimatology (tree-ring analysis), and oxygen-18 isotopic analysis. Other methods using written records have also increased our knowledge of more recent climatic conditions while instrumental records only apply over the past few hundred years.

The study of climatic history is valuable because what has happened in the past may well happen again. This involves description and investigation of causes and effects of climatic fluctuations and their statistical interpretation.

(a) Climatic history of the Earth

During the past, the earth has been experiencing a long sequence of alterations between glacial and interglacial epochs of climate, in which the glacial epochs have tended to recur at approximately 100,000 years intervals. For about the past 8000 years, the Earth has been in a comparatively warm interglacial phase of this ice-age sequence, with less ice than at anytime in the past 100,000 years.

If we consider that the age of the earth, 4.6 billion years, is represented by one year, then one second is equivalent to about 146 years. The Precambrian Era comprises about seven-eighth of the earth's life span, and in our concentrated time it covers the period from January 1 to November 16. Very little is known of the climate of this period during which cooling processes began, cataclysmic upheavals occurred, and the earth's atmosphere began to form and evolve in the late Precambrian into something approaching what we have now Next comes the Paleozoic

Era, which is between November 16 and December 12 in our concentrated time scale. It is suggested that widespread glaciation, rise of land plants, drifting of North America and Eurasian towards Gondwana, occurred during this period. The reptiles also seem to have appeared at this time. The most intense glaciation since the last Precambrian ice age occurred in the Permo Carboniferous time of Paleozoic era, about 260 Million years before present (MYBP)

In our special time scale, between December 12 and 26 the Mesozoic Era occurred The whole era is characterized, from present evidence, by high temperatures in lands that are now in northern latitudes. Mesozoic Era is succeeded by Cenozoic Epoch which extends from December 26 to about 8:30 P.M. on December 31. Appearance of modern mammals, development of circum-antarctic current, glaciation on Alaska Mountains and Western Antarctic ice sheet occurred during this period. The time from 8:30 P.M. to 11:49 P.M. on December 31 on our concentrated time scale covers the period from 1.8 MYBP to 100,000 years before present (YBP) and comes in the Quaternary period. From the strong evidences, based on data from two Ocean cores, it is surmised that changes in earth-sun geometry are the fundamental causes of the succession of Quarternary ice ages.

We are up to 11:59 P.M. on December 31 on our time scale when we consider 100,000 to 10,000 YBP. It appears that around 100,000 YBP there was a very rapid warming, culminating in a global temperature as high as any in the past million years. Then, around 75,000 YBP and between 22,000 to 14,000 YBP there were intense glacial maxima, which were sometimes abruptly terminated. After 14,000 YBP, there was a warming trend that culminated around 6000 YBP. The last 10,000 years are referred to as the Holocene Period climatically they correspond generally to a warmer spell. On our comparative time scale we are now at about 7 seconds before mid night on December 31. The early medieval period of 800 to 1200 A.D. has been called the little climatic optimum because of the relative warmth of most of the Northern Hemisphere. The interval from about 1430 to 1850 A.D., known as the Little Ice Age, saw a global temperature decrease of about 1.5^{0}c. During the last 100 years which corresponds to the last second of our time scale the most accurate measurements of the atmosphere have been made. Records indicate a gradual warming trend from about 1880 to 1940, a decrease from 1940 to 1960 or 1965, and no discernible trend from 1965 to the present.

(b) Past climatic changes in India

In recent years definitive data on past climatic change has become available from Arabian Sea, Rajasthan and Kashmir, though the total time range covered is different in different regions.

It appears that before c. 3.5 Myr the climate of Kashmir valley fluctuated between warm temperature and sub-tropical. The first cold phase is discernible after 3.5 Myr. This climatic change appears to be due to the rise if Pir Panjal range which acquired its present height of about 5000m around 3.5 Myr only A succession of five glacial-interglacial oscillations can be recognised between 0.7 to 0.03 Myr.

In Rajasthan the dating of climatic events is not very precise for the earlier phases. It appears that the Jayal and Amarpura formations cover the Early to Middle Quaternary It appears that the Thar Desert came into being c.200 Kyr The southwest monsoon began strengthening by c.13 Kyr with a significant increase in rainfall during mid-Holocene. Equally, interesting is the finding that the major sand dune activity is datable to PScPS 14-15 Kyr the period just preceding the strenghtening of the Indian South-West monsoon.

The cores from the Arabian sea show a distinct cooling at c.18 Kyr. In fact, recent work clearly shows that the uplift of Tibetan Plateau which brought up a low relief land mass of 2.4 million sq.km to a height of about 5 Km has played a role in the evolution of the Indian monsoon.

(c) Climatic Variability

Climate over the earth is not constant with time: they change on different time scales ranging from the geological to the diurnal through annual ,seasonal and intra-seasonal time scale. Such a variability is an inherent characteristic of the climate. To regard the normal alone as an adequate expression of climate would be a serious error; it is better to regard current climate as the entire ensemble of recently observed atmospheric conditions.

Like other aspects of atmospheric behaviour, the fluctuations in climate are also of great complexity. The study of climatic fluctuations involves description and investigation of causes and effects of these fluctuations and their statistical interpretation.

It is observed that many of the fluctuations are not randomly distributed around a constant normal. In fact, there are variations in the normal itself, may be in the form of a trend or periodicity The periodic phenomena reproduce themselves regularly and hence have predetermined period and phase. Quasi-periods are less regular and non-periodic phenomena are random fluctuations.

Availability of observed data for the last one or two centuries help us to understand more details about climatic fluctuations. Seasons are very much part of the climate and the seasonal variations are periodic, being controlled by the orbital movement of the earth around the Sun and the tilt of the earth's axis. Similarly, diurnal variations of many meteorological parameters are periodic, controlled by rotation of the earth on its axis. There are two categories of mechanisms responsible for interannual variability: a) changes in the internal dynamics, that is changes in the intensity of mean circulation of the atmosphere or ocean or due to shifts in location or timing of these circulation systems and b) changes in the boundary conditions which include changes in sea surface temperature, soil moisture, snow cover etc. There is ample evidence that local and regional climates can be modified by man. Various activities of man modify the composition of the atmosphere and physical and biological properties of the underlying surface.

Since we are unable to explain fully the physical reasoning of the fluctuations, statistical analyses of climatological time series have been employed to get more insight about the problems of climatic variability A climatological time series may consist of wholly random variations, or wholly non-random variations, or of a sum of both random and non-random components. There is no single statistical tool, that is uniformly efficient, identifying all possible alternatives to randomness in the series. The power spectrum analysis is, however, very effective and sufficiently flexible to distinguish between different types of non-randomness and also amenable for direct tests of their statistical significances.

Variability of climate in terms of temperature and rainfall is a natural consequence of variability of the atmospheric circulation. Circulation variability entails variability in cloud cover, resulting in variability in the earth's long wave radiation budget. An important component of climatic variability is in the sea surface temperature.

The principal forces governing climate, whether global or local are radiative. There is the incoming radiation from the sun, part of which is directly reflected back by clouds and from the surface, and the second great element is the infrared radiation flux from the earth back into space.

By judicious use of older instrumental observations and proxy data, and exploiting known teleconnections of climate the record of temperature can be extended to the sixteenth century

Several studies have been reported on the long-term variation in surface air temperature in the past century for the whole globe (Mitchell, 1963; Angell and Korshover,1978;) as well as for the hemispheres (Borzenkova et al.,1976; Brinkmann,1976; Barnett,1978; Jones et al.,1982) These studies have indicated a warming of the Northern Hemisphere between 1880 and 1940 and cooling thereafter A reversal of the post 1940 cooling during the 1960s has been suggested by some workers (Lamb et al., 1975; Budyko, 1977; Jones et al.,1982) but this is not yet well established because of data limitations.

Very few studies have been made on temperature trends in India. The annual maximum and minimum temperatures of 20 meteorological observatories situated in India and neighbourhood were studied by Pramanik and Jagannathan (1954) The study revealed that there is no general tendency of systematic increase or decrease of temperature over these stations. Jagannathan (1963) and Jagannathan and Parthasarathy (1972) have analysed the trends in the characteristics of seasonal variation of temperature in the arid and semi-arid regions of the globe which included 8 Indian stations with about 55 to 100 years data. Recently, Hingane et al. (1985) and Sarker and Thapliyal (1988) have studied the trends in long period temperature data from about 70 stations well distributed over India.

If oscillations govern temperature, this tendency is even more pronounced in precipitation. In many regions of the world, this most fickle of climatic elements fluctuates from inundation levels to drought and back. Some of the most populous regions of the world are subject to the monsoonal vagaries; and considering the intimate relation of crop production to rainfall and irrigation, rainfall governs the nutritional status of the vast majority of mankind.

Precipitation must be looked at in terms of local or regional conditions. It does not lend itself to consideration on a continental, hemispheric or global scale.

Extremes of variation of rainfall result in floods and droughts and severe economic stresses of many countries have been known to be due to these abnormalities. But studies show that most of the severe droughts and floods are normal to the climate, in the sense that they have occurred before, and presumably will occur again. They are inevitable consequences of the year to year variability, and need not imply a climatic change.

The best known example of an almost periodic interannual variation is the quasi-biennial oscillation of wind direction and speed and temperature in the lower stratosphere in the tropics. The discovery of the tropical stratospheric quasi-biennial oscillation (Clayton, 1884,1885) has been followed by very widespread reports of quasi-biennial behaviour in local troposheric climate and circulation parameters.

The existence of periodicity in annual rainfall implies that wet and dry years may recur with a certain regularity and long term periodicity implies that wet and dry years tend to persist for a few years. A general review of investigations about cyclic behavior in the atmosphere is given by Lamb (1972) Stringer (1972) reported that atleast 35 quasi-periods with more than one year in length have been discovered in records of pressure, temperature, precipitation and extreme weather conditions over many parts of the earth surface even though the physical aspects behind this tendency is not fully explored. The very common quasi-biennial oscillation (QBO) in which the climatic events recur every 2 to 2.5 years was first observed in stratospheric winds in low latitudes (Reed,1960), but Landsberg (1962) and Landsberg et al.(1963) established the existence of QBO as a world wide phenomenon in surface meteorological parameters also.

The QBO in Indian rainfall was first reported by Koteswaram and Alvi (1969);later many others also reported this phenomenon in Indian rainfall (Bhargava and Bansal,1969, Jagannathan and Bhalme, 1973 and Parthasarathy and Dhar, 1974) Existence of QBO in other climatological time series such as annual frequencies of cyclonic disturbances in Bay of Bengal (Bhalme, 1972), mean annual temperature (Jagannathan and Parthasarathy, 1973), drought indices (Parthasarathy and Rakhecha, 1972) have also been reported. Using rocket sonde data over Thumba, George and Narayanan (1975) observed QBO in the middle stratosphere over Indian equatorial region. Raja Rao (1977) and Raja Rao and Lakhole (1978) tried to relate the phase of QBO with the southwest monsoon while Thapliyal (1984) tried to predict Indian droughts with stratospheric winds.

Possible association of middle atmospheric oscillation over India with Indian summer monsoon was investigated by Mukhopadhyay and Sarkar (1990) Trends and periodicities of monsoon and annual rainfall have also been studied by Subramaniam et.al (1992) and Bhukan Lal et.al (1992)

The solar cycle, the oscillation of 8 to 15 year period, is generally observed in many meteorological parameters Sen Gupta

(1957) showed a negative correlation between sunspot activity and rainfall amounts in Tamil Nadu. Koteswaram and Alvi(1970) observed a negative relationship between and sunspot in west coast stations, particularly Cochin and Trivandrum. Bhargava and Bansal (1970 a, b) studied the correlation between sunspot cycle and temperature and found that they have spatial and temporal modulation. Jagannathan and Bhalme (1973) showed a positive relationship between sunspots and southwest rainfall at a number of sub divisions, especially along the foothills of Himalayas. Bhalme(1975) found that breaks in monsoon are more during sunspot maxima while storms and depressions are less. Mukherjee and Singh (1978) found that correlations of sunspot cycle with rainfall have spatial and temporal modulations. Reddy et.al. (1979) found that there is a correlation between sunspot activity and rainfall amounts during southwest monsoon season, but not during northeast monsoon. Ananthakrishnan and Parthasarathy (1984) observed a negative relationship between sunspots and rainfall in south eastern parts of Indian peninsula and a positive relationship in other parts of peninsula.

Koteswaram and Alvi (1969) and Parthasarathy and Dhar (1974) reported the influence of solar cycle in Indian rainfall.

The southwest monsoon has large inter-annual variability in the quantum of rainfall and in the dates of its onset and withdrawal. The onset of the southwest monsoon over Kerala marks the beginning of the principal rainy season for India, during which the country receives the bulk of its annual rainfall. The remarkable punctuality of the monsoon's arrival over the Kerala coast around the end of May / beginning of June is well known.

In general, the date of onset of the monsoon is determined by a marked increase in rainfall which has a fairly large spatial extent and is maintained over a reasonably long period (Ananthakrishnan et.al 1979) Superposed epoch analysis of averaged rainfall by Ananthakrishnan and Soman (1988) reveals the same.

A large number of studies have been made on the synoptic features of the onset phase of the southwest monsoon, which were summarized by Ananthakrishnan et al (1968) and Rao (1976) After the Monsoon Experiment 1979 (MONEX_79), some studies using First Global GARP Experiment (FGGE) data sets have addressed the diagnostic and prognostic aspects of the monsoon onset (Krishnamurti et. al 1981; Krishnamurti and Ramanathan 1982;Pearce and Mohanty 1984; Kershaw 1988; Slingo et.al 1988) A composite study of some meteorological features during the onset phase over south Kerala was attempted by Soman and Krishnakumar (1993) A similar study on the onset phase of Australian summer monsoon has been made by Hendon and Liebmann (1990)

There are periods when most parts of the country experience striking decrease in rainfall. Such a synoptic situation is referred to as break in monsoon. August is slightly more susceptible to break days and longer 'breaks',particularly the middle of the month. The beginning of July and end of August have less number of break days.

Active and break cycles of monsoon activity on the intra-seasonal time scale have been well experienced in the Indian summer monsoon. These breaks appear to be two cycles, either of 10-12 days or of 40-50 days duration (Feins et.al,1987) Joseph and Pillai (1988) observed an intra-seasonal variability with the 30-50 days mode in the cyclogenesis in the equatorial trough and in the monsoon rainfall. Keshavamurthy et .al (1988) concluded that northward movement of this 30-50 day oscillation in the Indian monsoon region appears to be controlled by the basic zonal wind profile and convective activities. 30-60 day periodicities in the monsoon fluctuations was confirmed by workers like Chowdhury et al (1988 a,b) and Chandra Sekhar et al. (1990), investigating into the fluctuations of cloud cover and outgoing long wave radiations. Murakami et al (1986) and Chen (1990) suggested that the interaction between the annual cycle and the 30-50 day mode results in the monsoon life cycle. Morphology of 30-50 day oscillation found in summer monsoon in different directions, different weather parameters and at various levels have been discussed by Keshavamurthy et al (1990)

El Nino / Southern Oscillation (ENSO) is the most prominent climate variability with interannual time scales in the Tropics. It has been widely accepted that ENSO is a manifestation of the atmosphere-ocean interaction (Philander,1990) Since observations of atmospheric and ocean fields are limited, details of the ENSO mechanism have not been fully disclosed.

The discovery of Southern Oscillation led Walker (1923) to believe that a future search may well reveal factors which have close association with the monsoon. Individual disastrous droughts over India and associated circulation anomalies have been examined by many workers (Keshavamurthy and Awade, 1974;

Kanamitsu and Krishnamurti,1978; Raman et al 1980; Sikka, 1980) It is known that monsoon rainfall over India is less (more) than normal during the El Nino (cold) events (Angell, 1981; Rasmusson and Carpenter,1983; Ropelewski and Halpert, 1987,1989) This may indicate that monsoon activity is regulated by ENSO.

Pant and Parthasarathy (1981) computed a linear correlation coefficient of 0.59 between the June - August area -averaged precipitation over India and a contemporaneous Southern Oscillation Index developed by Wright (1977) Angell (1981) correlated summer monsoon rainfall over India with the average SST anomaly along the equator between the South American coast and the International date line. Tanaka (1982) considered the El Nino years of 1965, 1972 and 1976 to be years with a week monsoon. Bhalme et al (1983) devised April Pressure Index (PI), which can be regarded as a measure of the Southern Oscillation for the prediction of large-scale droughts/ floods over India. Rasmusson and Carpenter (1983) analysed the relationship between equatorial Pacific warm episodes (El Nino events) and inter-annual fluctuations in precipitation over India and Srilanka. Barnett (1985) has suggested that the ENSO cycle originates in the Indian Ocean, and while Yasunari (1990) has opined that monsoon activity plays an active role in ENSO. Currently, the relationship between monsoon and ENSO is not clarified (Webster and Yang,1992) The relationship of interannual variability of monsoon with ENSO was explored by Nagai et.al (1995)

2.2 Agricultural droughts and Crop-weather modelling:

2.2.1 Concept of drought

(a) Droughts

Drought is a general term implying a deficiency of precipitation of sufficient magnitude so as to interfere with some phase of the economy It is one of the serious natural calamities which frequently inflict one part or the other of the world. Historical evidences show that droughts and resultant famine conditions have been one of the most serious of natural hazards to man since ancient times in our country. Drought is a creeping disaster, as a situation of drought develops gradually giving sufficient warning of its coverage, extent and intensity unlike floods, cyclones and earth quakes which offer little time and opportunity for planning and preparedness.

Though droughts have been defined variously, they are generally understood as periods of dryness due to lack of rain. The concept of drought varies from place to place depending upon the normal climatic conditions, available water resources, agricultural practices and various economic activities of the region. To the meteorologist, drought is a rainless situation for an extended period during which some precipitation should have been normally received depending on the geographical location of the place and season of the year, while to the agriculturist, drought is a shortage of moisture availability for his crops.

Drought is a meteorological phenomenon and the vulnerability to drought of any region, therefore, depends on the extent to which physical and climatic conditions play an adverse role in creating an unstable agriculture. Agricultural drought occurs when plant growth gets seriously affected on account of prolonged shortage of moisture in the soil. With prolonged deficiency of rainfall, hydrological drought occurs with marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers, cessation of spring flows and fall in ground-water levels.

There is no universally accepted definition of drought though, a detailed description of definitions of droughts has been given by Subrahmanyam (1967) Early workers defined drought as a prolonged period without rainfall. Air Ministry Meteorological Office (1936) defined absolute drought as a period of at least 15 consecutive days none of which had rainfall of 0.25mm or more. Blumenstock (1942) gave detailed methods for calculation of drought probabilities using rainfall data. According to Ramdas (1960), drought is a situation when the actual season rainfall is deficient by more than twice the mean deviation. Van Rooy (1965) developed a drought anomaly index based on rainfall departure and mean of the lowest ten values of rainfall in series. .Gibbs and Maher (1967) made a study of drought in Australia by using annual rainfall deciles as drought indicators. Using similar criterion, droughts in Bihar were studied by George and Kalyanasundaram (1969) A slightly modified criterion of Van Rooy, was adopted by Kalyanasundaram and Ramasastry (1969) for study of droughts in Bihar State. At the India Meteorological Department, a year with annual rainfall of 75% or less of normal is taken as a drought year and 50% or less as severe drought year.

For weekly rainfall, Ramdas and Mallik (1948) defined drought as a week with actual rainfall equal to half the normal rainfall or less Govindaswamy (1953,1962) studied weekly rainfall abnormalities in various meteorological sub-divisions in India adopting the same criterion. The criteria adopted by Mallik (1958) and Mallik and Govindaswamy (1962-1963) for drought studies were also the same.

(b) Agricultural droughts

The American Meteorological Society defined agricultural drought as "a period of abnormally dry weather sufficiently prolonged, for lack of water to cause serious hydrologic imbalance (i.e. crop damage, water supply, storage etc.) in the affected area", and further stipulated that the term should be reserved for periods of moisture deficiency that were relatively extensive in both space and time (Huschke,1959) This definition emphasizes Linsley's protracted dry spell concept which Palmer (1967) regrets has been ignored by many originators of drought definitions.

Serious attention was paid by Thornthwaite (1947) who discussed the problem of drought at great length from a practical point of view. He pointed out that drought cannot be defined as shortage in rainfall alone, for such a definition fails to take account of the amount of water actually needed" "Drought" he says "does not begin when rain ceases but rather only when plant roots can no longer obtain soil moisture"

Van Bavel (1953) proposed that agricultural drought should be defined on the basis of soil moisture conditions and the resultant plant behaviour rather than on some indirect interpretation of rainfall record. In a subsequent paper (Van Bavel and Verlinden, 1956), drought was treated as a condition in which there was insufficient soil moisture available to crops.

Considering the fact that soil characteristics as well as the type of crop planted govern the availability of soil moisture for use, Richard (1966) rephrased Van Bavel's definition as "agricultural drought exists when the soil moisture in the root zone is at or below the permanent wilting percentage. The condition continues until rain falls in excess of daily evapotranspiration"

Thus agricultural drought occurs when there is insufficient moisture in the root zone of the soil. Continuous measurement of soil moisture or determination of evapotranspiration in crop fields would be useful but not practical. Thus, in most cases indirect method of calculating changes in soil moisture using the concept of potential evapotranspiration and water budgeting approach, was resorted to.

As regards availability of soil moisture to plants in the range of soil moisture from field capacity to permanent wilting percentage, which determines the nature of soil drying rate curves, there are conflicting results. Veihmeyer and Hendrickson (1955) and Veihmeyer (1956) concluded that water is equally available throughout this range. This concept was supported by Van Bavel (1966) and Lowry (1959) This view, however, is not supported by most of the scientists. Pierce (1958) who grew meadow crops in lysimeters, concluded that the actual evapotranspiration rate was maintained at 90% of the potential rate until about two third of the available moisture has been exhausted from the top 30 to 36 inches of soil. Similar curves were presented by Richards and Richards (1957),Gardner (1960) Denmead and Shaw (1962) Penman(1948,1963) found that the amount of water within the rooting zone plus 25mm of water extracted from the soil below the root is available for transpiration at potential rate.

A group of workers believed in linear relationship between relative transpiration rate and available soil water (Thornthwaite and Mather,1955, Denmead and Shaw,1962) The linear relationship between the ratio of actual to potential evapotranspiration and soil storage was also found to hold good for savannah grass in Trinidad (Smith,1959) and for cotton and peanut in Australia (Slatyer,1956)

In order to understand clearly the variation of relative evapotranspiration rate with respect to plant growth and soil water stress, agroclimatic models using soil water balance data should be set up on the basis of water budget. Holmes and Robertson (1959) brought the fact that under non-irrigated conditions a budget that takes into account soil water stress, plant rooting characteristics, stage of growth and soil physical parameters is superior to simpler moisture budgets which do not incorporate this feature. Studies of agricultural droughts on basis of daily moisture balance were made by Van Bavel (1953), Allred and Chen (1953), Van Bavel and Verlinden (1956), Pengra

(1958) and Mehta (1968) In India several drought studies have been made (Subrahmanyam,1958a,1964; Raman and Srinivasamurthy, 1971; Krishnan,1971)

Palmer (1965) developed an improved version of water balance procedure incorporating a two layer approach. He considered the effective soil as made up of 2 layers, viz., surface layer with 25mm of available moisture, depending on the water-holding capacity of the soil. George et al. (1975) studied the drought spells that occurred in different meteorological sub-divisions of India during 1901-1971 by computing monthly Palmer index.

Considerable improvements in the water budgeting procedure have been incorporated in the versatile moisture budget approach evolved by Baier and Robertson (1966) This model incorporates procedures by which it is possible to allow for simultaneous removal of moisture from various layers in the soil by roots on the basis of potential evapotranspiration and available moisture content. Baier (1967) later incorporated a number of improvements in the model.

(c) Methods of analysis of drought

Before building up a sample of drought events, it is necessary to select an objective definition of drought which suits the purpose of the investigation, having regard to the type of meteorological data available over the period of study and the subject area. Further, the choice of a suitable definition of drought is not always simple, as certain variables such as evapotranspiration may not be measured regularly or are not available for the whole period or area. The different methods employed both in and outside India, for the study of drought can be categorized as: (a) Statistical techniques (b) Non-statistical technique (c) water balance methods (d) Dynamic methods.

Statistical techniques involve studies concerning rainfall behaviour such as departure from the normal, periodicities, trends etc. While non-statistical techniques are empirical in nature. On the other hand, water budget methods are based on a sound and rational physical approach. Dynamic methods relate anomalies in weather patterns with the occurrence of droughts.

It was Thornthwaite (1947) who laid the basis for the water balance methods in his paper entitled "Climate and moisture conservation" In this paper, Thornthwaite suggested that drought can never be defined in terms of rainfall shortage alone, since this does not take into account either the water need of the region or the important role of soil moisture on which the plants depend for their existence.

Palmer (1956 and 1957) studied droughts in Kansas State by defining a drought index using the general book-keeping procedure of Thornthwaite (1948) for determining water deficit.

In India, application of the water balance approach for a general study of aridity and droughts was first suggested by Subrahmanyam (1958b) He and his co-workers Subrahmanyam and Subramaniam (1964,1965) Subrahmanyam and Sastry (1969) Ramasastri (1973) Sarma (1974) Bora (1976) Ram Mohan (1978) used the departures of Aridity Index (I_a) of Thornthwaite (1948) from the median value to categorize droughts

A more useful parameter to study droughts from the agroclimatic point of view is the Index of Moisture Adequacy (I_{ma}) derived from water balance procedures. This index firstput forth by Subrahmanyam et al. (1963) with a view to study the cropping patterns in India, is defined as the percentage ratio of the actual evapotranspiration to the potential evapotranspiration on an annual basis. A value of 100% would mean that the moisture status is at the optimum level and agricultural operations can be carried out without any supplemental irrigation. High values of the index denote fairly sufficient quantities of water for use by the soil and plants for evapotranspiration. Some supplemental irrigation would help the actual evapotranspiration reach potential levels. Low values would indicate large moisture stress on the plants whose growth is inhibited resulting in low yields. Irrigation is then absolutely essential if crops are to survive under these conditions. Ram Mohan et.al (1984) employed I_{ma} to categorise droughts of Tamil Nadu.

Since drought is a large scale rather than a local phenomenon, there is a distinct possibility of its simultaneous incidence over neighbouring and adjoining areas. Such a spatial coherence in drought occurrence was studied by Maher (1968) in Australia and by George et.al., (1974) in India. Chowdhury et.al.(1976) studied spatial coherence in droughts during summer monsoons period over India using probability concepts and rainfall deficiency criteria. Subrahmanyam and Ram Mohan (1979) studied spatial coherence of droughts over Tamil Nadu using the Aridity Index, derived from water balance procedures.

2.2.2 Crop weather modelling

Climatic variables affect the crop differently during different stages of development. These effects are manifested through plant characteristics like height, number of tillers, leaf area and number of earheads which ultimately influence the yield. Further, climate may also create conditions which may be favourable or unfavourable for growth of diseases and pests, thereby affecting the crop yield. The effect of climatic parameters at different growth stages of the crop may help in understanding their response in terms of the final yield and also provide a forecast of crop yield in advance of harvest.

Recent world food problems have intensified interest in applying meteorological information as an aid to increase food production. The quantitative dependence of crop yields on meteorological conditions has already been established in many countries and, on the basis of these, it has been possible to make production and yield predictions at varying dates in advance of harvest.

A crop-weather model is a numerical interpretation of weather data in terms of crops development, growth and production. Its aim is to explain on the basis of physical and plant physiological processes the effect of one or several elements of the weather or climate on a measurable crop response, such as vegetative growth, reproduction, development or yields.

Any given crop variety has its own optimal requirements of and / or selective response to the factors of its environment like rainfall/soil moisture supply, day,night or mean air temperatures, soil warmth, duration of darkness, light intensity, etc. These responses and requirements, which determine the growth and development of a plant in a given environment vary not only between families but also from species to species in the same family and from variety to variety in the same species. In the same variety they may vary from one growth stage to another. However, as pointed out by Went (1957) the problem of weather relations of crops is not so intractable as many seem at first. Experiments reveal that, crops are often influenced significantly by one or two factors that are more crucial for their growth and development and crops belonging to the same family or related families may show a typical response towards a particular climatic element.

Crop-weather modelling has many uses in agriculture, such as land use evaluation, crop adaptation, crop monitoring and forecasting, crop management, pest and disease control, and the planning of research strategies.

Crop-weather modelling involves the consideration of two processes in the life cycle of the crop (a) the influence of weather on crop growth (b) the influence of weather on crop development. The yield and production of crops are affected not only directly by the influence of weather, but also indirectly by the influence of weather on the population dynamics of insects and diseases which are destructive to crops.

Over the past 25 years, a vast assortment of models have been developed for various agrometeorological purposes. Even though sophisticated dynamical models are developed with better understanding of the processes of energy and mass exchange in crop growth, statistical models are still being developed due to difficulty in acquiring the necessary data for the former However, statistical models are usually applicable only to the local conditions for which they were developed.

The theoretical construction of the models employ two methods statistical and simulation methods. Simulation provides an insight into crop weather relationship, explains why some factors are more important for growth and yield while others are not.

For atleast 160 years, statistical relations have been used to describe the correlation between crop yields and individual weather elements, like average monthly temperature or precipitation. When such relationships are combined in a multiple regression equation, the result is a statistical crop-climate model. By the 1960s, this approach was being pursued extensively both in North America and in the Soviet Union, as exemplified by the widely- cited statistical analysis of Thompson (1969) and Ulanova (1975), respectively Statistical methods further can be subdivided into two categories, ie, empirical statistical method and physico-statistical method.

(a) Empirical statistical models

Crop-weather relationships can be studied extensively by employing simple statistical techniques like correlation and multiple regression. Crop-weather models thus developed are called empirical statistical models.

Empirical statistical models are extensively used for crop-weather analysis and in these studies two methods have generally been employed (i)Fisher's response curve technique and (ii) Curvilinear analysis. The papers by Fisher (1924) and Obuhov (1949) are examples of basic works in the field of finding empirical statistical relationships for calculating yields. For examining the influence of rainfall on the yield of wheat at Rothamsted, Fisher (1924) developed a new statistical technique which takes into account not only the total amount of the rainfall during certain period but also the manner in which it is distributed over the period under consideration. He used this technique to find the response curve which gives the average change in the yield of wheat associated with an additional unit of rainfall at anytime of the year.

The techniques of Fisher's response curve and curvilinear analysis were applied by Hendricks and Scholl (1943), Gangopadhyaya and Sarker (1964), Abraham (1965), Ramamurti and Banerjee (1966), Srinivasan and Banerjee (1973), Huda (1978), Huda et.al (1975 a,b),Sarker (1965,1978,1980,1984) Saha and Banerjee (1975), Rupakumar (1986) etc. These methods can be applied only when fairly long climatological and crop yield data are available.

Empirical-statistical models are also employed for yield forecasting. Obuhov made wide use of multiple regression analysis for studying the influence of meteorological conditions on yields. This type of analysis is used quite extensively in models of the linear-regression type, expressed in the form:

$$Y = a + \sum_{i=1}^{n} B_i * x_i$$

In this approach, one or several variables such as weather factors, soil characteristics, biometric observations for a time trend representing technological advancement are related to crop yield. The weighting coefficients in these models are obtained in an empirical manner using standard statistical techniques such as multivariate regression analysis. The method is mainly based on regression technique of Draper and Smith (1966) This methodology is a practical approach for the forecasting of crop yields, though it does not easily explain cause and effect relationships.

Many countries in the world are presently using these models for forecasting crop yields. Multiple regressions were developed by Thompson (1962,1969) to predict wheat yields in USA.Baier and Robertson (1968) and Baier and Williams (1974) used soil moisture and rainfall for predicting cereal yields. Williams (1972,1973), Lomas and Shashowa(1974) developed models to predict the wheat yields for areas equal or larger than a State. In Canada, Williams et.al (1975) developed an empirical relationship for predicting wheat yield using precipitation, potential evapotranspiration, soil texture, topography and trend terms. Application of empirical techniques for yield forecasting of a country can be seen in papers of Hashemi (1973), Coffing (1973) and Ulanova (1975)

India Meteorological Department (IMD) has developed a empirical-statistical model using correlation and regression techniques to forecast crop yields on operational basis for the country Models for Kharif rice and wheat have been developed and are used at operational level. Work in this direction has been done in IMD by Das et.al (1971) Appa Rao et.al (1977,1978,1981), Chowdhury and Sarwade (1985)

Huda et al.,(1975(b) fitted a second degree equation between rice yield and weather elements during growing phases of crop. Rainfall temperature and relative humidity were considered on a weekly basis and their effect on final yield was studied.

Studies were initiated at IASRI(1977) to find the relationship between the biometric characteristics of the crop and final yield. Models were developed assuming simple relationships, namely, linear and log linear between the yield and biometric characteristics. A model was developed at Directorate of Economic/ and Statistics to determine actual periods in Crop growth for paddy crop.

(b) Physico- Statistical Models

The apparent shortage in world food, has resulted in renewe interest in a system for making pre-harvest appraisals of crop production. Such appraisals, made as early in the season as possible, could have considerable impact on decisions regarding type and acreage of crops sown, and on the orderly and economical marketing and movement of harvested products.

Weather on a day-to -day basis both before seeding and during the growing period has a pronounced influence on the development (Robertson 1968)and growth (Baier,1973) of a crop and on its final yield. Models which describe the processes involved in crop development and yields by means of regression analysis were developed (Baier, 1973, Dmitrenko,1980) These models which provide a unique method for modifying the expected yield at the end of the last period are called physico-statistical models.

Factorial least square technique is one technique applied in physico-Statistical models. The model permits the analysis of historical weather and crop yield information for the purpose of determining the influence on development and final yield of various weather factors at critical phenological periods in the life cycle of the crop.

The model with slight modifications for each application has been used for studying the effect of weather on the rate of development of wheat (Robertson,1968),maize(Amores-Vergara,1973), barley (Williams,1974)and soyabean (Major et al ,1975) for studying the areas in the Canadian great Plains favourable for wheat production(Williams,1969); for studying the effect on wheat yield (Baier, 1973;Robertson,1974); and for studying the effect of weather on the yield of Oilpalm (Robertson and Foong,1976,1977 and Foong,1980)

(c) Dynamical model

Progress has been made in understanding such important physiological processes in plants as photosynthesis, transpiration,growth and development. Practical attempts to integrate this new knowledge has been incorporated in the form, of dynamic models used for estimating the productivity of agricultural crops.

Several dynamic models have been developed in many countries for determining yields of the most important agricultural crops. Dynamic models differ appreciably from each other depending on their objectives. They differ in the degree of detail describing the individual processes, as well as the amount of data that are required.

Dynamic models for crops like Barley, Maize,Sorghum, Wheat, Cabbage, Potato etc have been developed in USA,Australia and UK, (Sirotenko(1981);Curry et al.,(1971), Cocks et al(1978) Galjamin (1981); Zabroda et al(1979)

In India Pearl Millet simulation model was developed by Huda et al., (1984a) Sorghum Simulation Model (SORGE) was developed by Arkin et al.,(1979) and modified by Huda et al.,(1984b) for its application in the semi arid tropics.

At Centre for Advance Studies on Agrometeorology (CASAM),Pune Varshneya and coworkers are working to validate and adopt Crop Environment Resource Evaluation System (CERES Model) developed under USA conditions by Ritchie et al(1985)

A fundamental important property of dynamic models is the fact that duration of the period of calculations (months, season) and also the time step (hour,day), does not affect the number of coefficients. A dynamic model is determined purely by the degree of details described in the process. This property differentiates dynamic models from other types.

2.3 Materials and Methods:

2.3.1 Water balance studies

The studies are based on the data recorded at 24 raingauge stations distributed randomly over the State. These stations include all observatories of India Meteorological Department and 17 State Government raingauge stations (Fig 2.1) Details concerning the stations and period of data considered for the study is given in Table 2.1

The monthly temperature data for all the five IMD stations have been collected from Meteorological Office, Trivandrum and Poona and their data periods are given below.

Station	Years	Station	Years
Trivandrum	1931 - 1991	Cochin	1931 - 1980
Calicut	1931 - 1991	Alleppey	1944 1991
Kottayam	1973 - 1986		

Average monthly temperature values for all these stations for the given periods have been calculated, and these values have been taken as the monthly normals for the analysis.

2.3.2 Method employed in the present drought study

Thornthwaite (1948) developed an elegant book keeping procedure for making the comparison of precipitation and potential evapotranspiration on a monthly basis taking into consideration the role of soil in storing rain water during periods of excessive precipitation and supplying the so stored water for evapotranspirational purposes in times of inadequate rainfall. The book keeping procedure thus yields important

	STATION	ABBREVIATION	LATITUDE °N	LONGITUDE °E	DATA PERIOD
1.	Kasargode	KSD	12° 31	74° 59	1931 - 1986
2.	Irikkur	IRK	11° 58	75° 33	1931 - 1980
3.	Cannanore	CNR	11° 52	75° 22	1931 - 1986
4.	Manantoddy	MTY	11° 48	76° 01	1931 - 1986
5.	Kuttiyadi	KTD	11° 40	75° 45	1931 - 1980
6.	Vythiri	VYT	11° 33	76° 02	1931 - 1980
7.	Calicut	CLT	11° 15	75° 47	1931 - 1991
8.	Mannarghat	MRT	10° 59	76° 28	1931 - 1986
9.	Perinthalmanna	PRM	10° 58	76° 14	1931 - 1980
10.	Alathur	ATR	10° 38	76° 33	1931 - 1986
12.	Marayur	MYR	10° 16	77° 09	1931 - 1980
13.	Cranganore	CGR	10° 13	76° 12	1931 - 1986
14.	Devikulam	DVM	10° 04	77° 06	1931 - 1980
15.	Cochin	CHN	09° 58	76° 14	1931 - 1986
16.	Karikode	KKD	09° 50	76° 40	1931 - 1986
17.	Sherthala	STL	09° 42	76° 20	1931 - 1986
18.	Kottayam	KTM	09° 35	76° 32	1931 - 1991
19.	Alleppey	ALP	09° 33	76° 20	1931 - 1986
20.	Thiruvalla	TVL	09° 23	76° 33	1931 - 1986
21.	Konni	KNI	09° 13	76° 51	1931 - 1986
22.	Kayamkulam	KYM	09° 11	76° 30	1931 - 1986
23.	Quilonode	QLN	08° 53	76° 36	1931 - 1991
24.	Trivandrum	TVM	08° 29	76° 57	1931 - 1991

Table 2.1 - Details of raingauge stations and their record periods

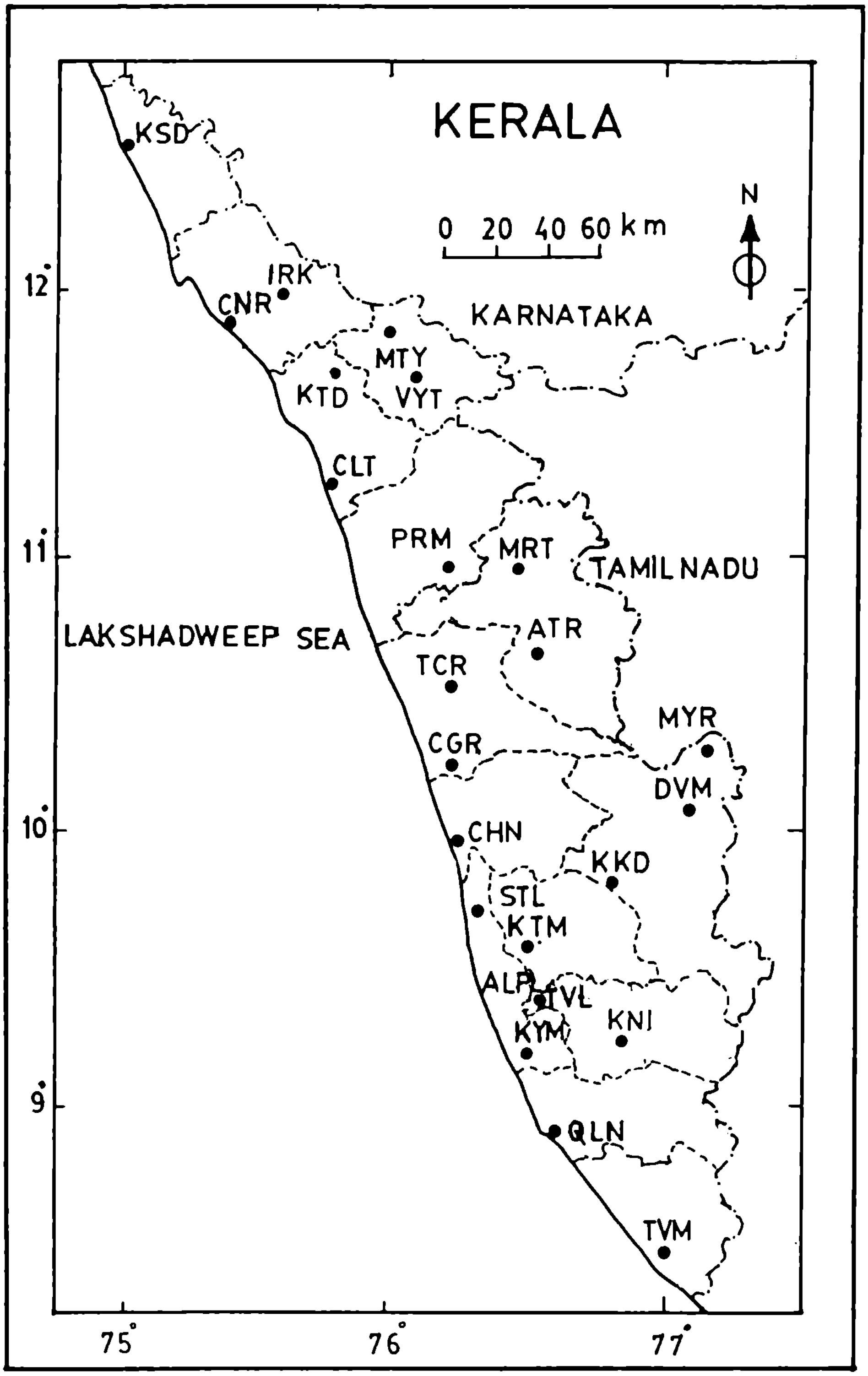


Fig 2.1 Location of raingauge stations selected for water balance studies

information about the elements of water balance, namely, actual evapotranspiration, water surplus and water deficiency, which play an important role in hydrology, agriculture, forestry, ecology,etc.

<u>(a) Computation of Potential Evapotranspiration (PE)</u>

As the direct measurement of evapotranspiration is very difficult, Thornthwaite introduced the concept of "Potential Evapotranspiration" (P.E) as the maximum amount of water lost to the atmosphere from a large surface covered with vegetation and where there is no shortage of soil moisture at all times for full and uninhibited use. This concept gives good results when the growth and distribution of vegetation are also considered.

Since the Potential Evapotranspiration (P.E.) or the water need is a very difficult parameter to measure experimentally, Thornthwaite (1948) evolved a semi-empirical formula for its computation from records of air temperature and length. According to this method, Unadjusted Potential Evapotranspiration (in cm),

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

where, t = mean monthly temperature in ^{o}C
I = annual heat index being equal to $\sum_{n=1}^{12} i_n$

where i_n= mean heat index of the n^{th} month equals $(t_n / 5)^{1.514}$ where t is the mean temperature of n^{th} month.

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

This formula holds good only if the mean monthly temperature is 26.5^{o}C. Above this limit, the P.E. is represented by the curvilinear equation.

$UPE = -41.586 + 3.2233t \quad 0.043254t^2$

The formula gives unadjusted values of P.E. It is to be adjusted for the number of days in a month and the number of hours of sunshine in the day during which evapotranspiration principally takes place, using the table given by Subrahmanyam (1982)

Thornthwaite himself was aware of the limitations when he admitted that his P.E. lacked an all inclusive definition and necessitated a rational method for its determination (Thornthwaite, 1960) Considering its simplicity and the fact that no method developed after Thornthwaite's original equation was an improvement of it, this method is quite acceptable.

In order to workout the water balance for all the 24 stations, it is essential to compute P.E. values for all the stations. For stations where temperature data were not available, the interpolation technique has been applied to estimate monthly P.E. values (Ram Mohan and James, 1989) In the above mentioned technique, calculated values of seasonal lapse rate of P.E. and height of a station is employed to get the P.E. value of the station.

The equation is as follows

$$PE_2 = PE_1 \quad (H_2 - H_1) \gamma_{P.E}$$

where $\gamma_{P.E}$ is the lapse rate of P.E.

PE_1 = Potential Evapotranspiration of base station of height H_1

PE_2 = Potential Evapotranspiration of another station of height H_2

Using this procedure, P.E. values for all the stations which do not have the measured temperature data, have been interpolated on a monthly climatic basis.

(b) Computation of water balance parameters

To evaluate the water balance of a station it is necessary to compare precipitaion (water supply) with potential evapotranspiration (water need) making allowance for the storage of water in the soil and its subsequent utilization for evapotranspirational purposes. At some stations, precipitation is always greater than the potential evapotranspiration so that the soil remains full of water and a water surplus (W.S) occurs. In other places, month after month, precipitation (P) is less than P.E.; there is no enough of moisture for the vegetation to use and a moisture deficit (W.D) occurs.

Though the results obtained through the use of the water balance procedure developed in 1948 were quite satisfactory, the procedure was modified by Thornthwaite and Mather (1955),so that it now provides more realistic values of the various moisture parameters derived.

According to 1955 procedure, the average moisture-holding capacity of the soil is assumed to be 300mm and the rate of soil moisture depletion follows the well known decay curve: the lesser the amount of moisture in the soil, the lower is the rate of evapotranspiration. The modified book - keeping procedure are detailed in the publications of Thornthwaite and Mather (1955,57) and Subrahmanyam (1982)

Field capacity, the maximum amount of water that a soil can retain in the root zone against gravity depends upon the type of the soil and vegetation. Thornthwaite and Mather (1957) presented a table giving the values of water holding capacity corresponding to soils of different field capacities.

While precipitation and potential evapotranspiration are the two basic elements of water balance, actual evapotranspiration (A.E.), water deficiency and water surplus are the derived elements.

Actual evapotranspiration is the amount of water that is actually available for evaporation and transpiration and depends on P.E., precipitaion and the actual moisture content of the soil. When there is sufficient amount of water, it is equal to P.E. and in dry situations, it may be less than P.E., being equal to the sum of the amount of precipitation and the moisture withdrawn from the soil.

Water deficiency is the amount by which precipitation and soil moisture together fail to meet the P.E. or in other words, the amount of water needed for supplemental irrigation in agriculture, for the most efficient growth of crops.

Water surplus represents the excess of precipitation after meeting the demands for P.E. and the recharge of the soil storage. This factor is very important in the assessment of water resources for their maximum utilization.

(c) Categorization of droughts

From the previous discussions,it is evident that annual rainfall value gives only a general indication of drought while its seasonal distributions is responsible for severe droughts in a year of normal or even above- normal annual rainfall.

In the present work, the Index of Moisture Adequacy (I_{ma}) derived from water balance procedures is employed to investigate the occurrence of different categories of drought. It is defined as the percentage ratio of the actual evapotranspiration to the potential evapotranspiration on annual basis. A value of 100% would mean that the moisture status is at the optimum level and agricultural operations can be carried out without any supplemental irrigation. High values of the index denote fairly sufficient quantities of water for use by the soil and plants for evapotranspiration. Some supplemental irrigation would help the actual evapotranspiration reach potential levels. Low values would indicate large moisture stress on the plants whose growth is inhibited resulting in low yields. Irrigation is then absolutely essential if crops are to survive under these conditions.

In the present study the Indices of Moisture Adequacy (I_{ma}) have been calculated and their percentage departures from the climatic normals on an annual basis have been plotted. Categorization of drought has been done as suggested by Ram Mohan et al. (1984) employing the standard deviation (σ) as the basis of reference when the departures have been negative, as follows

Departure of the I_{ma} from the mean	Drought intensity
less than 1/2 σ	Moderate
between 1/2 σ and σ	Large
between σ and 2σ	Severe
above 2σ	Disastrous

(d) Frequency of droughts

After identifying the drought years of various intensities as per the above procedure, the decennial frequency, ie., number of drought years of each category in each successive decade interval was computed as well as graphically presented for each station.

(c) Severity and duration of drought

However, more important than the delineation of drought years of various severities, is the knowledge of the exact duration of drought spells. The study of the duration of droughts is of great practical importance in agriculture and hydrology.

The drought spells during the years 1982 to 1984 have been selected for detailed study of their durations and severities on a monthly basis. The ratios of departures of the monthly I_{ma} values from their climatic normals to the standard deviations of the corresponding months were plotted. Months with negative values indicate a drought spell, while the magnitude of the negative departure from the normal is an assessment of its severity

(f) Spatial coherence of droughts

The probability of simultaneous, occurrence of droughts at different stations when one of them experienced a drought, was computed following the technique given by Subrahmanyam and Ram Mohan (1979) After the years of droughts and their categories of severity were delineated for all stations as given above, the probability of simultaneous occurrence of droughts at different stations when one of them experienced a drought has been computed. To enable this, a particular station is chosen as the 'key' station. Years when droughts of any intensity (moderate, large, severe or disastrous) occurred at each of the other 23 stations (auxiliary stations) simultaneous with moderate droughts at the key station were noted. The percentage number of such occasions was then calculated for each auxiliary station. This procedure was carried out for the other three categories of droughts too. Then, all such calculations were successively repeated with all the 19 stations as the key stations.

(g) Climatic shifts

Fluctuations in the annual water balance of a station may be of such magnitude that their very climatic types could be shifted by one or more categories in the drier or the wetter direction. Such temporary shifts of climate are of great interest to the agroclimatologists for their frequency and magnitude reflect the conservation of climate and determine the progressive improvement, stability or deterioration in the climatological potentialities of a region for development. Ram Mohan (1978) investigated the shifts in climatic types due to fluctuations in the annual water balance of stations in Tamil Nadu. Moisture index I_m which is equal to I_h-I_a, where, I_h = Humidity index which is the percentage ratio of the annual water surplus to the annual water need, and I_a = Aridity index which is the percentage ratio of the annual water deficit to the annual water need is employed for the classification of climatic types as follows.

Climatic type	Symbol	Moisture Index (I_m %)
	Humid climates	
Perhumid	A	100 and above
Humid	B_4	80 to 99
	B_3	60 to 79
	B_2	40 to 59
	B_1	20 to 39
Moist subhumid	C_2	0 to 19
	Dry Climates	
Dry subhumid	C_1	-33.3 to 0
Semiarid	D	-66.5 to 33.4
Arid	E	-66.6 and below

Table 2.2 Moisture Index and Climatic types. (After Thornthwaite, 1948 and Carter & Mather, 1966)

Accordingly, the moisture index (I_m) values for individual years were plotted and climatic shifts were investigated.

2.3.3 Crop-weather relationship studies

(a)Correlation analysis

Correlation analysis refers to the techniques used in measuring the closeness of the relationship between variables.

The measure of correlation called the correlation coefficient or correlation index summarizes in one figure, the direction and degree of correlation.

Correlation is described or classified in several different ways. Three of the most important ways of classifying correlation are positive or negative, simple, partial and multiple and linear and non-linear.

If both the variables are varying in the same direction, correlation is said to be positive, and if the variables are varying in opposite direction, negative. The distinction between simple, partial and multiple correlation is based upon the number variables studied. When only two variables are studied it is a problem of simple correlation. When three or more variables are studied it is a problem of either multiple or partial correlation. The distinction between linear and non-linear correlation is based upon the constancy of the ratio of change between the variables. If the amount of change in one variable tends to bear a constant ratio to the amount of change in the other variable, then the correlation is said to be linear. Correlation would be called non-linear or curvilinear if the amount of change in one variable does not bear a constant ratio to the amount of change in the other variable.

The various methods of asserting whether two variables are correlated or not are the scatter diagram method, graphic method, Karl Pearson's coefficient of correlation, rank method, concurrent deviation method and the method of least squares. Of these the first two are based on the knowledge of diagrams and graphs where as the others are mathematical

Of the several mathematical methods of measuring correlation, the Karl Pearson's method, popularly known as Pearsonian coefficient of correlation (r) is most widely used in practice (Gupta,1981)

The formula for computing Pearsonian r is

$$r = \Sigma xy / N \sigma x \sigma y$$

Here

$x = (X-\bar{X})$; $y = (Y-\bar{Y})$

σ_x = Standard deviation of series X

σ_y = Standard deviation of series Y

N = Number of pairs of observations

r = the correlation coefficient.

This method is to be applied only where the deviations of items are taken from actual means and not from assumed means.

The value of the coefficient of correlations obtained by the above formula always lie between + 1 and - 1. When r=+1, it means there is perfect positive correlation between the variables. When r=-1, it means there is perfect negative correlation between the variables. The coefficient of correlation describes not only the magnitudes of correlation but also its direction.

The Karl Pearson's coefficient of correlation is based on the following assumptions:

i) there is a linear relationships between the variables

ii) the two variables under study are affected by a large number of independent causes so as to form a normal distribution.

iii) there is a cause and effect relationship between the forces affecting the distribution of the items in the two series.

(b)Regression analysis

After having established the fact that two variables are closely related, we may be interested in estimating (predicting) the value of one variable given the value of another. Regression analysis reveals average relationship between two variables and this makes possible estimation or prediction.

Regression analysis provides estimates of values of the dependent variable from values of the independent variable. The device used to accomplish this estimation procedure is the regression line. A second goal of regression analysis is to obtain a measure of the error involve in using the regression line as basis for estimation. For this purpose the standard error of estimate is calculated. This is a measure of the scatter or spread of the observed values of Y variable around the corresponding values estimated from the regression line. With the help of regression coefficients we can calculate the correlation coefficient. The square of correlation coefficient (r) called coefficient of determination, measures the degree of association or correlation that exists between there two variables It assesses the proportion of variance in the dependent variable that has been accounted for by the regression equation.

If we take the case of two variables X and Y, we shall have two regression lines as the regression of X on Y and the regression of Y on X. The regression line of Y on X gives the most probable values of Y for given values of X and the regression line of X on Y gives the most probable values of X for given values of Y. However, when there is either perfect positive or perfect negative correlation between the two variables (r=+1 or -1) the two regression lines will coincide. The farther the two regression lines from each other, the lesser is the degree of correlation and the nearer the two regression lines are to each other, the higher is the degree of correlation. If the variables are independent, r is zero and the lines of regression are at right angles.

Regression equations also known as estimation equations are algebraic expressions of the regression lines. Since there are two regression lines, there are two regression equations.

The regression equation of Y on X is expressed as

$Y_o = a + b X$

and the equation of X on Y is expressed as

$X_o = a + b Y$

Here a and b are constants which determine the position of the line completely. These constants are called the parameters of the line.

(c)Multiple regression analysis

Multiple regression analysis enables us to measure the joint effect of any number of independent variables upon a dependent variable.

A regression equation is an equation for estimating a dependent variable, say, X_1, from the independent variables X_2, X_3. and is called a regression equation of X_1, on X_2, X_3. In functional notation this is sometimes written briefly as (Gupta, 1981)

$$X_1 = F\ (X_2, X_3 \ldots.)$$

For the case of three variables, the simplest regression equation of X_1 on X_2 and X_3 has the form

$$X_{1.23} = a_{1.23} + b_{12.3}\ X_2 + b_{13.2}\ X_3$$

$X_{1.23}$ is the computed or estimated value of the dependent variable and X_2, X_3 are the independent variables.

The constant $a_{1.23}$ is the intercept made by the regression plane. It gives the value of the dependent variable when all the independent variables assume a value equal to zero. $b_{12.3}$ and $b_{13.2}$ are called partial regression coefficient. $b_{12.3}$ measures the amount by which a unit change in X_2 is expected to affect X_1 when X_3 is held constant and $b_{13.2}$ measures the amount of change in X_1 per unit change in X_3 when X_2 is held constant.

(d) Principal component analysis (PCA)

Principal component analysis is a multivariate statistical technique that is often useful in reducing the dimensionality of a collection of unstructured random variables for analysis and interpretation. It may be helpful to replace a large number of variables by a smaller number of variables or functions of variables without an accompanying loss in the analytical objectives. PCA can provide an exploratory modelling technique and substantial data reduction. When a large number of random variables are available for potential study it may be of interest to inquire initially whether they can be replaced by a fewer number of random variables, either a subset of the original or certain functions of them, without loss of much information (Rao,1964) Almost, if $X_1, X_2, \ldots\ldots, X_p$ constitute p random variables with a large amount of variability, principal component analysis can be used to explain or understand the variability. The methodology of analysis is explained by Anderson(1958)

Consider the random vector $X' = (X_1, X_2, \ldots, X_p)$ with mean vector $E(X) = \mu$, and positive definite covariance matrix $Var(X) = \Sigma$. Suppose $Y = \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_p X_p = \alpha' X$ is an arbitrary linear combination of $X_1, X_2, \ldots, X_p$ with coefficients $\alpha_1, \alpha_2, \ldots, \alpha_p$. $Var(Y) = Var(\alpha' X) = \alpha' \Sigma \alpha$, a positive definite quadratic form in the coefficients α_1, $\alpha_2, \ldots \alpha_p$. Without any loss of generality the coefficients are assumed to be normalized by requiring $\sum_{i=1}^{p} \alpha_i^2 = \alpha' \alpha = 1$. Next step is to choose $\alpha' = (\alpha_1, \alpha_2, \ldots \alpha_p)$, such that $Var(Y) = \alpha' \alpha$ is a maximum, subject to the normalization a'a=1. This is done by the method of Langrange multipliers.

In summary, let $\alpha'_1 = (\alpha_{11}, \alpha_{12}, \ldots, \alpha_{1p})$ be the characteristic vector corresponding to normalized by $\alpha' \beta = \sum_{i=1}^{p} \alpha_{1i}^2 = 1$, and let $Y_1 = \alpha_1' X, \ldots, \alpha'_p X$ where is the characteristic root. Then Y_1 is the linear combination of the X_i with normalized coefficients that has maximum variance among all such linear combination, and $Var(Y_1) = \lambda_1$ The linear combination $Y_1 = \alpha_{11} X_1 + \alpha_{12} X_2 + \ldots + \alpha_{1p} X_p$ is the first population principal component of the random vector X.

The proportion of the total variation attributed to each principal component is largest for the first principal component and successively smaller for the second, third etc., principal components. If τ is the total variation, the proportion τ that λ_j constitutes is often referred to as the proportion of the total variation accounted for by the j_{th} principal component. Thus $\lambda_j / \Sigma_{j=1}^{p} \lambda_j$ is the proportion of the variance of to the total variation. If this ratio is large for each of the first few principal components, study about the variability in the X_i may be confined to study about these first few principal components.

Subsequent to the discovery and rediscovery of PCA in various guises, over the years of the first half of the present century by such workers as Pearson (1901), Spearman (1904), Hotelling (1933), Lorenz (1956) and Obukhov(1960), the technique has been applied to a wide variety of problems of data analysis and interpretation in meteorology and oceanography Patterson et al. (1978) used this technique to demarcate southeast Australia into 52 homogeneous zones and workers like Gadgil and Joshi (1980), Chowdhury et al. (1993) applied this technique to demarcate India into homogeneous agroclimatic zones.

(e) Principal Components Regression

If X_i is a single random variable, denoted here simply as X and W_q non random variables, for practical applications like Principal Component Regression, question may arise such as, "how many W variables should be included and how should unimportant ones be discarded and how should muticollinearities in the W variables be eliminated" (Kendall, 1957)

It is assumed the prior to the univariate general linear model analysis, a sample principal components analysis of $W_1, W_2, \ldots W_q$ is performed. The W_j variables are standardized by subtracting the mean and dividing by the square root of the unbiased estimator of the variances, ie. standardized $W_j = W_j' = (W_j - \bar{W}_j)/S_j$

where S_j = Standard deviation

The jth sample principal component is

$\hat{Y}_j = \alpha_{j1} W_1 + \alpha_{j2} W_2 + \ldots + \alpha_{jq} W_q$

and the jth principal component or score for the u th sample observation is

$\hat{Y}_{ju} = \alpha_{ji} W_{1u} + \alpha_{j2} W_{2u} + \ldots + \alpha_{j\alpha} W_{qu}$

$(u=1,2, \ldots, n)$

The $\hat{Y}$ matrix of Principal Components score thus obtained are then used in the linear model for E(X); that is

$E(X) = \gamma_0 + \gamma_1 \hat{Y}_1 + \gamma_2 \hat{Y}_2 + \ldots + \gamma_j \hat{Y}_j$

CHAPTER III

PHYSICO-CLIMATIC FEATURES AND AGRICULTURE STATUS OF KERALA

The different physico-climatic features of Kerala State such as its location and extent, physiography, drainage soil types and vegetation are discussed in this chapter. A survey of the distributions of the different climatic parameters over the State and a description of the climatic types observed over the region are included in section Two. The third section gives a detailed study of the agricultural status of the State.

3.1 Kerala State - General features:

Kerala State lies in the South-west corner of the Indian peninsula between 8^{o} 18' and 12^{o} 48' north latitudes and 74^{o} 52' and 77^{o} 22' east longitudes, as a long narrow strip of land, 32 to 133 km wide, between the Western Ghats in the east and the Arabian Sea in the west with a 580km long coastal line. In the south, the State is bounded by Tamil Nadu and in the north by Karnataka. The land mass of Kerala has an undulating topography, stretching from the east with a series of hills and valleys intersected by numerous streams and rivers flowing into the Arabian Sea on the west. The State has an area of 38,864 sq.km. which is only 1.2% of the total area of the country.

3.1.1 Physiography

Kerala is a land highly diversified in its physical features and agro-ecological conditions. The undulating topography ranges in altitude from below mean sea level (MSL) to 2694 m above MSL. Fig 3.1 shows the physiographic features of the

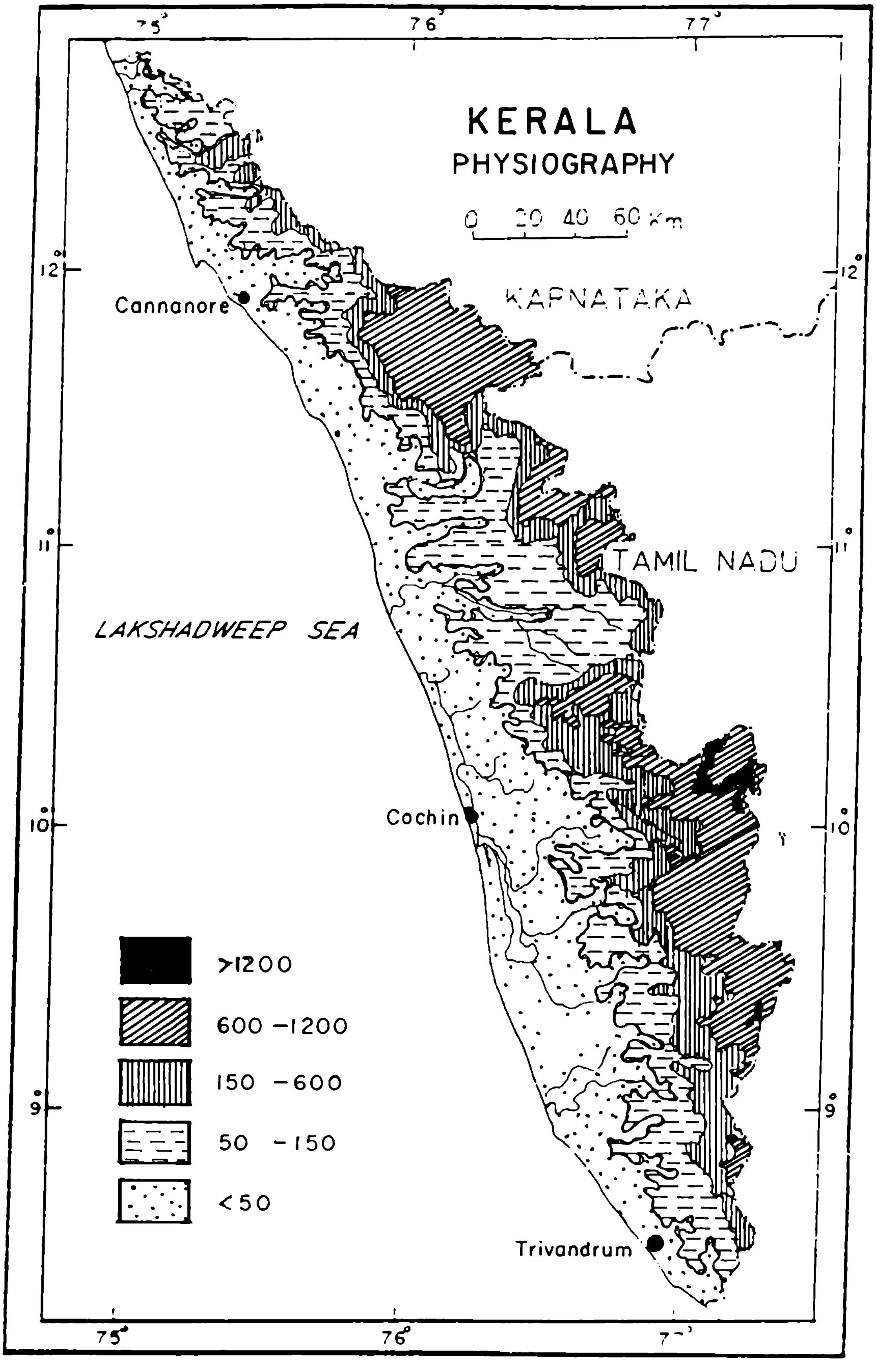


Fig 3.1 Physiography of Kerala

State.

Based on topography, the land area in the State fall generally into three well defined natural divisions each running almost parallel in north-south orientation. They are lowlands, midlands and highlands.

The highlands consists of mountain ranges in the eastern parts of the State, which form a natural wall with an average height of 1 km., separating Kerala from the adjoining States. The Anamalai and Nilgiris are the tallest mountains in the Western Ghats and are separated by 30 km. wide Palghat Gap where the elevation drops below 300 m.. The Palghat Gap has a significant role in the meteorology of Kerala. The highland regions are ideally suitable for plantation crops such as tea, coffee, cardamom and rubber. Though the area under this division is the largest (18,654 sq.km.), the density of population is very small. The main occupation of the people are activities associated with cultivation.

The lowland region is a strip of area running along the coast with a maximum width of about 25 km. from the shore near Alleppey. This lowland area has a number of lakes among which Vembanad lake is the largest, followed by Ashtamudi kayal Kuttanad region in the lowlands is a unique agricultural area covering about 875 km^2 in the districts of Alleppey and Kottayam. The formation and behaviour of mudbanks are peculiar phenomena of the Kerala coast: these are the regions of calm waters of monsoon season and are abundant in fish yield. This area has extensive paddy fields and scattered areas with coconut, arecanut etc. It has an area of 3979 sq.km. where about 25% of the population of the State lives. The annual rainfall of this region varies from 190 cms. in the south to 350 cms. in the north.

Sandwiched between the lowlands and highlands is the midland region, characterised by undulating terrain. The soil in this zone is lateritic or its varieties. This area has diversity of crops like paddy, coconut, arecanut, pepper, ginger, sugarcane, tapioca, rubber etc.. Having an area of 16,231 sq. km. and elevation ranging from 8 to 75 metres, the midland has a density of population accounting for about 60% of the total. From south to north, variation of the annual rainfall is from 140 cms. to 400 cms. in this region.

3.1.2 Soils

Soil is an important earth resource and precise scientific information is necessary for the proper use and management of the soil. The major components of soil such as mineral matter, organic matter and soil water have to be considered for land use planning. Based on physicochemical properties and morphological features, soils of Kerala are classified into the following ten broad groups (Department of Agriculture, 1978) 1) Red loam 2) Laterite 3) Coastal alluvium 4) Riverine alluvium 5) Greyish Onattukara 6) Brown hydromorphic 7) Hydromorphic saline 8) Acid saline 9) Black soils and 10) Forest loam. Fig 3.2 shows the different soil types of the State.

Red loams of Kerala are localised in occurrence and are found mostly in the southern parts of Trivandrum district. Soils have red colour and are essentially Kaolinitic in nature, acidic

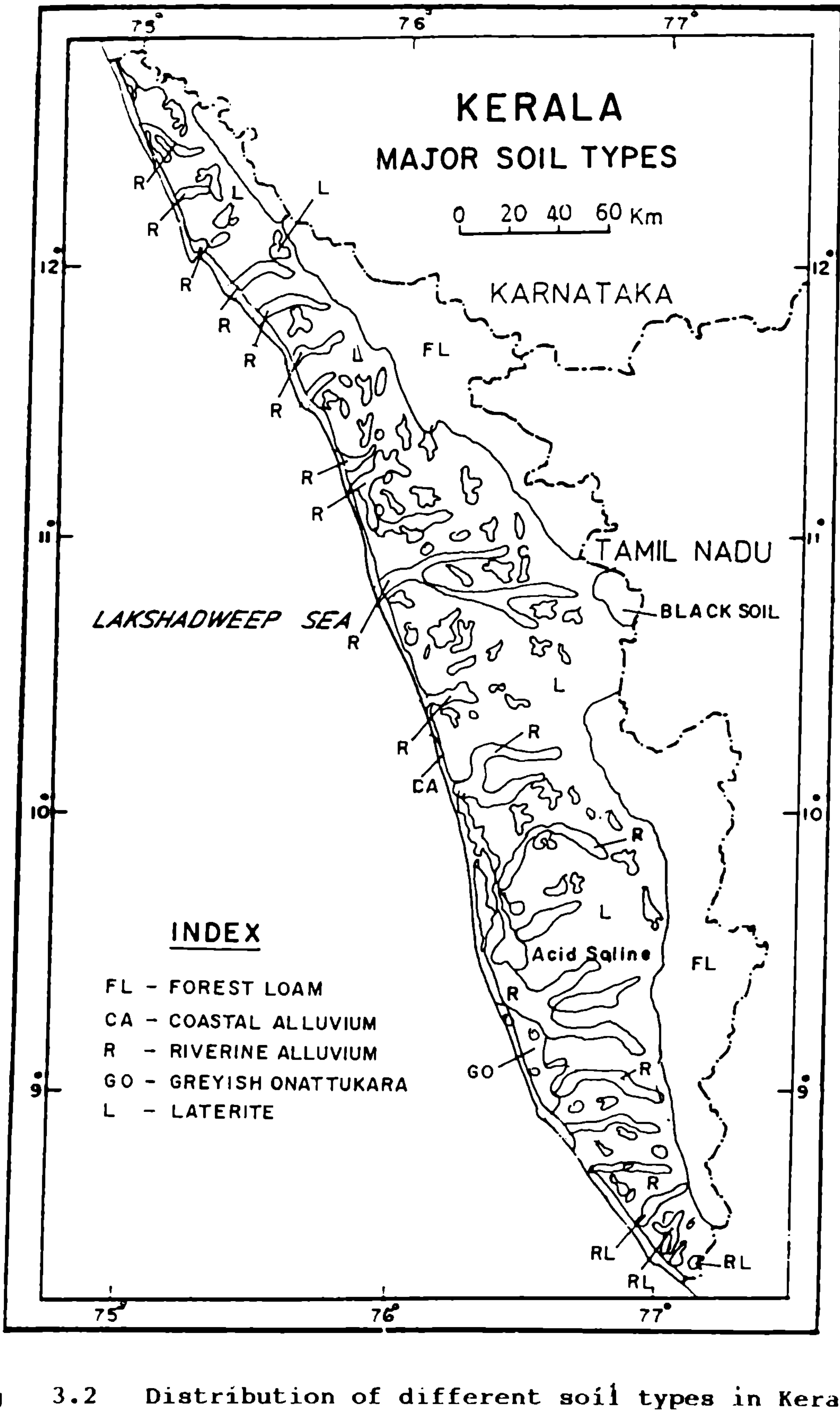


Fig 3.2 Distribution of different soil types in Kerala

in reaction, highly porous and friable. They are low in organic matter content as well as in all the essential plant nutrients.

Laterites, cover a major portion of mid and mid-upland regions and are the most extensive of soil groups found in Kerala. Heavy rainfall and high temperature prevalent in the State are conducive to the process of laterisation. In Calicut, Malappuram and Cannanore districts, extensive stretches of indurated laterites with hard surface crust are common occurrence. Laterites are in general poor in available nitrogen, phosphorus and potassium, low in bases and organic matter. These soils are well drained and respond well to management practices.

Coastal alluvium soils are seen in the coastal tracts along the west and have been developed from recent marine deposits. The water table is high in the low- lying areas. Low content of organic matter and clay are characteristics of this soil.

Riverine alluvium occurs mostly along the banks of rivers and their tributaries. It shows wide variation in its physico chemical properties depending obviously on the nature of the alluvium that is deposited and the characteristics of the catchment area through which the river flows. They are very deep soils, moderately supplied with organic matter, nitrogen and potassium.

Greyish Onattukara soils are confined to Onattukara region comprising of Karunagappally, Karthikapally and Mavelikkara taluks of Quilon and Alleppey districts. In low-lying areas, the water-table is high and drainage is a problem. These soils are acidic and are extremely difficult in all the major plant nutrients.

Brown hydromorphic soils are mostly confined to valley bottoms of undulating topography in the mid land and in low-lying areas of coastal strip. Drainage and acidity is a major problems in some areas. They are moderately supplied with organic matter, nitrogen and potassium and are deficient in lime and phosphate.

Hydromorphic saline soils are usually met with in the coastal tracts of the districts of Ernakulam, Alleppey, Trichur and Cannanore. Wide fluctuations in the intensity of salinity have been observed. During rainy season, the fields are flooded and most of the salt is leached out, leaving the area almost free of salts. Maximum accumulation of toxic salts is observed during the summer months from March to April. In some areas under-composed organic matter is observed in lower layers, causing problem of acidity

The acid saline salts of Kuttanad are grouped into three categories viz. Kayal soils, Karappadam soils and Kari soils.

The Kayal soils are found in the reclaimed lake beds in Kottayam and Alleppey districts. These soils are slightly acidic, medium in organic matter and poor in total and available nutrients, but are fairly rich in calcium. They are seriously affected by salinity

Karappadam soils occur along the inland waterways and rivers, and are distributed over a large part of upper Kuttanad. These soils are characterized by high acidity, high salt content and fair amount of decaying organic matter. They are highly deficient in phosphorus and lime.

Kari soils occur in patches in the districts of Alleppey, Kottayam and Ernakulam. These are black, poorly drained, heavy textured soils distributed in flat areas lying one to two meters below the sealevel. These soils are highly acidic in reaction and accumulation of salts to toxic level often affects the crop growth and yield in these region.

Black soils of the State are restricted in their occurrence to Palghat district. They are usually located in gently sloping to nearly level lands. Levels of potassuim and calcium are moderate, while the soil is low in nitrogen and phosphorus.

Forest loam are restricted in occurrence to the eastern parts of the state. These soils are generally acidic, rich in nitrogen, but poor in bases because of heavy leaching.

3.1.3 Vegetation

The Fig 3.3 depicts the vegetation types identified by the Forest Department through forest resources surveys. The luxurious vegetation that clothes the land of Kerala for most part of the year is a distinct feature of the State. The five main types of vegetation and their areal extent are as follows:

Wet evergreen and semi-evergreen	50.5%
Most deciduous	33.4%
Dry deciduous	1.8%
Montane subtropical and temperate	1.7%
Plantation and others	12.6%

Wet-evergreen, semi-evergreen and moist deciduous forests are located in the rainfall zone of 200-300cms with temperature

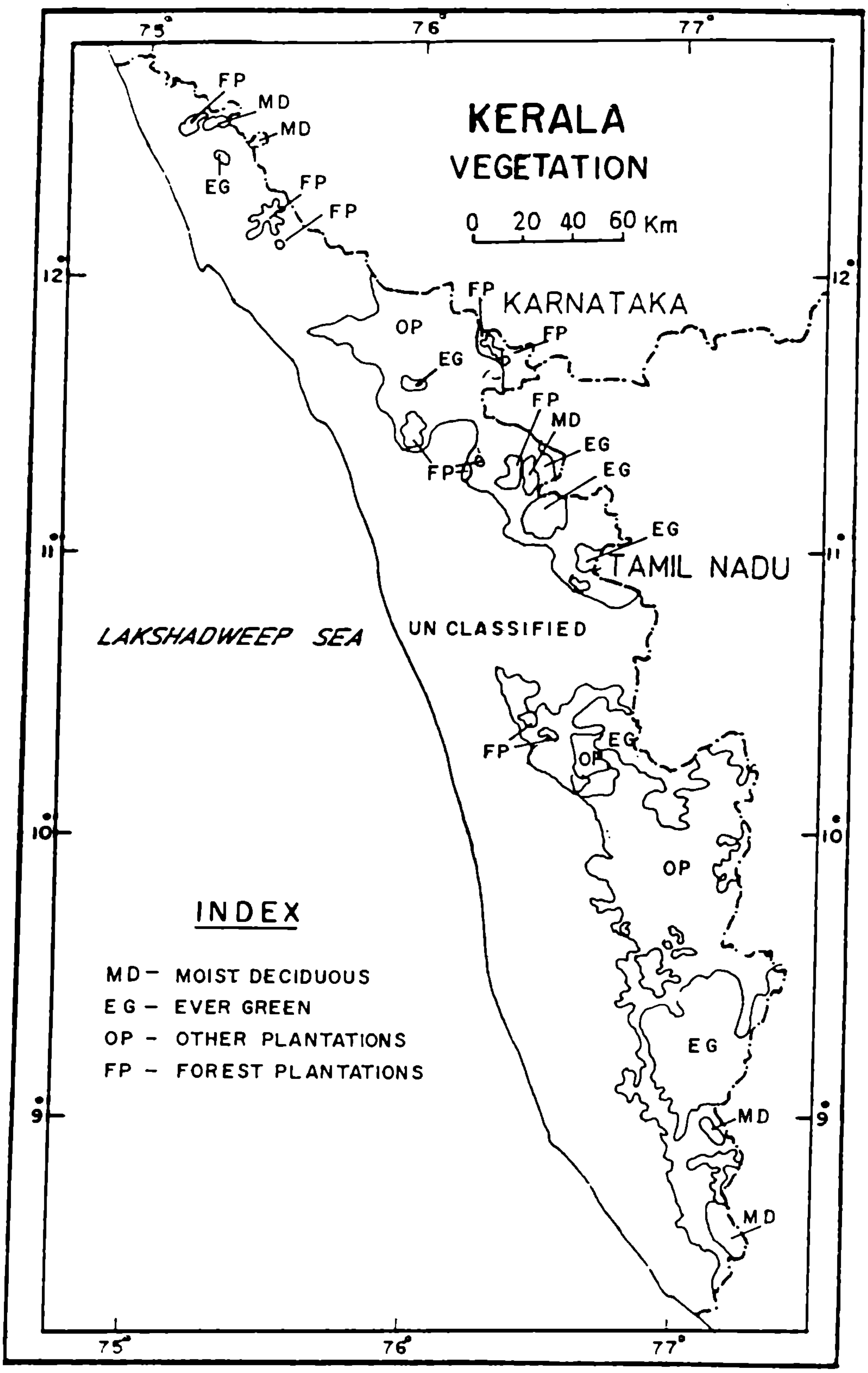


Fig 3.3 Vegetation map of Kerala

more than 20^{O}C and elevation above 300metres. Isolated areas of tropical wet evergreen forests on the slopes of Western ghats are characterised by large and very tall trees in the first storey and an undergrowth of ferns and tall herbs in the second storey

Trees in the moist deciduous type of forests remain leafless during the period December to June. The dry deciduous forest is confined to Pambar valley, a rain-shadow region, where annual rainfall is about 100cm and temperature in winter is considerably low. The Montane wet temperate forests known as temperate shola, occur in the valleys of high ranges.

3.1.4 Water resources of the State

Kerala is blessed with abundant water resources, the main sources being surface water and ground water. The availability of water from these two sources mainly depends on the rainfall and rainfed cropping system is generally followed.

Out of the 44 rivers originating from the Western Ghats, 41 flow towards west into the Arabian Sea and the remaining 3 towards east into the Bay of Bengal. The rivers of Kerala are typical monsoon-fed and fast flowing ones. The principal west flowing rivers of the State are Bharathapuzha, Periyar, Pampa and Chaliyar. The east flowing rivers are Kabani, Bhavani and Pambar. The distribution pattern of rainfall in Kerala is not uniform and during the two monsoons, heavy rains occur resulting in floods.

The general drainage pattern of Kerala is dendritic. At places, it is subparallel and radial. Most of the rivers are structurally controlled and follow conspicuous lineaments, the general directions being NW SE and NE SW.

The annual yield, utilizable yield and other details of the river basins of Kerala are given in the Table 3.1. According to PWD estimates, the total run-off of all the rivers of the State amounts to 78,041 Mm^3 70,323 Mm^3 is the contribution from the catchments in Kerala and the remaining from that of Karnataka and Tamil Nadu. The quantity that is considered utilizable is computed as 42,772 Mm^3

Problems are always encountered in connection with the scientific development and management of surface water resources of the State. Insufficiency and inadequacy of hydrological, meteorological and allied data, lack of integrated basin plan for achieving scientific development and management, salinity intrusion and pollution concentration are some of them.

Groundwater is a resource of immense magnitude, but of uneven availability and inexhaustible. Kerala has traditionally depended on surface water for meeting most of the drinking, irrigation and industrial requirements. Even the limited utilization of ground water has been mainly through open wells in the coast and in the midlands and springs in the highlands. In the coastal region of the State, ground water occurs predominantly under water table condition in the sandy aquifers which are normally a few meters thick, while in the midland region, ground water is commonly encountered under water table condition in the lateritic aquifers. Another major source of ground water in the midland regions is the sandbeds of the rivers draining through the region. In the case of highland region,

Sl. No.	River basin	Length (Km)	Catchment area(inside Kerala) (Km^2)	Annual yield (in Kerala) (Mm^3)	Annual utilizable yield (in Kerala) (Mm^3)	Irrigation water requirements (Mm^3)
1	Manjeswar	16	90	309	106	149
2	Uppala	50	76			
3	Shiriya	67	290	620	358	187
4	Moryal	34	132	1718	1218	507
5	Chandragiri	105	570			
6	Chittari	25	145			81
7	Nileswar	46	190	1356	937	329
8	Karingode	64	429			
9	Kavvayi	31	143			
10	Peruvaba	51	300	1143	603	
11	Ramapuram	19	52			
12	Kuppam	82	469	1236	786	223
13	Valapattanam	110	1321	1784	1823	331
14	Anjarakkandy	48	412	986	503	89
15	Tellicherry	28	132	251	122	81
16	Mahe	54	394	803	445	194
17	Kuttyadi	74	583	1626	1015	352
18	Korapuzha	40	624			
19	Kallayi	22	96			
20	Chaliyar	169	1535	7135	2616	3541
21	Kadalundi	130	1122			
22	Tirur	48	117	1165	60	221
23	Bharathapuzha	209	4400	6540	3349	46984
24	Keecheri	51	401	1024	345	822
25	Puzhakkal	29	234			
26	Karuvannur	48	1054	1887	963	970
27	Chalakudy	130	1404	2591	1539	1093
28	Periyar	244	5284	11391	8004	1899
29	Muvattupuzha	121	1554	3814	1812	2141
30	Meenachil	78	1272	2349	1110	1180
31	Manimala	90	847	1829	1108	402
32	Pamba	176	2235	4641	3164	1732

Contd...

Table 3.1 Details of river basins in Kerala

Contd.

Sl. No.	River basin	Length (Km)	Catchment area (inside Kerala) (Km^2)	Annual yield (in Kerala) (Mm^3)	Annual utilizable yield (in Kerala) (Mm^3)	Irrigation water requirements (Mm^3)
33	Achenkovil	128	1484	2287	1249	889
34	Pallikkal	42	220	2270	1368	1162
35	Kallada	121	1699			
36	Ithikkara	56	642	761	429	493
37	Ayroor	17	66			
38	Vamanapuram	88	687	1324	889	755
39	Mamon	27	114			
40	Karamana	68	702	836	462	466
41	Neyyar	56	497	433	229	502
42	Kabani	*	1920	4333	4333	2182
43	Bhavani		562	1019	1019	476
44	Pambar		384	708	708	298

(Source Water Resources of Kerala, 1974. Public Works Department Government of Kerala) ground water normally occurs in the form of springs which most often are perennial.

3.2 Climate:

The State of Kerala has a climate which is controlled to a large extent by its position in the south-west coast of the peninsula and the undulating topography. The most conspicuous feature of Kerala's climatology is the existence of the monsoons in association with the reversal of temperature and pressure gradients over the State.

The State falls under perhumid and humid climatic types except the southern most pockets and the eastern part of the Palghat region which come under moist subhumid climatic type. The State as a whole experiences megathermal climate which shows that the crop growth is not inhibited by temperature, but governed by rainfall alone.

Based on the climatic conditions over the State, the year is divided into four seasons;

Cool weather season (winter)	January - February
Pre-monsoon	March - May
Monsoon	June - September
Post-monsoon	October - December

Winter is the coldest and the driest season over the State. The pre-monsoon season is characterised by increasing day time temperatures and thunderstorm activities. The monsoon (Southwest monsoon) season is the primary rainy season which contributes about 66% of the annual rainfall. The post-monsoon season sometimes referred to as retreating monsoon constitutes the secondary rainfall season, especially in South Kerala.

(a) Surface air temperature

Tropical location and proximity to oceans have given rise to very small annual and diurnal temperature variations over the State. But the physiographic features comprising of low lands along the coast, the plain midlands and the high ranges are responsible for the variation in temperature in the east-west direction. The mean annual temperature varies from 25.4^{o}C to 31.0^{o}C in the central part of Kerala. However, major portion of the midlands experience temperature below 27.5^{o} C. The diurnal variations are not high (5-7^{o} C) except in the highland regions where the difference goes upto 15^{o} C. March, April and May are the summer months during which the mean annual temperature varies between 29-31^{o} C.

The daily maximum may shoot upto 40 ^{o} C in summer and the minimum may come down to 16^{o} C in winter. Due to high rainfall during the southwest monsoon, the temperature comes down during July-August and starts increasing from October onwards.

(b) Relative Humidity

Due to the proximity to the sea, the moisture content over the region is very high. The monsoon currents bring lot of moisture from the Arabian sea and the moisture content decreases towards the east, away from the coast. According to

Ananthakrishnan et al. (1979b), monthly mean relative humidity at the surface is of the order of 75% in winter mornings and increases to about 90% in the monsoon months at coastal stations. The average humidity for the plains of the State is 77% with a maximum of 88% in July and minimum of 66% in January. Both morning and evening relative humidity variation shows almost same pattern with the highest value in July and the lowest in January. The morning values vary from 91% to 72% and afternoon values vary from 85% to 60%.

(c) Pressure

The mean sealevel pressure in the State is about 1009 mb. during summer and about 1012 mb. during winter. In all seasons, the pressure gradient over the State is in the eastward direction. Annual range of pressure variations in the State is small, around 4 mb. only (3.4 mb. at Trivandrum, 4.0 mb. at Cochin and 4.5 mb. at Calicut)

Pressure exhibits a diurnal variation with maximum around 1000 LMT and 2200 LMT and minimum around 1600 LMT and 0400 LMT. This diurnal range of pressure increases from the coast to the inland regions and this range is also less than 5 mb. (IMD, 1986) The maximum diurnal pressure variations occurs in February when the cloudiness is the least while the variation is minimum during June and July.

(d) Winds

The wind flow over most parts of the State is thermally driven, which is governed by the differential heating of land and water bodies. In general, easterly and northeasterly winds occur during night and early morning hours and westerly during day time because of the land and sea breezes. Notable differences in the speed and direction have been observed between the coastal and inland stations. The number of calm days are more in inland regions than coastal regions due to sheltering effects of the Western Ghats.

During the monsoon season, strong westerly winds dominate the diurnal variation of winds everywhere. One interesting feature of winds in the southwest monsoon season is that, it blows northwesterly instead of southwesterly, especially over the southern coastal areas. The maximum windspeed is observed during this season and decreases from November onwards. Alleppey, Cochin and Trivandrum have wind speeds of more than 20km/h, while Palghat and Punalur experience less than 5 km/h.

(e) Cloudiness

Maximum cloudiness over the State is observed during monsoon season especially in June and July when about 7 oktas of the sky remain covered with clouds. A secondary maximum is observed in October- November, especially in southern parts in association with post- monsoon activities. Minimum cloudiness over the State is observed from January to March.

(f) Sunshine

Due to overcast skies during the southwest monsoon, the bright sunshine hours are less than 4 h./day while in winter it is about 10 h./day

(g) Special weather phenomenon

Monsoon are large scale seasonal wind systems which are basically thermally driven. On an average, 66% of the rainfall of Kerala is produced by southwest monsoon and about 18% by northeast monsoon. The major synoptic systems or components which causes the rainfall during the monsoon period are the monsoon trough, monsoon depressions, offshore vortices, mid-tropospheric cyclones, orographic influences etc..

The State experiences the influence of storms and depressions mainly in the post-monsoon season and in the month of May. Storms in the post- monsoon period usually originate in the Bay of Bengal between 5^{O} N and 13^{O}N latitude and in the month of May between latitude 7^{O} N and 12^{O} N. Only a few of the storms develop into their full strength: most of the systems remain as lows or depressions. These tropical storms cause intensive winds and heavy rainfall over the whole State, especially in South Kerala depending upon the track of movement.

Thunderstorms occur in the pre- monsoon and post-monsoon periods, especially the South Kerala. Thunderstorms in the north east monsoon season occur mostly at night or early morning hours. Maximum thunderstorm activity occurs in month of April and a secondary maximum in the month of October.

(h) Climatic Classification

The basic idea behind climatic classification is to provide a concise description of various climatic types in terms of effective factors, which are primarily related to heat and moisture. Several methods have been suggested for the classification of climates. Attempts have been made for obtaining a classification that will permit the establishment of regional boundaries between areas of uniform climatic conditions. But this task is beset with lot of difficulties. For, in addition to changes in micro- environmental factors, sets of limiting conditions for the classification of climates will vary according to the purpose for which classification is made, such as establishment of limits of areas suitable for a crop or pasture or regions suitable for human settlements. Most widely known climatic classifications are bio- climatological in nature and actually attempt to relate the extent and type of natural vegetation on the surface of the earth to climatic conditions.

Employing the moisture and thermal regimes of climatic classification (Thornthwaite(1948)and Carter & Mather(1966)), Kerala state was classified by James(1991) One salient feature of this classification is that there is no arid climate over Kerala State (Fig 3.4). Northeast Kerala and areas surrounded by the southern pocket of heavy rainfall have the perhumid type of climate. In the extreme south, moist subhumid prevails and in the remaining region, the climate is of the humid type. In the thermal regime of climatic classification, most parts of the State, except eastern high altitude stations have megathermal type of climate (Fig 3.5) This confirms the findings of Subrahmanyam (1958) that the distribution of thermal efficiency is more than adequate to support an efficient and luxuriant growth of vegetation.

Taking into consideration the physiography climate, soil

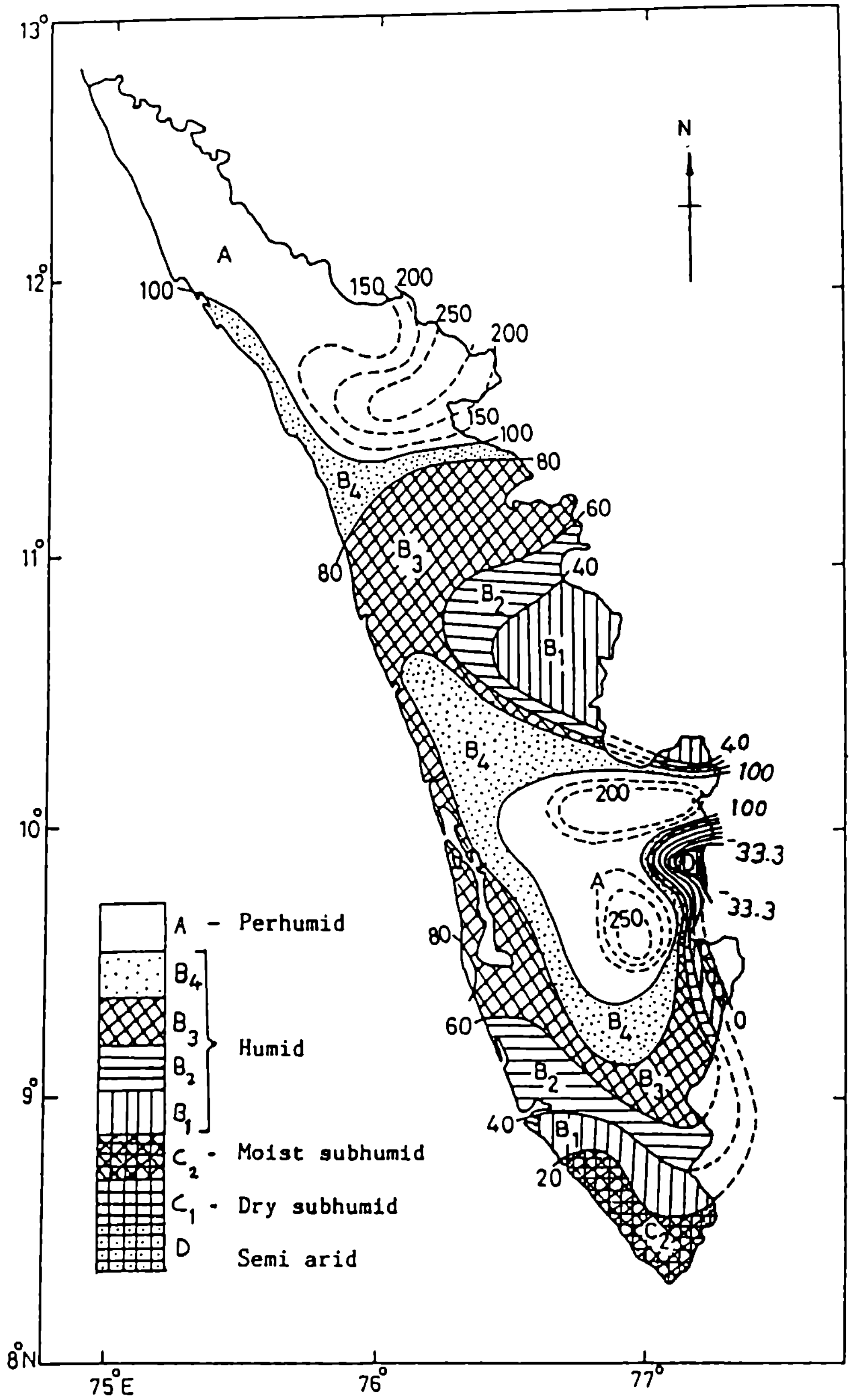


Fig 3.4 Climatic classification of Kerala - moisture regime (After James (1991))

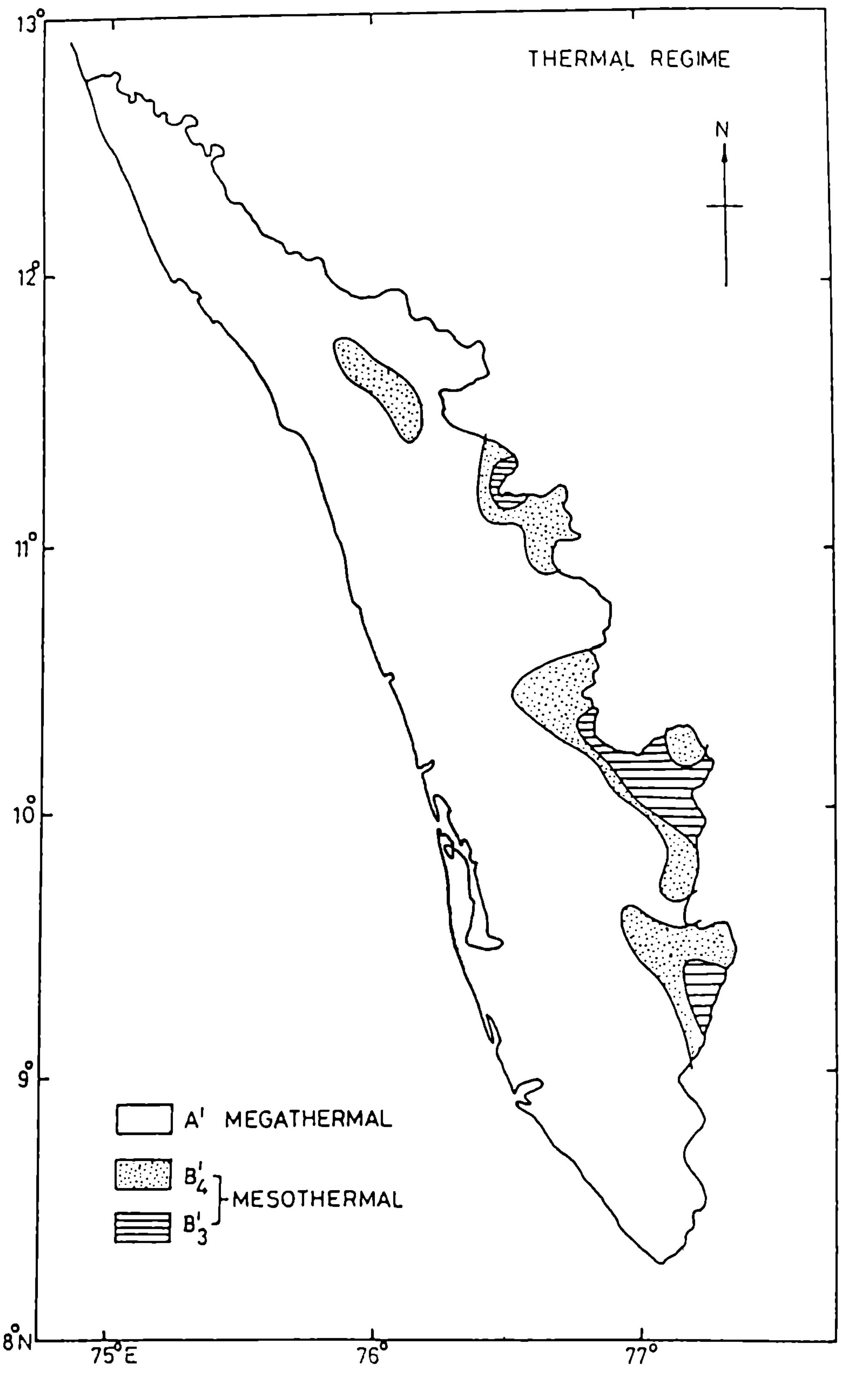


Fig 3.5 Climatic classification of Kerala - thermal regime (After James (1991))

characteristics, sea water intrusion, irrigation facilities, land use pattern and the recommendations of the Committee on Agro-climatic Regions and Cropping Patterns Constituted by the Government of Kerala in 1974, the State was divided into five Agroclimatic regions. These zones are Northern Central, Southern, High Range and Problem areas.

The northern zone consists of the four northern districts of Kerala viz. Kasargode, Cannanore, Calicut and Malappuram, covering 28.2 percent of the area of the State. This comes under the perhumid and humid type of moisture regime of climatic classification. The zone receives rains during both the monsoons. Although the zone is endowed with plentiful rainfall, a prolonged dry spell of 4 to 5 months duration does occur every year from December to May. The mean maximum and minimum temperatures of the region are 33^{o}C and 23^{o}C respectively. The major types of soils are coastal alluvium, laterite and forest loam. Rice m coconut, arecanut, pepper, banana, cashew and rubber are the important crops of the zone.

The central zone consists of three central districts of Kerala viz. Palghat, Trichur, and Ernakulam excluding the high ranges, coastal saline tracts and other isolated areas like Kole lands with special soil and physiographic conditions. This zone covers 25 percent of the area of the state. This zone also comes under the perhumid and humid type of the climatic classification of moisture regime. The zone is characterized by comparatively heavier rainfall during the South- West monsoon and less rainfall during the North East monsoon period leaving in between a dry spell of 6 months from December to May. The mean maximum and minimum temperatures of the zone are 31.4^{O} C and 21.1^{O} C ,respectively. The soil type is mainly laterite. The crops raised are mainly rainfed. This zone is the major rice growing tract of the State. Coconut, arecanut, ground nut, sesamum, pulses, banana and pineapple are the other important crops of the zone.

The southern zone comprises the districts of Trivandrum, Quilon, Pathanamthitta, Alleppey and Kottayam. This zone covers 18.68 percent of the area of the State. This zone comes under the Perhumid, humid and moist sub humid categories of the moisture regime. The region has a tropical humid climate, with an aggressive summer and plentiful seasonal rainfall. The hot season from March to May is followed by the South-West monsoon from June to September The Northeast monsoon occurs from October to November. Unlike in the other regions of the State, the rainfall is comparatively well distributed with the result that the effective annual rainfall is more than that in the other four zones. The mean maximum and minimum temperatures are 36.76^{O} C and 21.15 ^{O} C, respectively. The soils are lateritic, the texture ranging from sandy to sandy loam and clay loam. The major crops of the region are rice, coconut, tapioca, pepper, cashew, rubber, arecanut, sugar cane, pulses and banana.

The high range zone comprises the districts of Wynad and Idukki, Hill ranges of Palghat, Quilon and Trivandrum districts. Since the districts of the region are not contiguous, the agricultural characteristics differ widely. The Wynad range is situated at an elevation ranging from 700 to 2100m above MSL. The region receives heavy rainfall during the South- West monsoon (June-September) North-East monsoon and Pre-monsoon showers account for the major portion of the remaining precipitation. The dry spell occurs during December to March. The mean maximum and minimum temperatures are 29.6^{o}C and 19.6^{o} C, respectively. The soil type is forest loam, characterized by a surface layer of humus and other organic matter at various stages of decomposition. This region is famous for plantation crops and spices. Coffee, the most widely cultivated crop, is the main source of income to the vast majority of small farmers. Pepper, Cardamom, ginger, tea etc. are the other important crops of this region.

The Idukki range is situated at an elevation ranging from 800to 1100M above MSL. The district receives both South -West and North- East monsoon rains. Very heavy rainfall occurs during the months of June, July and August while the rainfall is very low during December to March. Mainly, two types of soils viz. forest loam and laterite are seen in this district. Plantation crops like tea, cardamom and rubber are largely grown in these soils. The other important crops are coconut, .pepper, coffee, banana, and vegetables.

The special zone of "problem areas" comprises of 5 areas viz. Onattukara, Kuttanad Pokkali, Kole and Sugarcane lands spread over the six districts of kerala viz. Alleppey, Quilon, Kottayam, Ernakulam, Trichur and Malappuram. In the first four areas coconut and rice are the principal crops. The coconut plantation in the entire area is affected by the complex diseases of Root Wilt. Tapioca, and other tubers, fruit trees, banana and vegetables are the other important crops of these areas.

Geographically the Sugarcane land lies towards the east as an ascending narrow strip of land with mountains and sea in the east and west, respectively. The soils are mainly laterite and alluvium. This region gets rainfall during both the months of May to September. The winter during December-January is mild and dry spell occurs during February-April. Rice and Sugarcane are the important crops in low lying and submersible areas and coconut in the plains. Tuber, condiments and spices, vegetables and banana are the other important crops.

3.3 Agriculture status of the State:

3.3.1 Land use pattern

From the climate of the State it is clear that, the temperatures ranging between 22^{o}C and 30^{o}C and high rainfall amounts during monsoon season, have given rise to a wide variety in landuse in the State. This section deals with the present status of landuse pattern in the State.

According to 1992-93 figures, out of the total geographical area of the State, the net sown area is 22.49 lakh ha. and total cropped area 30.46 lakh ha.. Table 3.2 gives a detailed picture of classification of area under utilization, district - wise and for the State as a whole according to 1992 - 93 records. Here the total geographical area is divided into four classes (a)net sown area (b) non-agricultural (c) forest and (d) miscellaneous, which includes barren uncultivated land, pastures, grazing land, miscellaneous tree crops, cultivable waste and fallow and current fallow. The percentage distribution of land in the State according to use is also given.

Districts	Geographical area(Ha.)	Net Sown area(Ha.)	Non-agriculture (Ha.)	Forest (Ha.)	Misc. (Ha.)
Trivandrum	218600	144621	20952	49861	3166
		(66.15)	(9.58)	(22.8)	(1.4)
Quilon	251838	143116	23882	81438	3402
		(56.83)	(9.48)	(32.34)	(1.35)
Pathanam-thitta	268750	99585	10985	155214	2966
		(37.05)	(4.09)	(57.75)	(1.10)
Alleppey	136058	105027	23890	----	7141
		(77.19)	(17.56)	(---)	(5.25)
Kottayam	219550	181175	21831	8141	8403
		(82.52)	(9.94)	(3.7)	(3.83)
Idukki	514962	187161	16930	260907	49964
		(36.34)	(32.88)	(50.66)	(9.7)
Ernakulam	235319	182229	34684	8123	10283
		(77.44)	(14.74)	(3.45)	(4.37)
Trichur	299390	154692	27613	103619	13766
		(51.67)	(9.22)	(34.61)	(4.6)
Palghat	438980	2198456	33038	136257	51229
		(49.76)	(7.53)	(31.04)	(11.67)
Malappuram	363230	208439	21975	103417	29399
		(57.39)	(6.05)	(28.47)	(8.09)
Calicut	233330	162821	21181	41386	7942
		(69.78)	(9.08)	(17.73)	(3.4)
Wynad	212560	115895	7308	78787	10570
		(54.52)	(3.44)	(37.07)	(4.97)
Cannanore	296797	204457	23140	48734	20466
		(68.89)	(7.79)	(16.42)	(6.87)
Kasargode	196133	141919	15389	5625	33200
		(72.36)	(7.85)	(2.87)	(16.93)
State	3885497	2249593	302798	1081509	251134
		(57.89)	(7.79)	(27.83)	(6.46)

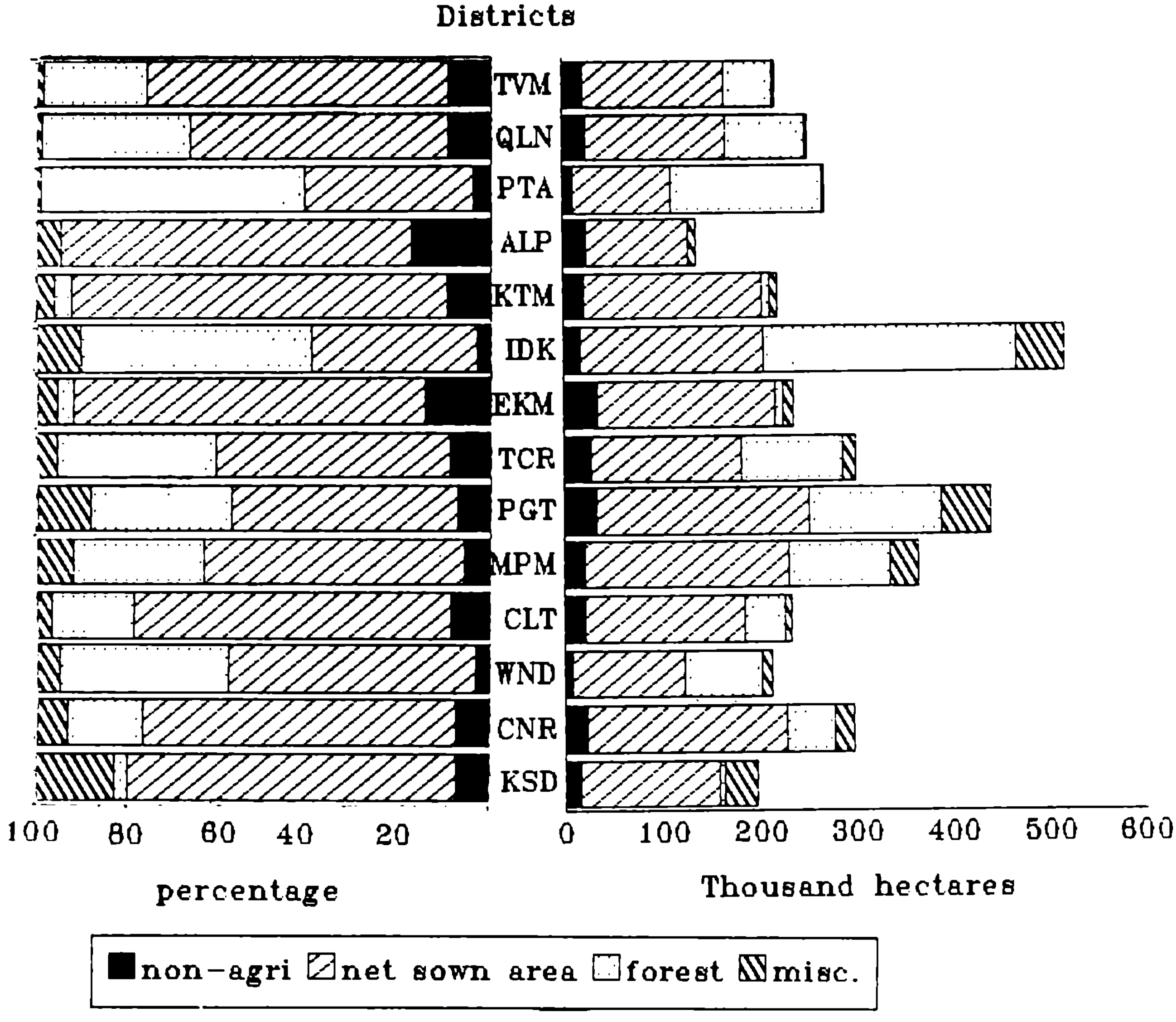
Table 3.2 Classification of area under land utilisation and its percentage distribution in the State (1992-1993)

The suitability of land and climate for a number of crops tempted the farmers to cultivate a host of crops in the same piece of land in mixed stands. This has resulted in an intensive cultivation of dry land in the State. The overall intensity of cropping in Kerala is fairly high. The ratio between gross cropped and net area sown is 1.35 as against the national level of 1.18. But this parameter in the context of Kerala is deceptive because nearly 45 per cent of the net area sown is under perennial crops.

Fig 3.6(a) gives the classification of area under land utilization in the State (district-wise) and its percentage distribution.

From the percentage value of net sown area, it is evident that, even though Alleppey is the smallest district it is ranking second (77.19%) in the State, while Idukki the largest district contributes the least. Alleppey, Kottayam, Ernakulam and Kasargode have more than 70% of its land area under cultivation. The percentage values of non - agricultural area shows that all the districts except Alleppey, Idukki and Ernakulam contribute less than 10% of their land for non - agricultural use - Idukki ranks first with 32.88%. Coming to land under forest, Pathanamthitta contributes the most for forest (57.75%) while Alleppey has no forest at all.

Fig 3.6(b) gives the percentage distribution of land in the State as a whole, with 57.89% of the land under net sown area category followed by forest (27.83%), 6.46% under miscellaneous category and 7 79% under non agricultural category



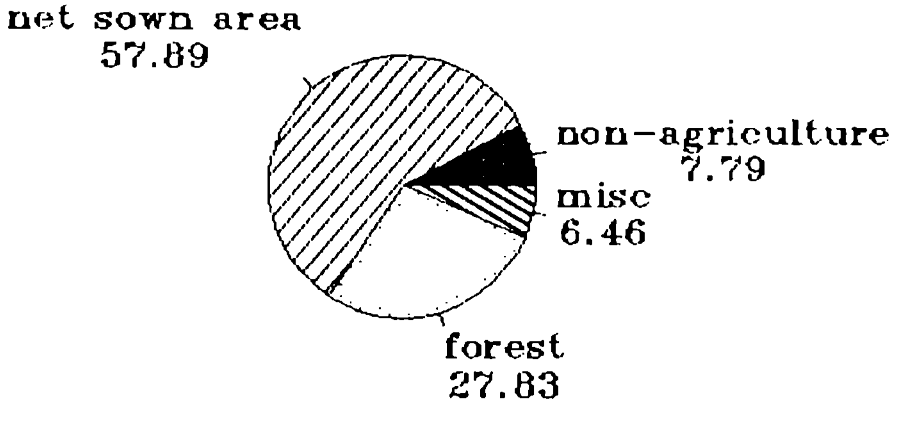


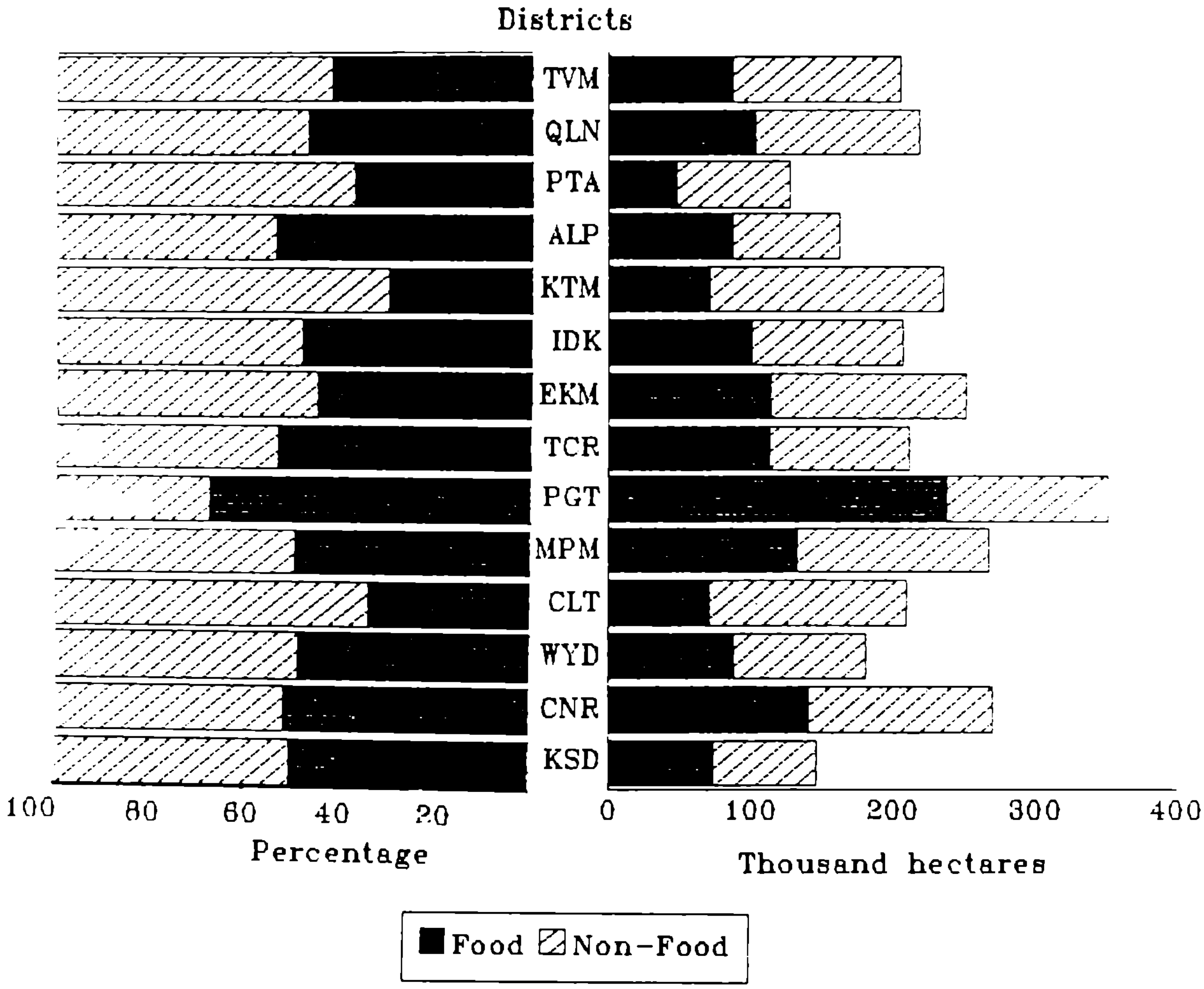
Fig 3.6 Area under different land uses - Kerala (1992 - 1993)

Table 3.3 and Fig3.7(a) give the area contributed for food crops and non - food crops under total cropped area of the State and in each district. In order to investigate the contribution of food crops and non food crops in the total cropped area of the State, the percentage distribution is calculated and presented in Table 3.3 and Fig 3.7(b) Cereals and millets, pulses, sugar crops, spices and condiments, fruits and vegetables come under food crops. Oil seeds, drugs and narcotics, plantation crops, fodder grass etc. are grouped under non food crops. 46.09% of the total cropped area of the State is contributed by food crops and 51.75% by non food crops. The districts Alleppey, Trichur, Palghat, Cannanore and Kasargode contribute more than 50% of their total cropped area for food crops. Under the non-food crops category, Kottayam, Pathanamthitta and Calicut contribute more than 60%. The extensive rubber plantation in Kottayam and coconut farms in Calicut district is the prime reason.

3.3.2 Major crops in the State

Agriculture in Kerala is unique in the sense that home stead system of cultivation is prevalent in almost all parts of the State. The nature of crops in the home steads depends mainly upon the requirements of the farmer and ranges from purely seasonal to perennial crops. One principal feature is that coconut constitutes the base crop in almost every home stead and it is intermixed with other seasonal, annual and perennial crops. Rice is the staple food of Keralites. Tapioca is a subsidiary food crop. The major crops include plantation crops such as coconut, arecanut, cashewnut, pepper, coffee, tea, rubber, annual crops like rice, tapioca, pulses, sesamum, cotton, ground nut,

(a) District - wise



(b) State

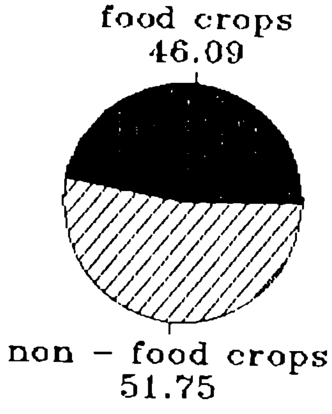


Fig 3.7 Area under food crops and non-food - Kerala (1992 - 1993)

District	Non Food (Hectare)	Food (Hectare)	Total Cropped area(Hectare)
Trivandrum	118360	87062	205422
	(57.62)	(42.38)	{6.74}
Quilon	115198	103628	218826
	(52.64)	(47.36)	{7.18}
Pathanam-thitta	80059	47733	127792
	(62.65)	(37.35)	{4.19}
Alleppey	74923	87657	162580
	(46.08)	(53.92)	{5.34}
Kottayam	164710	71068	235778
	(69.86)	(30.14)	{7.74}
Idukki	106832	100289	207121
	(51.58)	(48.42)	{6.71}
Ernakulam	137293	113807	251100
	(54.68)	(45.32)	{8.24}
Trichur	98590	113158	211748
	(46.56)	(53.44)	{6.95}
Palghat	113522	237995	351517
	(32.29)	(67.71)	{11.54}
Malappuram	134556	133049	267605
	(50.28)	(49.72)	{8.78}
Calicut	137886	71695	209581
	(65.79)	(34.21)	{6.88}
Waynad	92526	88440	180966
	(51.12)	(48.87)	{5.94}
Cannanore	129915	140544	270459
	(48.04)	(51.96)	{8.88}
Kasargode	72140	73836	145976
	(49.42)	(50.58)	{4.79}
State	1576510	1403995	3046471
	(51.75)	(46.09)	

Table 3.3 Classification of area under food crops and non-food crops and their percentage distributions in Kerala (1992-1993)

ragi, tobacco and fruit crops like mango, banana, pineapple, jack seasonal crop like cowpea, blackgram, redgram etc. In addition to this, in homesteads vegetables and tubers are largely grown. In recent years, Cocoa is also cultivated as an intercrop in coconut gardens as well as in homesteads.

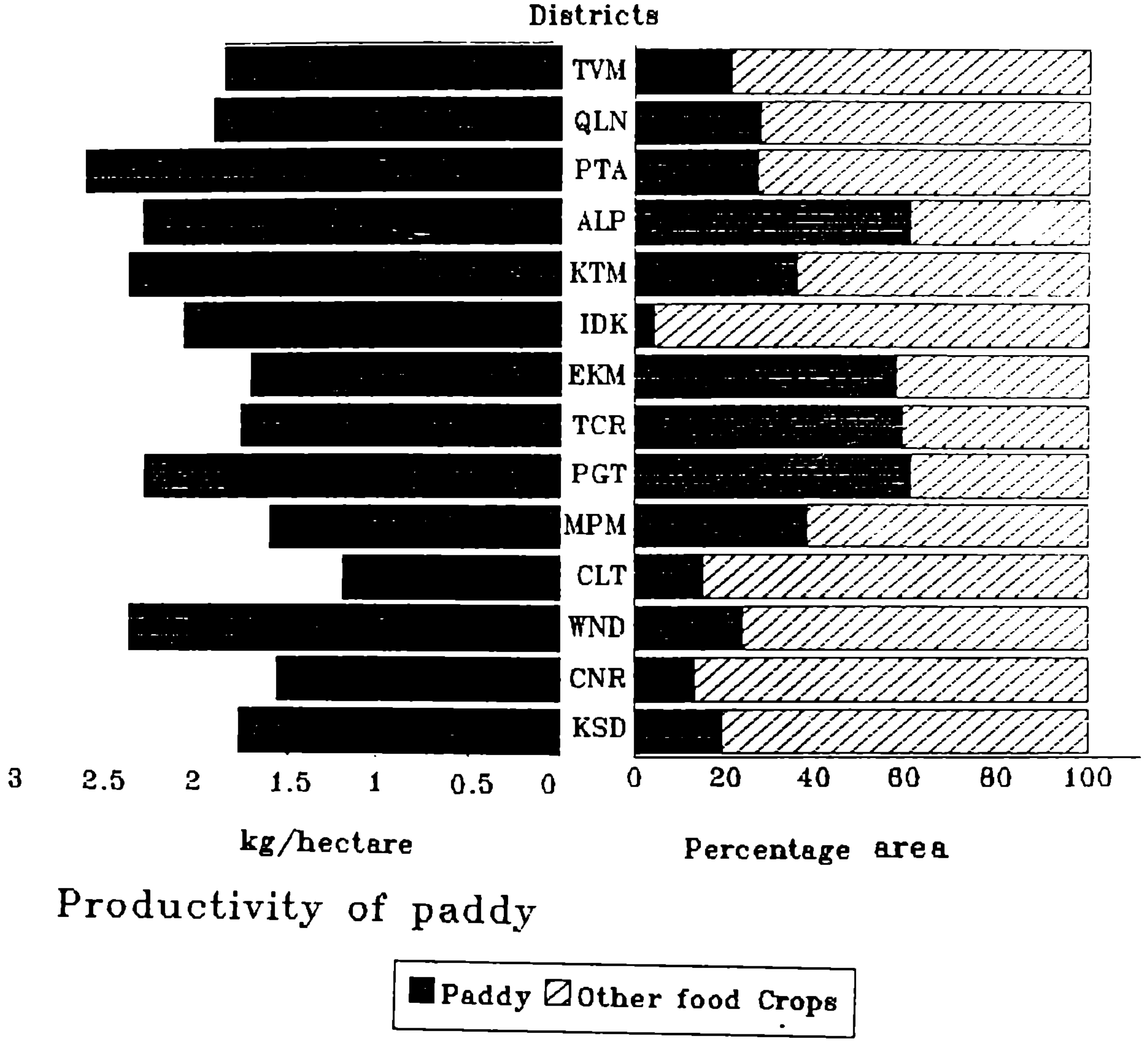
3.3.3 Area and productivity of principal crops

A wide variety of crops are cultivated in Kerala. The Table 3.4 and Table 3.5 gives area and productivity of principal crops in the State and in each district.

Rice is the staple food of Kerala. According to the figures (Table 3.6,Fig 3.8), 5.37 lakh ha. of the State is under paddy cultivation with a productivity of 2.02 kg/ha. While considering the area under the crop in each district Palghat ranks first followed by Trichur and Ernakulam. On the other hand, productivity wise Pathanamthitta is the first with 2.62 kg/ha., which is higher than the State value. Pathanamthitta is one district where area under the crop is very less compared to other districts (2.4% of State total) Districts which have rice productivity values more than 2 kg/ha. are Pathanamthitta, Alleppey, Kottayam, Idukki, Palakkad and Wynad. Here Alleppey is the only district in the lowland, while all the others are either in the midlands or highlands.

Tapioca (cassava) is a crop of great economic significance in Kerala and easily fits into the cropping systems prevailing in the State. Coming to the area and productivity of tapioca in the State, 1.35 lakh ha. land is under tapioca cultivation and the productivity is 19.5 kg/ha. When investigated at district

(a)



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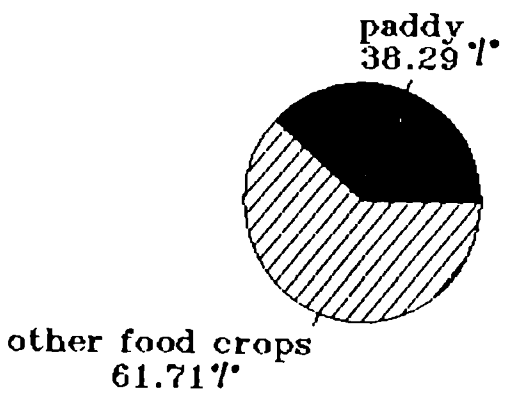


Fig 3.8 (a) Productivity of paddy and percentage area under paddy and other food crops - Kerala (district - wise)

(b) Percentage area under paddy and other food crops - Kerala (State)

Districts	Paddy	Coconut	Tapioca	Pepper	Rubber
Trivandrum	18361	86601	31760	4161	27864
Quilon	28460	76658	29748	8164	32819
Pathanam-thitta	12892	25635	8918	5117	50492
Alleppey	53344	67501	6274	1947	2569
Kottayam	25448	44992	10827	9704	110997
Idukki	4397	17298	5662	39163	35785
Ernakulam	66158	65201	5710	6963	65757
Trichur	67151	85600	3101	5596	7571
Palghat	146095	39514	10075	3359	25531
Malappuram	50908	98931	9471	8785	21723
Calicut	10755	122007	3157	14690	12189
Wynad	21135	5605	1420	32613	5567
Cannanore	18334	93304	6634	35654	27015
Kasargode	14170	48165	2276	7562	18217
State	537608	877012	135033	183478	444096

Table 3.4 Area under principal crops in Kerala (1992-1993)

Districts	Paddy	Coconut	Tapioca	Pepper	Rubber
Trivandrum	1.86	5970	18.8	0.23	0.77
Quilon	1.92	5120	19.3	0.309	0.96
Pathanam-thitta	2.62	5500	20.3	0.35	0.83
Alleppey	2.31	4548	17.7	0.105	0.99
Kottayam	2.39	4512	25.5	0.1616	0.87
Idukki	2.09	4914	25.5	0.36	0.89
Ernakulam	1.72	6626	20.8	0.194	0.72
Trichur	1.77	7407	17.4	0.17	1.4
Palghat	2.3	4125	18.6	0.12	0.62
Malappuram	1.61	5863	17.2	0.18	0.84
Calicut	1.21	7442	12.1	0.197	1.18
Wynad	2.38	1427	28.8	0.31	0.46
Cannanore	1.57	5337	17.0	0.26	0.72
Kasargode	1.78	5191	13.2	0.22	0.80
State	2.02	5843	19.5	0.27	0.83

Table 3.5 Productivity of principal crops in Kerala (1992-1993)

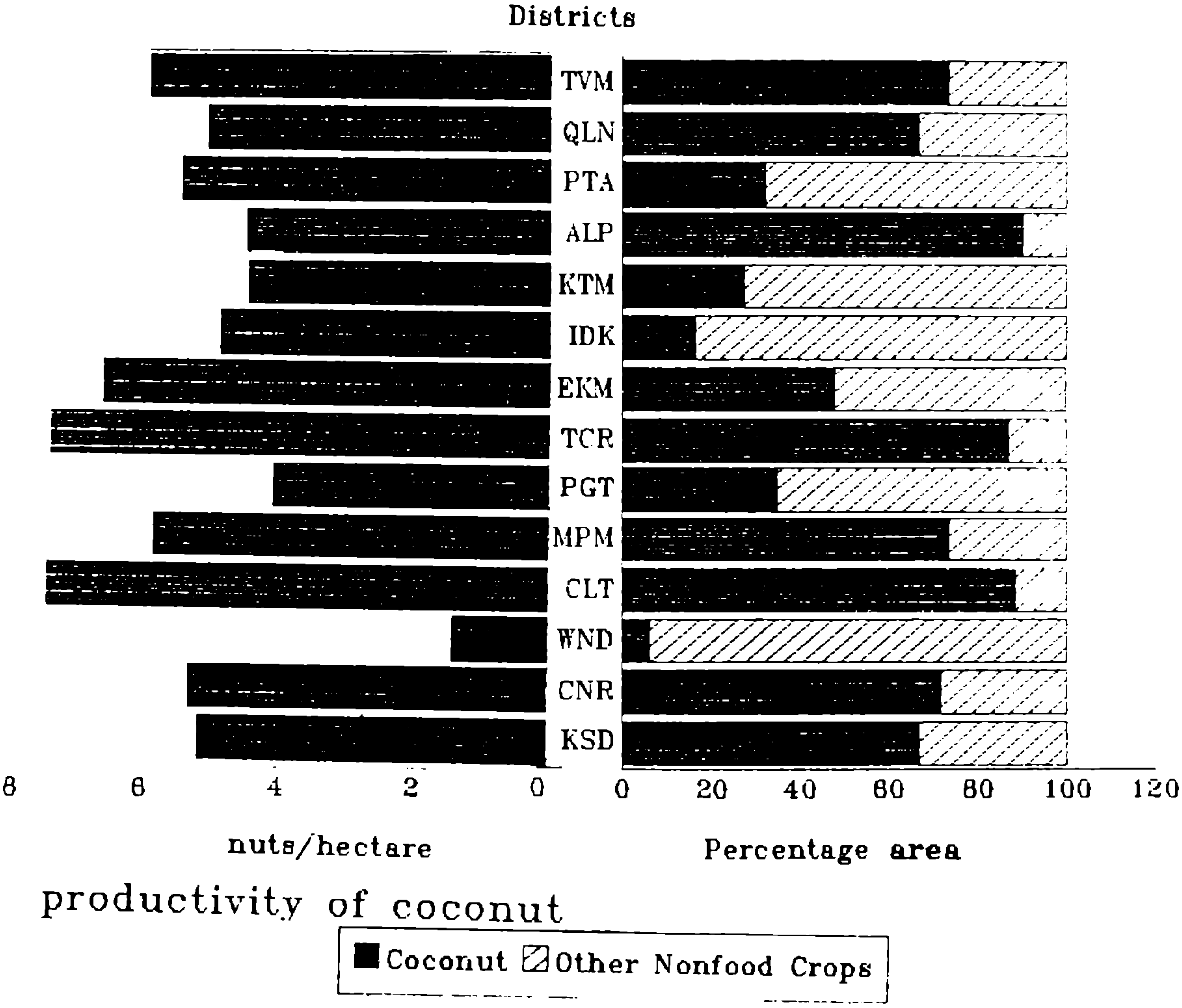
District	Paddy (Ha.)	Other Food Crops (Ha.)
Trivandrum	18361	68701
	(21.09)	(78.91)
Quilon	28460	75168
	(27.46)	(72.54)
Pathanam-thitta	12892	34841
	(27.01)	(72.99)
Alleppey	53344	34313
	(60.86)	(39.14)
Kottayam	25448	45620
	(35.81)	(64.19)
Idukki	4397	95892
	(4.38)	(95.62)
Ernakulam	66158	47649
	(58.13)	(41.87)
Trichur	67151	46007
	(59.34)	(40.66)
Palghat	146095	91900
	(61.39)	(38.61)
Malappuram	50908	82141
	(38.26)	(61.74)
Calicut	10755	60940
	(15.00)	(85.00)
Wynad	21135	67305
	(23.9)	(76.1)
Cannanore	18334	122210
	(13.05)	(86.95)
Kasargode	14170	59666
	(19.19)	(80.81)
State	537608	571000
	(38.29)	(61.71)

Table 3.6 Area under paddy and other food crops in Kerala (1992-1993)

District	Coconut (Hectare)	Other Nonfood (Hectare)
Trivandrum	86601	31759
	(73.17)	(26.83)
Quilon	76658	38540
	(66.55)	(33.45)
Pathanam-thitta	25635	54424
	(32.02)	(67.98)
Alleppey	67501	7422
	(90.09)	(9.91)
Kottayam	44992	119718
	(27.30)	(72.70)
Idukki	17298	105104
	(16.19)	(83.81)
Ernakulam	65201	72092
	(47.49)	(52.21)
Trichur	85600	12990
	(86.82)	(13.18)
Palghat	39514	74008
	(34.81)	(65.19)
Malappuram	98931	35625
	(73.52)	(26.48)
Calicut	122007	15879
	(88.48)	(11.52)
Wynad	5605	86921
	(6.06)	(93.94)
Cannanore	93304	36611
	(71.82)	(28.18)
Kasargode	48165	23975
	(66.77)	(33.23)
State	877012	699498
	(55.63)	(44.37)

Table 3.7 Area under coconut and other non-food crops in Kerala (1992-1993)

(a)



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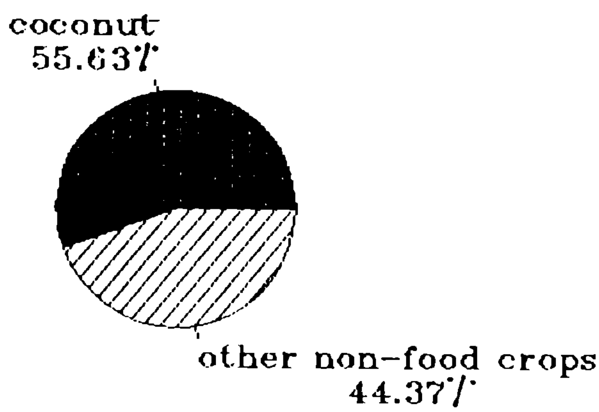


Fig 3.9 (a) Productivity of coconut and percentage area under coconut and other non-food crops - Kerala (district - wise)

(b) Percentage area under coconut and other non-food crops - Kerala (State) level, Trivandrum ranks first followed by Quilon. Kottayam, Idukki and Wynad are the districts with productivity more than 25 kg/ha.. It is evident from this that Tapioca is a highland crop.

India is the third largest producer of coconut in the world. The country with 1.1 million hectares accounts for nearly 1/8th area under coconut in the world. Kerala has nearly 8.77 lakh hectares under cultivation (1992-'93) The productivity is 5843 nuts/ha.(Table 3.7,Fig 3.9) Calicut, Trichur and Ernakulam are the districts which rank high in the case of coconut productivity. All the three districts have a long coast line.

Pepper, an important export oriented commodity, is also a crop of small and marginal farmers. The area under its cultivation in the State is 1.8 lakh ha. with Cannanore and Idukki contributing the most. The State productivity is 0.27 kg/ha. and Idukki, Quilon and Pathanamthitta contribute the most.

Rubber is the one crop which has registered substantial increase in area by about 1.05 lakh hectares during the decade, an increase of about 50.7 percent. The State area under the crop is 4.4 lakh ha. with productivity 0.83 kg/ha. Kottayam, Ernakulam and Pathanamthitta contribute the most (51.1%) About 25% of the State area is in Kottayam district. While State productivity is 0.83 kg/ha , Calicut, Alleppey and Quilon have productivity more than 0.9 kg/ha..

CHAPTER IV

RAINFALL VARIABILITY AND AGROCLIMATIC DROUGHTS OVER KERALA

A detailed analysis of the rainfall pattern over the State is presented in the first section of this Chapter, while the drought climatology of the region has been discussed in the second section.

4.1 Spatial and temporal distribution of rainfall over the State:

The results of the studies pertaining to spatial and temporal distribution of annual as well as seasonal rainfall over the State carried out by James (1991) are presented in this Section.

Analysis of data pertaining to the period 1931-1980 for 42 stations distributed uniformly over the State reveals that the average annual rainfall of Kerala is 294.3 cm; it is about 2.5 times the average rainfall of India and about thrice the world average rainfall.

There are two pockets of very heavy rainfall over the State (Fig 4.1), having average annual rainfall of more than 500 cm: one in the south and the other in the north. Among the stations selected for this study, the highest mean annual rainfall (507 cm) has been recorded at Neriamangalam and the lowest (60 cm) at Chinnar The rainfall varies from about 175 cm in the extreme south to about 350cm in the extreme north. The highest annual point rainfall (842.5 cm) has been recorded at Peermede, in 1968 and the lowest (12.3 cm) at Chinnar in 1939.

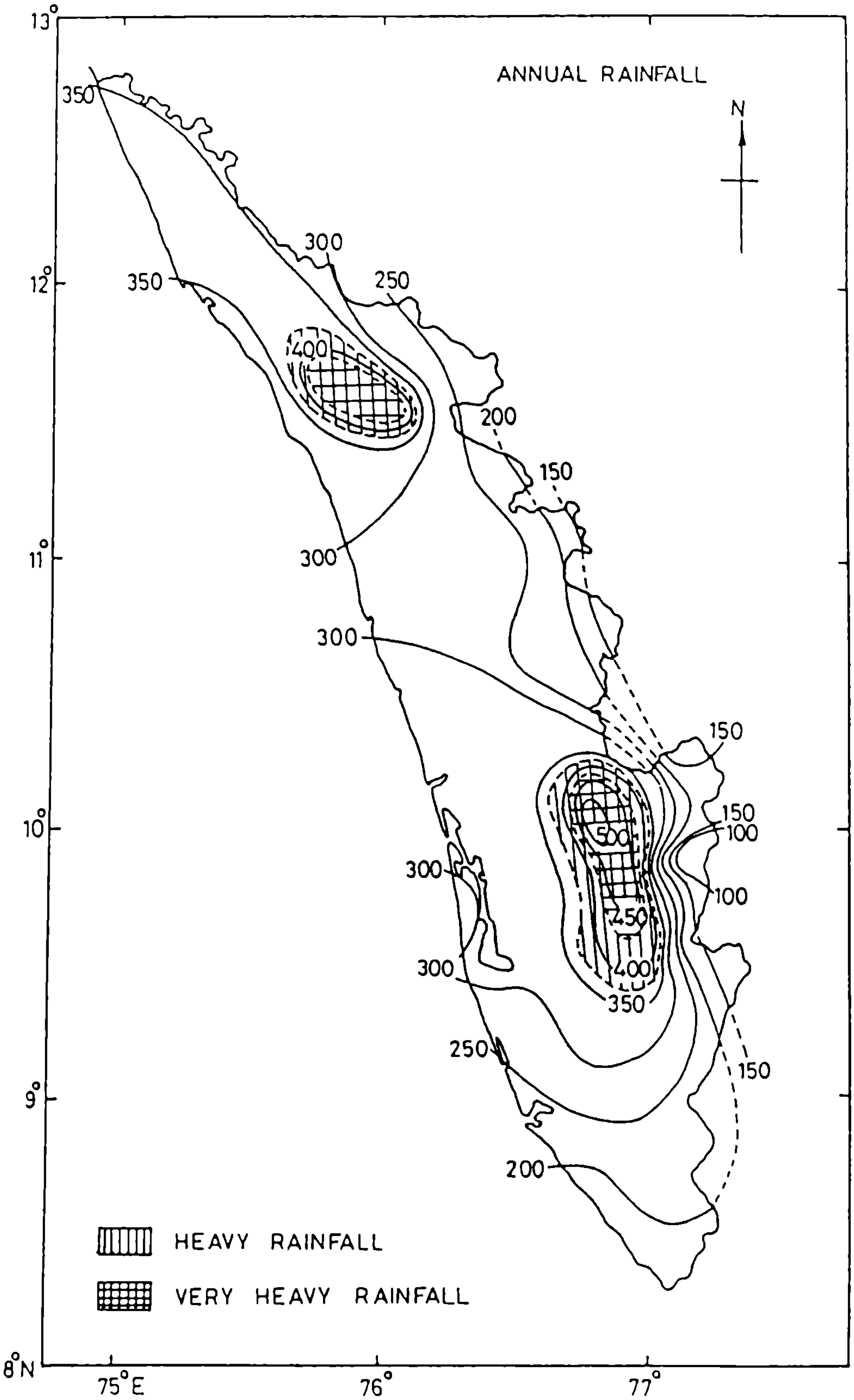


Fig 4.1 Spatial distribution of annual rainfall of Kerala (cm)
(After James (1991)

The seasonal contributions to average annual rainfall are 1%, 15%, 66% and 18% for the winter, pre-monsoon, monsoon and post-monsoon seasons respectively. The rainfall pattern in the monsoon season also exhibits two pockets of very heavy rainfall (Fig 4.2) The maximum rainfall in the monsoon season occurs at Vythiri (347 cm), which is about 80% of its annual value and the lowest at Chinnar (17 cm), where it is only 28% of the annual rainfall. The percentage contribution of monsoon rainfall to the annual is more than 80% in the northern parts, and gradually decreases to about 45% in the extreme south, where post-monsoon rainfall is comparatively higher (about 30% of annual) The heavy rainfall pockets observed in the annual and monsoon rainfall patterns in the north are not seen in the post- monsoon rainfall pattern.

Stations in the southern parts of the State have their highest monthly rainfall in June, but over the northern parts, the maximum occurs in July. The heaviest mean monthly rainfall of 140 cm occurs at Vythiri, followed by Kuttiyadi (130 cm), both in July and in the northern heavy rainfall pocket. Over the northern parts, the major contributions to annual rainfall are in the months of June, July and August, and in the southern parts, the rainfall is more widely distributed among the months. A double maximum exists in the monthly rainfall pattern all over the State, except in the extreme north.

The highest weekly rainfall (35 cm) occurs at Vythiri during the 29th week. This station experiences weekly rainfall of more than 30 cm over four consecutive weeks, and more than 25 cm each during six consecutive weeks. Almost all stations have shown

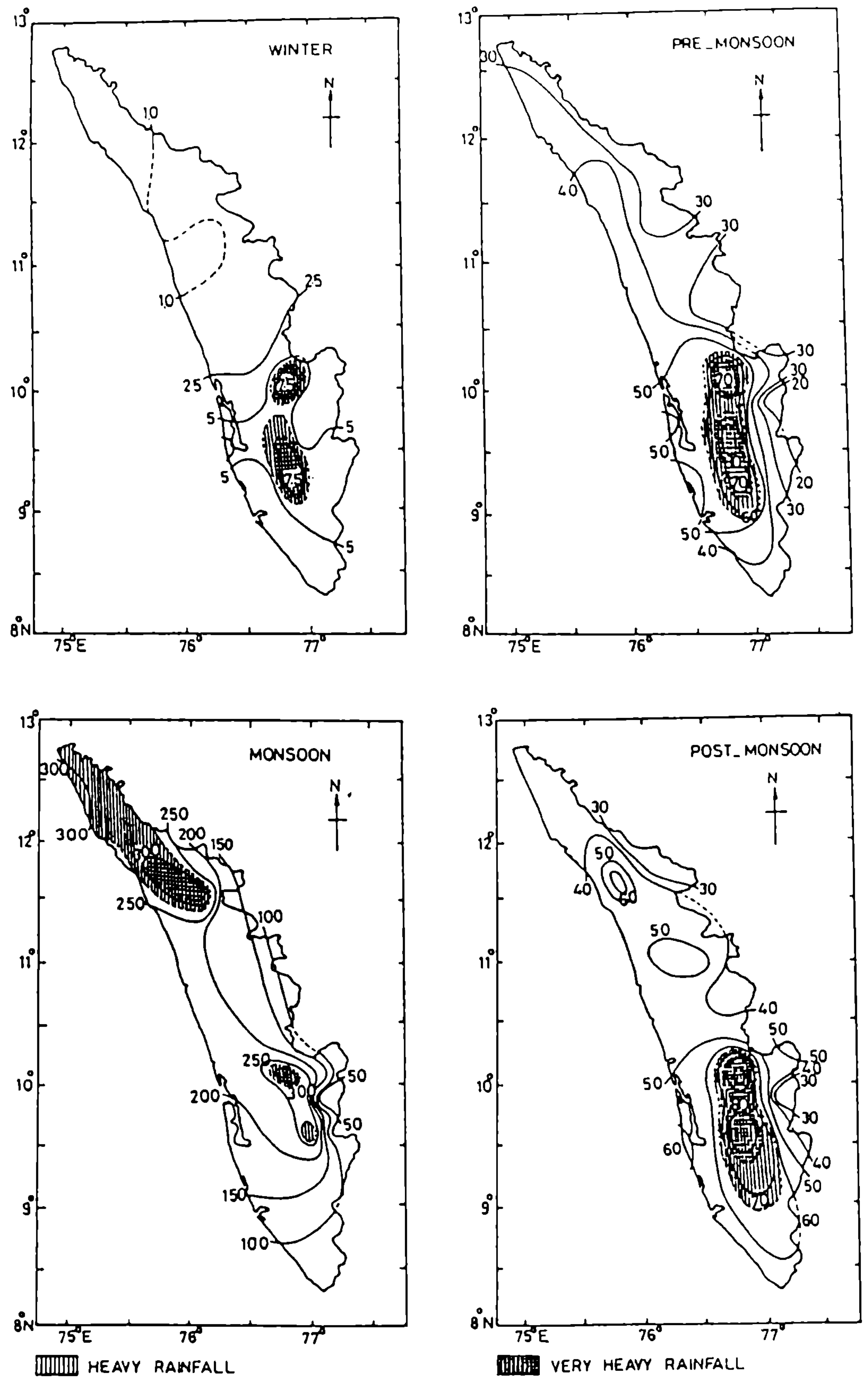


Fig 4.2 Spatial distribution of seasonal rainfall of Kerala (After James (1991)

a secondary maximum corresponding to the post-monsoon season.

Trend analysis of annual rainfall (Fig 4.3) has shown that some stations in the southern half of the State exhibits a significant decreasing trend, but only two stations in the northern half of State has shown such a trend. None of the stations in the State has shown any significant increasing trend. The stations which have shown significant decreasing trends appear to be randomly distributed.

For the monsoon season, only Punelur has shown a significant decreasing trend in rainfall. Half period averages have shown that both stations in the high ranges - Peermede and Vythiri also exhibit a decreasing tendency. All the other stations show a slight increasing tendency in monsoon rainfall. For the post-monsoon season, all stations except Palghat have shown a decreasing tendency. Punelur, Peermede and Vythiri have shown a decreasing tendency in monsoon, post-monsoon and annual rainfall. On the other hand, Palghat has shown an increasing tendency in all the three cases.

Time series analysis of annual rainfall over State employing power spectrum analysis gave the following results. A periodicity of infinite wave length was observed at Punelur. Some stations showed a quasi-periodicity in one or more harmonics in the wavelength range 10.3-24.0 years, while most of the stations in the southern half of the State showed a quasi-periodicity in the 2.9-4.3 years wavelength range.

It is clear from the above discussions that the State as a whole experiences large spatial and temporal variation both in

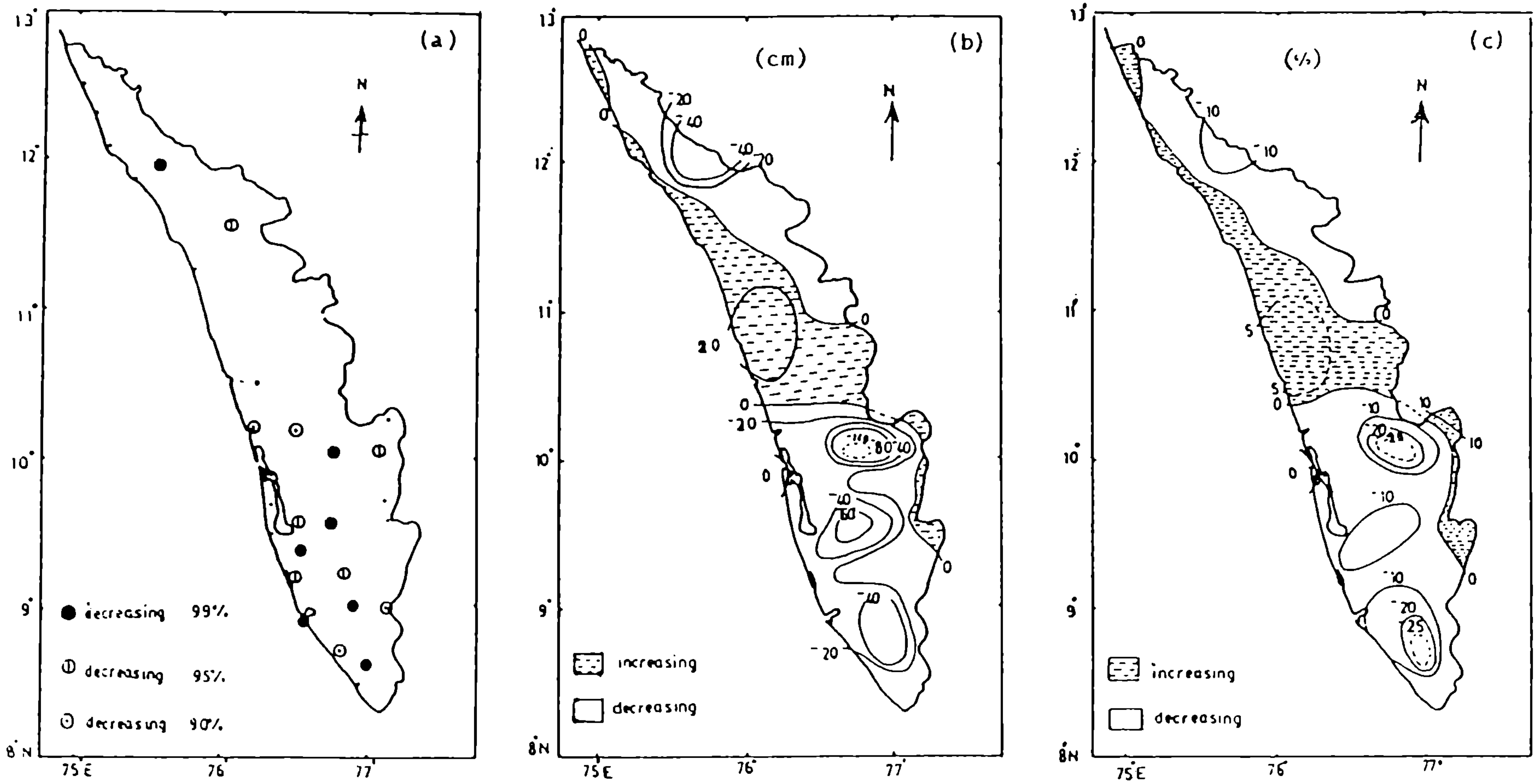


Fig 4.3 Trend aspects of annual rainfall series of Kerala (After James (1991))

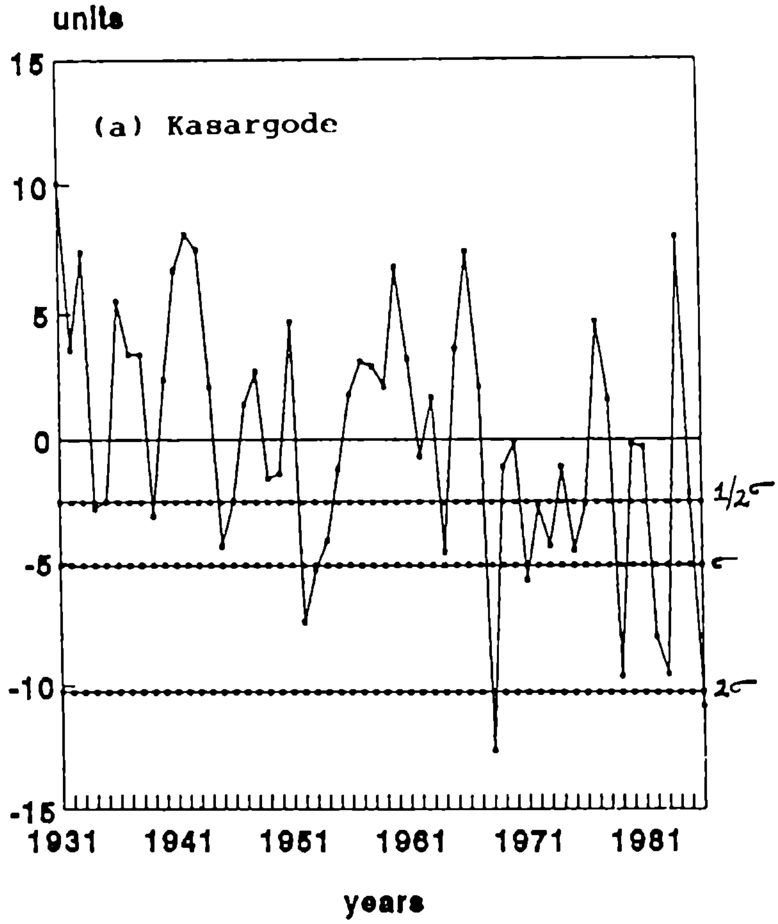
annual and seasonal rainfall. This variation in rainfall is in a way responsible for the occurrence of floods and droughts. While rainfall alone cannot be held responsible for the occurrence of floods, droughts are generally understood as a period of dryness due to lack of rain.

4.2 Agroclimatic droughts over Kerala:

4.2.1 Categorization of droughts

Fig 4.4 presents the march of percentage departures at 6 selected stations of Index of Moisture Adequacy (I_{ma}) from the climatic normals on an annual basis. As discussed in section three of chapter II, whenever the departures were negative droughts were categorized in relation to the standard deviation. The results of this study is presented in Table 4.1. Table 4.1 which shows the total number of drought years and number of droughts of various categories experienced by the stations.

Alleppey experienced the least number of droughts (19) and Kasargode the most (30) Vythiri was free from disastrous droughts during the entire study period. Konni experienced the largest number of moderate droughts (13), followed by Sherthala and Cranganore (12) Kasargode experienced the most number of large droughts (12) Trivandrum, Cochin and Trichur experienced 10 large droughts each. Alathur and Calicut experienced 10 severe droughts during the study period. The stations which experienced largest number of disastrous drought years (3) are Thiruvalla, Sherthala, Marayur, Cranganore, Kuttiyadi and Irikkur.



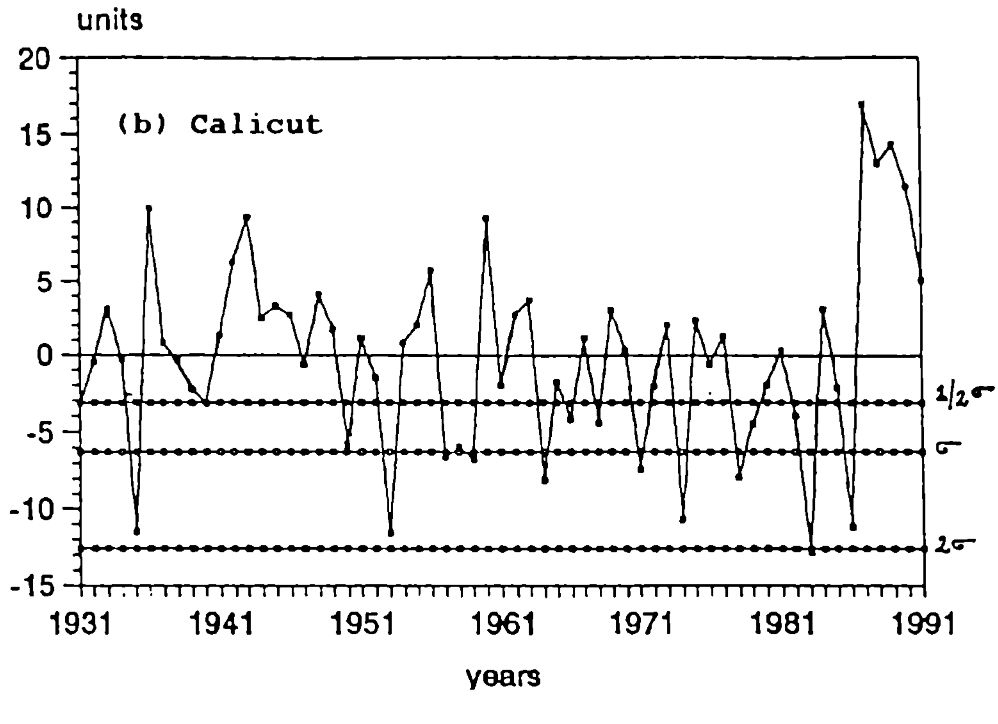
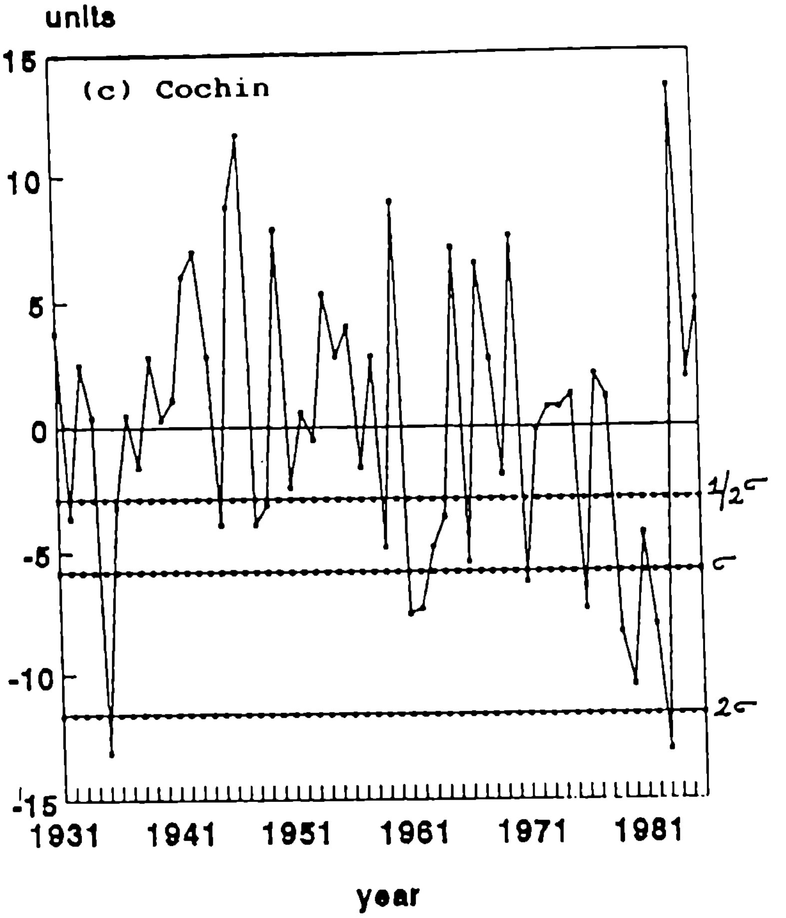


Fig 4.4 Yearly march of Index of Moisture Adequacy (%)



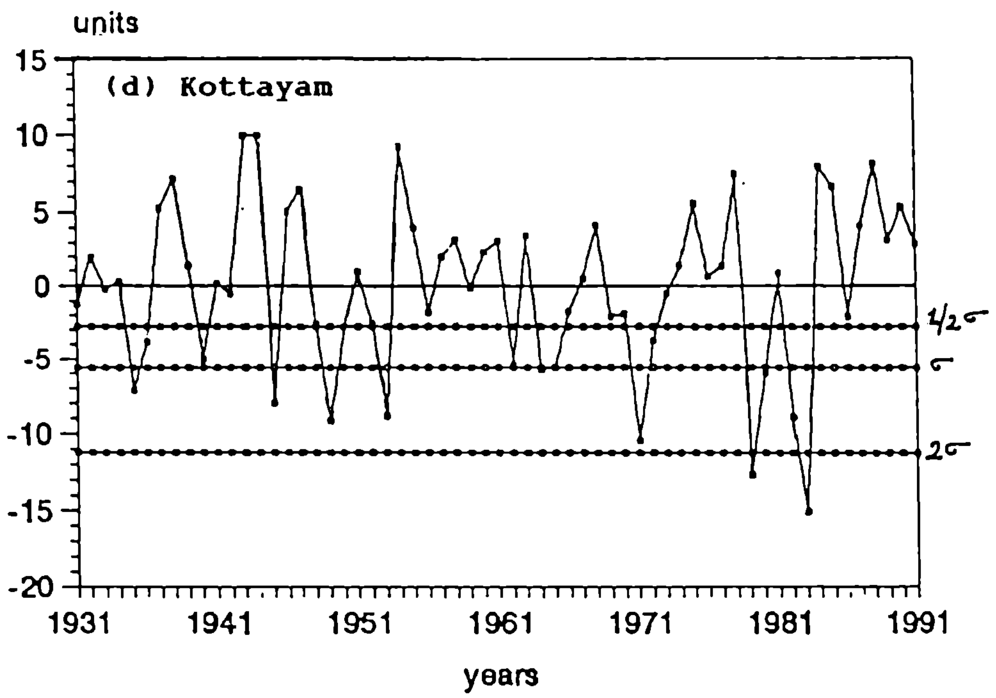
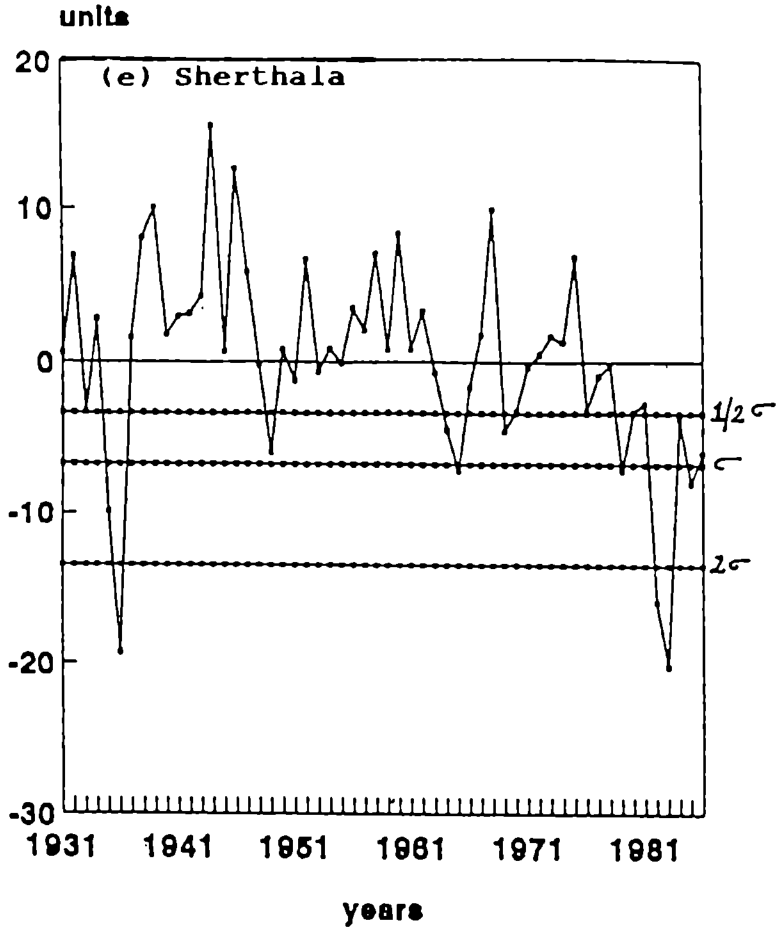


Fig 4.4 Yearly march of Index of Moisture Adequacy (%) (contd.)



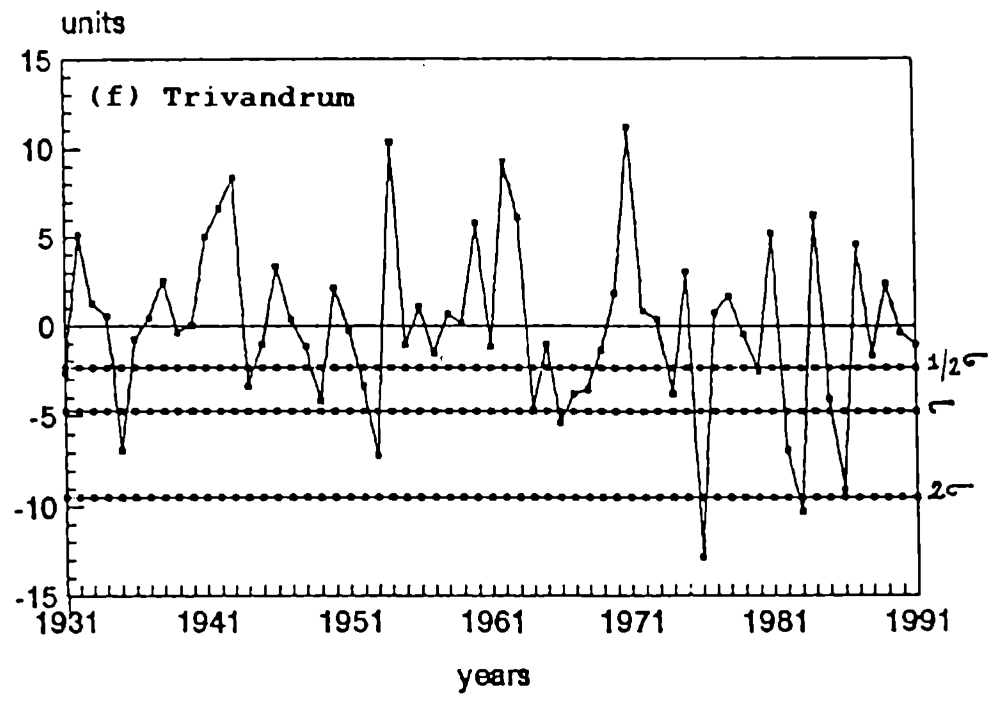


Fig 4.4 Yearly march of Index of Moisture Adequacy (%) (contd.)

STATION		NO OF YEARS STUDIED	NO OF DROUGHT YEARS	NO OF MODERATE DROUGHT YEARS	NO OF LARGE DROUGHT YEARS	NO OF SEVERE DROUGHT YEARS	NO OF DISASTROUS DROUGHT YEARS
Trivandrum	(TVM)	@ 60	28	11	10	5	2
Quilon	(QLN)	@ 60	27	11	6	9	1
Kayamkulam	(KYM)	55	24	11	6	6	1
Konni	(KNI)	55	27	13	5	8	1
Thiruvalla	(TVL)	55	22	9	5	5	3
Alleppey	(ALP)	55	19	7	5	5	2
Kottayam	(KTM)	@ 60	26	11	7	6	2
Sherthala	(STL)	55	24	12	5	4	3
Karikode	(KKD)	55	25	10	8	5	2
Cochin	(CHN)	55	25	6	10	7	2
Devikulam	(DVM)	* 49	23	10	6	5	2
Marayur	(MYR)	* 49	19	10	5	1	3
Cranganore	(CGR)	55	26	12	7	4	3
Trichur	(TCR)	55	26	9	10	6	1
Alathur	(ATR)	55	23	8	4	10	1
Mannarghat	(MRT)	55	26	9	8	5	2
Perinthalmanna	(PRM)	* 49	22	8	7	6	1
Calicut	(CLT)	@ 60	25	10	4	10	1
Vythiri	(VYT)	55	23	7	9	7	0
Kuttiyadi	(KTD)	* 49	19	6	6	4	3
Manantoddy	(MTY)	55	24	9	5	8	2
Cannanore	(CNR)	* 49	24	9	4	9	2
Irikkur	(IRK)	* 49	20	10	3	4	3
Kasargode	(KSD)	55	30	10	12	6	2

@ (1931 - 1991)
* (1931 - 1980)

Table 4.1 Incidence of drought years Kerala

4.2.2 Frequency of droughts

Fig 4.5 gives the occurrence of droughts of different categories at the selected stations in Kerala State during the period 1931- 1986 It is seen that droughts of some category or the other occur every year at least at a few stations in the State: there is no drought free years during the study period. As is to be expected, moderate droughts are most frequent, while disastrous droughts are experienced in a few years only. Large and severe droughts occur more often than disastrous droughts. There is no specific frequency in the occurrence of droughts nor is there any regular geography pattern.

From the figure, it is evident that the frequencies of occurrence of severe and disastrous droughts are more in the sixth, seventh and the first half of eighth decade. The early eighties, were the most drought affected period in the State. In 1981, Thiruvalla experienced a disastrous drought while Karikode and Vythiri experienced severe droughts and a few other stations had moderate and large droughts. In the year 1982, Alleppey and Sherthala experienced disastrous droughts with a majority of stations having droughts of severe intensity. In 1983, all the stations studied, except Alathur, experienced either a severe or disastrous drought: stations especially in South Kerala experienced disastrous droughts. Significantly, the year 1984 was in strong contrast to the previous year: only Mannarghat had a disastrous drought, with most of the stations being drought-free. None of the stations experienced a disastrous drought in 1985 while in 1986 only Kasargode and Alathur experienced disastrous droughts. The exceptionally large number

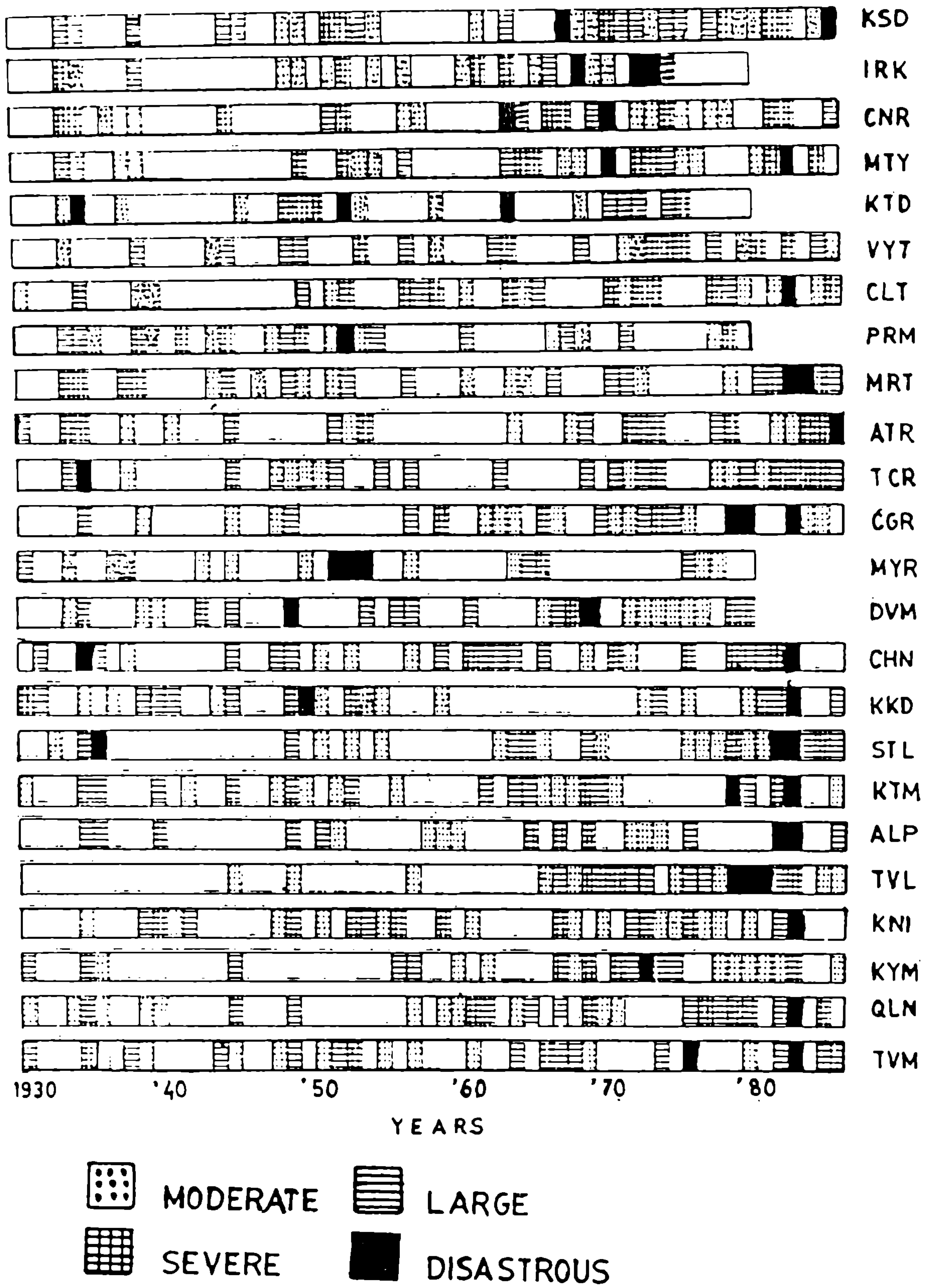


Fig 4.5 Categorisation of droughts on an annual basis - Kerala

of disastrous and severe droughts in these few years deserve detailed analysis of their exact duration and severity.

4.2.3 Duration and severity of droughts

Widespread droughts conditions of 1982 and 1983 and the drought-free year of 1984 were analyzed on a monthly basis by studying data for the period 1982-1984. As discussed in section - Three of chapter II the ratios of departures of the monthly I_{ma} values from their climatic normals to the standard deviations of the corresponding months were plotted (Fig 4.6) Drought spells are indicated by negative values while their severities are indicated by the magnitude of the negative departures from the normal. It is seen that a long duration spell spanning from September 1982 to June 1983 was experienced at most of the stations. For example, Trivandrum experienced seven drought spells between the years 1982 to 1984 The first one extends from January 1982 to April 1982, with the maximum intensity in February 1982. The second one with a short duration was limited to the month of September 1982. The third one extends from December 1982 to May 1983 and the fourth is also of a short duration, July 1983. The fifth spell extends from October 1983 to November 1983, the sixth from August 1984 to September 1984 and the seventh from November 1984 to December 1984(Table 4.2) From the table, it is seen that the drought spells which occurred in the year 1982 and 1983 were of longer durations than the other years.

On analyzing the weather sequences during the period, it is found that the State had received below normal rainfall from

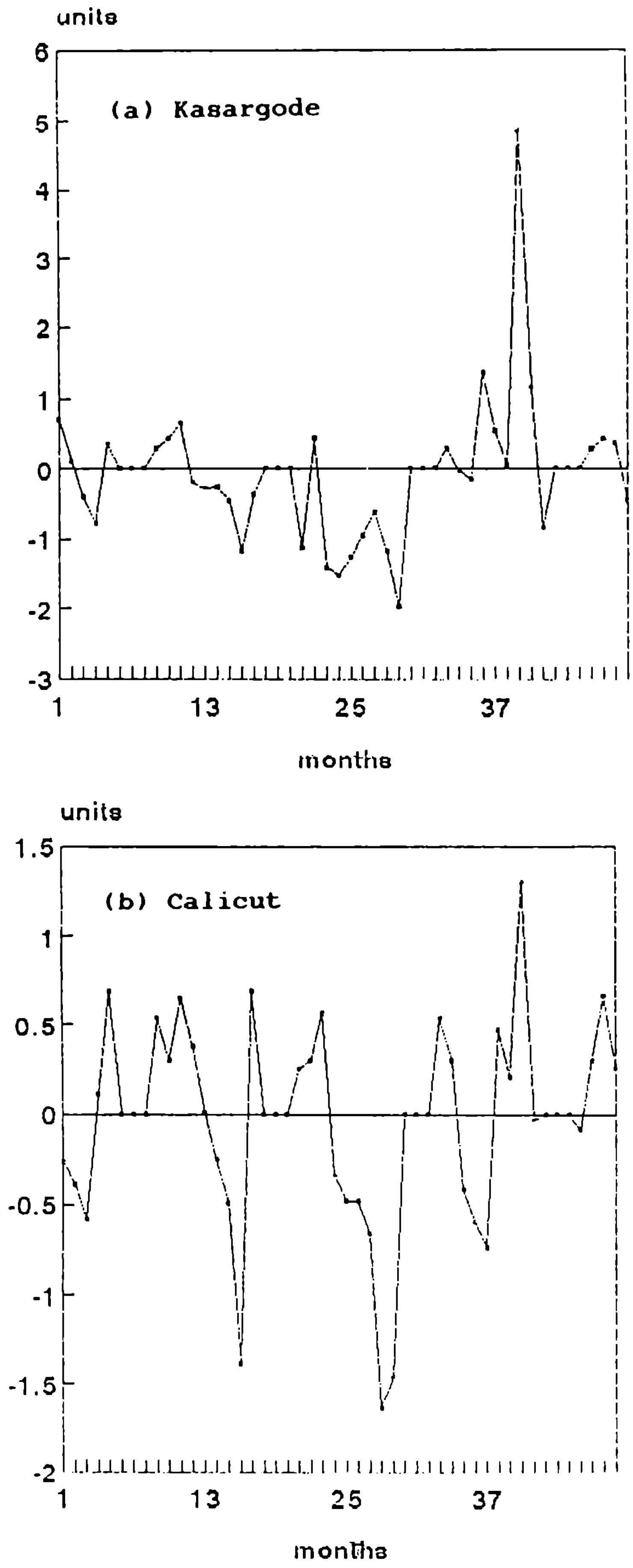
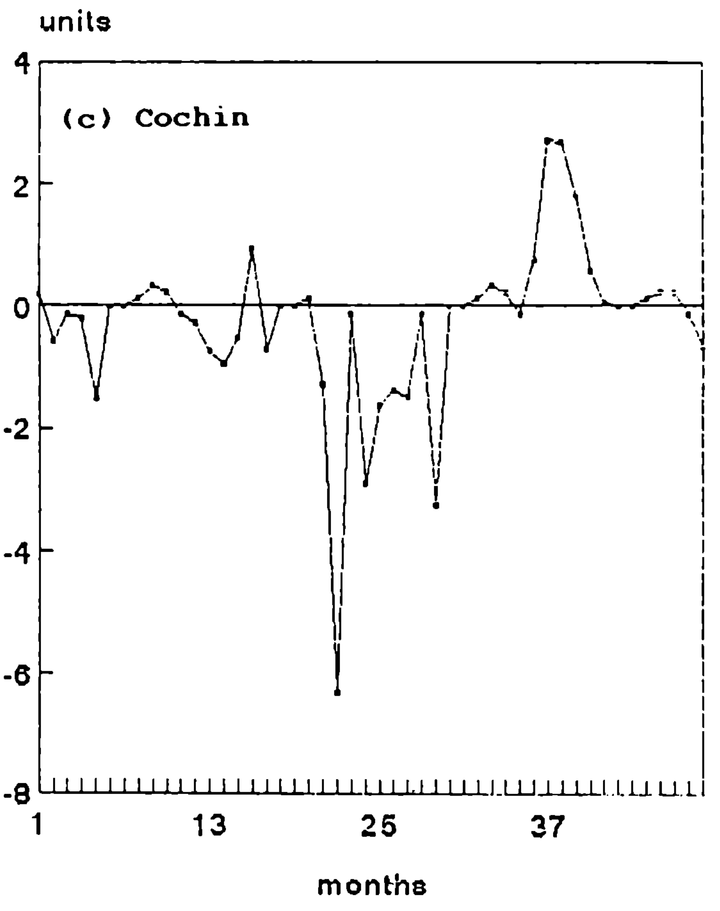


Fig 4.6 Severity and duration of drought spells (1982 - 1984)



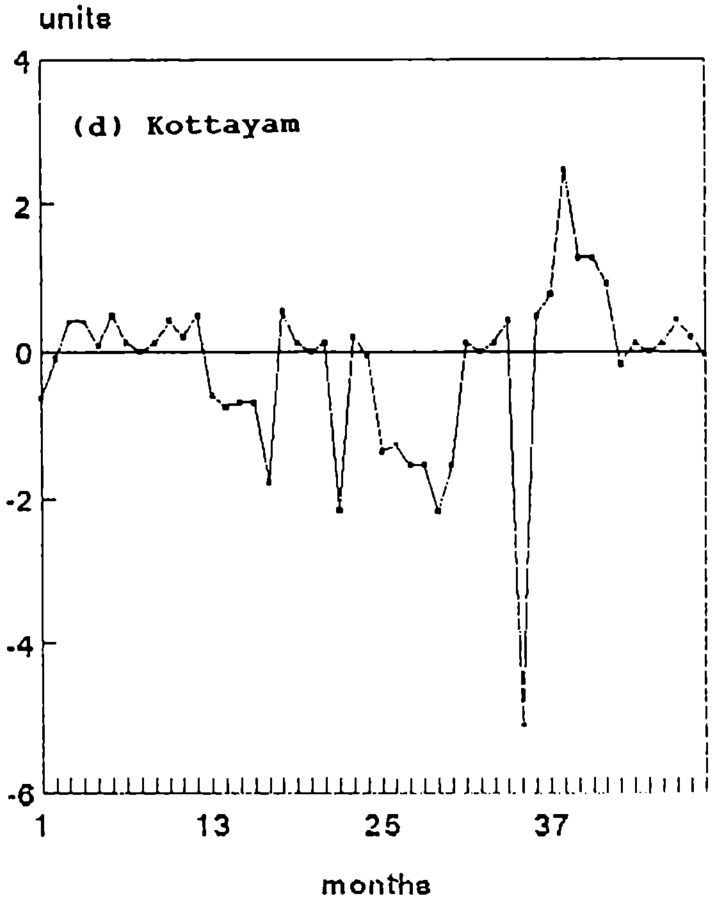


Fig 4.6 Severity and duration of drought spells (1982 - 1984) (contd.)

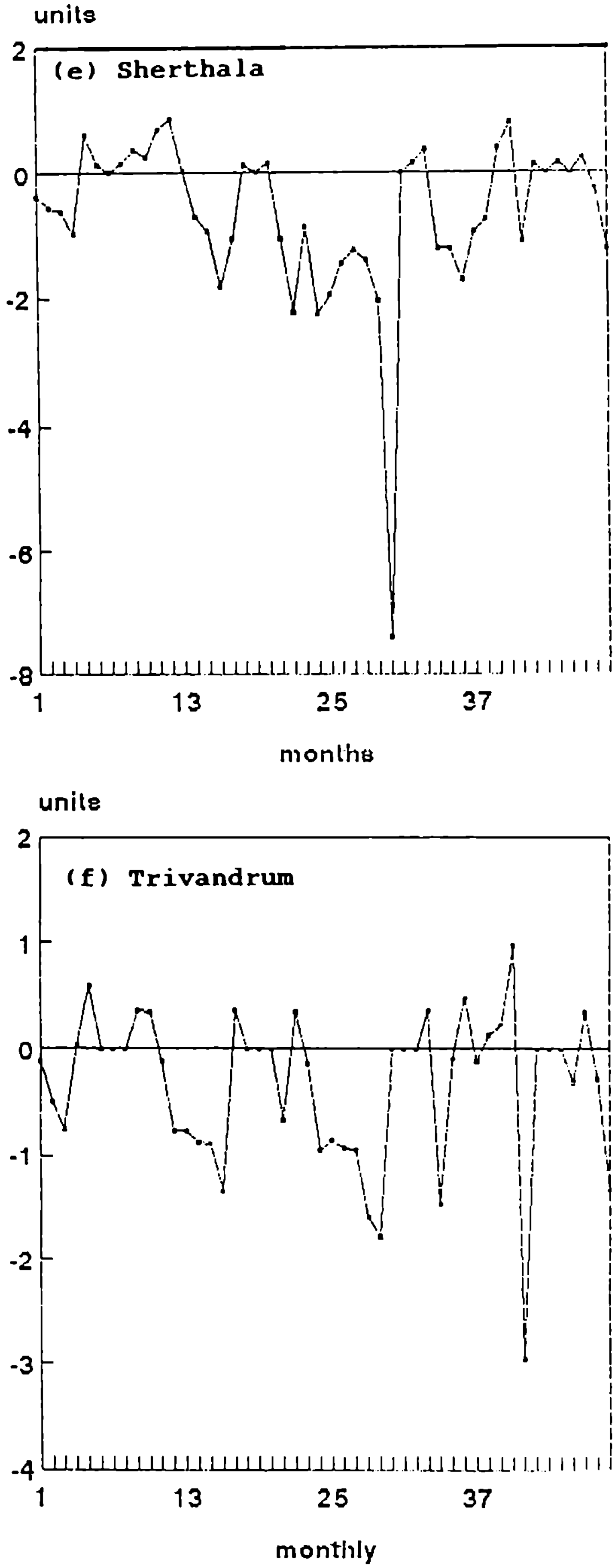


Fig 4.6 Severity and duration of drought spells (1982 - 1984) (contd.)

DRY SPELLS

STATION	1	2	3	4	5	6	7
Trivandrum	Jan. 1982 to Apr. 1982	Sep. 1982	Dec. 1982 to May 1983	July 1983	Oct. 1983 to Nov. 1983	Aug. 1984 to Sep. 1984	Nov. 1984 to Dec. 1984
Month with most severe drought	May 1982	Oct. 1982	May 1983	Nov. 1983	June 1984	Dec. 1984	
Kottayam	Jan. 1982 to May 1982	Oct. 1982	Dec. 1982 to June 1983	Nov. 1983	June 1984	Dec. 1984	
Month with most severe drought	May 1982	Oct. 1982	May 1983	Nov. 1983	June 1984	Dec. 1984	
Sherthala	Feb. 1982 to May 1982	Sep. 1982 to June 1983	Oct. 1983 to Feb. 1984	May 1984	Nov. 1984 to Dec. 1984		
Month with most severe drought	Apr. 1982	June 1983	Dec. 1983	May. 1984	Dec. 1984		

Table 4.2 Duration of drought spells - (1982 - 1984)

(Contd...)

DRY SPELLS

STATION	1	2	3	4	5	6	7
Cochin	Nov. 1981 to Mar. 1982	May 1982	Sep. 1982 to May 1983	Oct 1983 to Nov. 1983	Nov. 1984 to Dec. 1984		
Month with most severe drought	Feb. 1982	May 1982	Oct. 1982	Oct. 1983	Dec 1984		
Calicut	Jan. 1981 to Mar. 1981	Feb. 1982 to Apr. 1982	Dec. 1982 to May 1983	Nov 1983 to Jan. 1984	May 1984	Sep. 1984	
Month with most severe drought	Mar. 1981	Apr. 1982	Apr. 1983	Jan. 1984	May 1984	Sep. 1984	
Kasargode	Dec. 1981 to May 1982	Sep. 1982	Nov. 1982 to May 1983	Oct. 1983 to Nov. 1983	May 1984	Dec. 1984	
Month with most severe drought	Apr. 1982	Sep. 1982	May 1983	Nov. 1983	May 1984	Dec. 1984	

Table 4.2 Duration of drought spells - (1982 - 1984)

September 1982 to May 1983 The northeast monsoon was not active enough over the State during October November 1982 and the systems in the easterlies which in normal conditions give rain or thundershowers from January to May were less active. The cyclonic storms which formed, either decayed as soon as they crossed the coast or had a more northward displacement. Further, the onset of Southwest monsoon was on June 12th in the year 1983, a delay of 12 days from the normal date.

On the other hand, the northeast monsoon was active over the State during October and November 1983. The systems in the easterlies generally caused widespread rain or thundershowers on most of the days in December 1983. Rainfall during the months January to May 1984 was normal over the State: a number of systems developing in the easterlies affected the weather over Kerala. In the months April and May, the equatorial trough extending from South Andaman sea to South East Arabian sea across extreme south peninsula and Comorin area was quite active in which several moving or quasi-stationary cyclonic circulations in the lower troposphere were observed. Rain and thundershowers were widespread on a number of days during these months over the State. The onset of the southwest monsoon was on May 30th in the year 1984. Therefore, the heavy rainfall between December 1983 and April 1984 and an early onset of South west monsoon, elevated most stations to the drought free category.

4.2.4 Spatial coherence of droughts

The spatial coherence of droughts at all the nineteen stations was calculated for droughts of all the four categories as detailed in the methodology discussed earlier (Section Three of Chapter II) In the study, only probabilities above 50% were considered to be significant - values between 50% and 75% denoting moderate spatial coherence and values above 75%, high coherence.

(a) Probabilities of spatial coherence of moderate droughts

Table 4.3a presents the probabilities of spatial coherence of moderate droughts of all the stations considered for the study. In the study, only probabilities above 50% were considered to be significant - values between 50% and 75% denoting moderate spatial coherence and values above 75%, high coherence.

Among the stations considered for the study, when Kasargode, Karikode and Thiruvalla experienced moderate droughts, the probabilities of drought occurrence in the other area of the State are comparatively high.

When Kasargode is the key station, 13 other stations show moderate coherence. In the case of Karikode 10 other stations and in the case of Alleppey 12 other stations show moderate coherence.

Among the stations considered for the study, when Manantoddy, Calicut, Mannarghat, Kottayam, Konni and Quilon experience moderate droughts, the probabilities of drought occurrence in the other areas of the State are generally low. When Mannarghat is the key station, only Kottayam shows moderate coherence.

Auxiliary stations

KEY STN.	NO OF DROUGHTS AT KEY STN.	KSD	CNR	MTY	VYT	CLT	MRT	ATR	TCR	CGR	CHN	KKD	STL	KTM	ALP	TVL	KNI	KYM	QLN	TVM
KSD	10		20	60	60	40	30	30	60	50	50	60	60	60	30	60	50	50	60	60
CNR	9	55.5		38.3	55.5	66.6	33.3	44.4	44.4	66.6	33.3	44.4	33.3	11.1	44.4	55.5	22.2	55.5	44.4	44.4
MTY	9	44.4	33.3		55.5	11.1	22.2	44.4	44.4	22.2	44.4	22.2	55.5	22.2	11.1	22.2	55.5	33.3	33.3	55.5
VYT	7	57.1	42.9	28.6		71.4	71.4	42.9	71.4	57.1	57.1	57.1	42.9	42.9	42.9	57.1	42.9	57.1	42.9	28.6
CLT	9	33.3	22.2	33.3	22.2		44.4	44.4	44.4	33.3	22.2	44.4	33.3	55.5	44.4	33.3	55.5	22.2	77.7	66.6
MRT	9	33.3	44.4	44.4	33.3	77.7		33.3	11.1	33.3	33.3	33.3	22.2	55.5	33.3	22.2	22.2	11.1	44.4	44.4
ATR	7	71.4	71.4	85.7	28.6	42.9	57.1		42.9	28.6	71.4	57.1	42.9	71.4	28.6	42.9	71.4	42.9	42.9	85.7
TCR	9	55.5	22.2	33.3	55.5	22.2	44.4	44.4		22.2	66.6	44.4	44.4	44.4	33.3	55.5	55.5	44.4	22.2	33.3
CGR	12	58.3	50	33.3	50	33.3	66.6	41.7	50		66.6	16.7	33.3	50	25	50	41.7	41.7	41.7	58.3
CHN	6	33.3	33.3	50	50	50	33.3	66.6	66.6	33.3		33.3	33.3	33.3	50	33.3	50	33.3	33.3	83.3
KKD	10	60	40	50	50	30	30	30	50	50	50		60	20	50	30	80	30	30	60
STL	12	50	33.3	41.7	41.7	33.3	16.7	16.7	50	41.7	58.3	41.7		8.3	16.7	58.3	58.3	25	33.3	50
KTM	11	45.5	45.5	36.4	27.3	45.5	45.5	27.3	45.5	36.4	27.3	23.7	18.2		27.3	45.5	45.5	54.5	27.3	63.6
ALP	7	42.9	57.1	28.6	42.9	85.7	42.9	57.1	57.1	57.1	14.3	42.9	14.3	14.3		28.6	57.1	57.1	28.6	14.3
TVL	9	55.5	66.6	44.4	55.5	55.5	55.5	55.5	66.6	55.5	44.4	22.2	44.4	55.5	22.2		33.3	55.5	55.5	66.6
KNI	13	61.5	38.5	46.2	38.5	23.1	15.4	38.5	53.8	46.2	38.5	46.2	53.8	385	23.1	46.2		46.2	46.2	61.5
KYM	10	70	50	30	40	50	40	40	60	30	60	40	60	60	30	60	40		70	40
QLN	11	36.4	45.5	36.4	54.5	63.6	45.5	27.3	18.2	45.5	45.5	36.4	18.2	54.5	36.4	27.3	36.4	36.4		27.3
TVM	9	55.5	33.3	44.4	55.5	44.4	44.4	22.2	77.7	55.5	77.7	55.5	33.3	44.4	22.2	33.3	66.6	44.4	55.5	

Table 4.3a Spatial coherence of Moderate Droughts (%)

Out of the 19 stations, only 4 stations (Calicut, Mannarghat, Alathur and Cochin) show high coherence in the occurrence of moderate drought, simultaneous with other stations. When Calicut is the key station the probability of occurrence of moderate drought in Quilon is 77.7%. When Mannarghat is the key station the probability of occurrence of moderate drought in Calicut is 77 7%. Cochin has high coherence (83.3%) with Trivandrum, Alathur has high coherence (85.7%) with Manantoddy and Trivandrum.

(b) Probabilities of spatial coherence of large droughts

From Table 4.3 b it is observed that when Mannarghat, Trichur and Kayamkulam are considered as the "key" stations, moderate coherence is observed at 14, 12 and 12 stations respectively, while in the case of Kottayam, only Cranganore and Cochin show moderate coherence. 7 stations in the State show high coherence with Quilon. No station showed high coherence with occurrence of large droughts in Cochin, Karikode, Kayamkulam or Trivandrum. The stations Mannarghat, Trichur, Kayamkulam and Quilon exhibit high coherence with a larger number of stations in the northern parts of the State than in the south.

(c) Probabilities of spatial coherence of severe droughts

Trichur exhibited moderate spatial coherence with 14 stations, the highest for any key station. Kasargode and Cochin had moderate coherence with 12 other stations (Table 4.3c)

Similarly Trivandrum and Sherthala experienced high spatial coherence with 10 other stations. At the other extreme when

Auxiliary Stations

NO OF DROUGHTS AT KEY STN.		KSD	CNR	MTY	VYT	CLT	MRT	ATR	TCR	CGR	CHN	KKD	STL	KTM	ALP	TVL	KNI	KYM	QLN	TVM
KSD	12		66.6	66.6	83.3	41.6	50	66.6	41.6	66.6	41.6	41.6	33.3	25	33.5	50	66.6	50	50	41.6
CNR	4	75		25	25	75	75	50	50	25	0	25	75	100	75	50	25	25	50	50
MTY	5	80	100		80	40	80	60	60	80	60	20	20	40	20	40	40	60	80	60
VYT	9	44.4	33.3	33.3		44.4	55.5	33.3	77.7	55.5	55.5	44.4	33.3	44.4	22.2	55.5	33.3	44.4	66.6	55.5
CLT	4	50	50	50	25		50	25	50	50	50	25	50	75	0	50	0	25	25	25
MRT	8	62.5	37.5	50	62.5	62.5		37.5	62.5	62.5	75	50	50	62.5	50	87.5	50	62.5	50	62.5
ATR	4	75	50	25	50	75	25		75	0	25	25	25	75	50	50	25	75	50	75
TCR	10	80	60	60	60	60	50	50		50	50	40	40	40	30	60	30	60	50	60
CGR	5	80	80	60	40	40	60	20	60		40	40	40	40	40	80	80	60	60	40
CHN	10	40	20	20	60	30	30	20	40	70		40	50	50	30	30	30	30	50	40
KKD	7	57.1	57.1	28.6	42.9	57.1	42.9	57.1	28.6	28.6	28.6		14.3	42.9	42.9	28.6	42.9	42.9	42.9	57.1
STL	5	60	20	20	80	40	40	60	40	60	40	80		40	60	40	60	20	40	40
KTM	7	57.1	42.9	28.6	28.6	42.9	28.6	14.3	14.3	57.1	57.1	28.6	42.9		28.6	28.6	42.9	42.9	100	28.6
ALP	7	42.9	57.1	28.6	42.9	85.7	42.9	57.1	57.1	57.1	14.3	42.9	14.3	14.3		28.6	57.1	57.1	28.6	14.3
TVL	5	60	60	60	40	40	60	40	40	80	40	40	20	20	40		80	60	40	40
KNI	5	80	40	60	60	60	40	60	40	40	40	60	40	40	40	20		20	40	40
KYM	6	50	50	33.3	66.6	50	50	50	50	50	50	33.3	0	50	16.7	33.3	50		50	50
QLN	5	60	80	40	40	60	80	40	60	40	40	40	80	80	80	80	80	60		60
TVM	11	63.6	54.5	54.5	36.4	45.5	63.6	72.7	54.5	45.5	36.4	45.5	27.3	63.6	45.5	45.5	45.5	45.5	45.5	

Table 4.3b Spatial Coherence of Large Droughts (%)

Auxiliary stations

	NO OF DROUGHTS AT KEY STN.	KSD	CNR	MTY	VYT	CLT	MRT	ATR	TCR	CGR	CHN	KKD	STL	KTM	ALP	TVL	KNI	KYM	QLN	TVM
KSD	6		100	66.6	33.3	50	83.3	66.6	83.3	50	83.3	50	66.6	100	50	66.6	50	66.6	50	66.6
CNR	9	88.9		66.6	44.4	22.2	77.8	77.8	55.6	55.6	55.6	55.6	44.4	66.6	44.4	66.6	77.8	77.8	66.6	77.7
MTY	8	62.5	75		25	100	75	62.5	50	50	37.5	62.5	62.5	62.5	50	50	50	37.5	37.5	50
VYT	7	100	21.4	100		28.6	42.9	57.1	42.9	71.4	57.1	71.4	57.1	28.6	42.9	42.9	71.4	42.9	28.6	28.6
CLT	9	77.8	88.8	66.6	77.7		55.5	66.6	66.6	66.6	44.4	55.5	44.4	44.4	44.4	55.5	55.5	66.6	55.5	55.5
MRT	7	57.1	42.9	71.4	42.9	42.9		85.7	85.7	57.1	57.1	57.1	42.9	42.9	28.6	42.9	42.9	42.9	85.7	85.7
ATR	10	80	60	60	50	50	70		90	80	40	40	50	20	40	40	50	60	50	40
TCR	6	83.3	66.6	66.6	50	50	66.6	100		83.3	50	66.6	66.6	50	66.6	66.6	50	50	66.6	83.3
CGR	4	50	50	75	50	75	25	25	50		75	75	75	50	75	25	75	50	50	75
CHN	7	71.4	57.1	28.6	42.9	71.4	57.1	28.6	57.1	71.4		42.9	57.1	71.4	28.6	71.4	57.1	71.4	85.7	57.1
KKD	5	80	40	60	40	60	80	60	60	20	80		80	80	40	60	60	60	60	80
STL	4	75	75	75	0	75	100	75	75	75	50	25		75	25	50	25	50	100	50
KTM	6	100	66.6	66.6	66.6	33.3	83.3	83.3	83.3	50	100	83.3	66.6		66.6	66.6	66.6	66.6	83.3	100
ALP	5	40	40	40	40	40	60	20	40	40	40	40	40	100		60	60	40	100	60
TVL	5	100	80	80	40	40	60	60	80	60	80	40	40	100	60		60	80	100	60
KNI	8	50	50	37.5	37.5	50	50	25	25	62.5	37.5	75	50	62.5	75	50		25	50	50
KYM	6	83.3	83.3	83.3	66.6	33.3	66.6	66.6	83.3	83.3	66.6	50	33.5	83.3	83.3	66.6	66.6		83.3	83.3
QLN	9	66.6	33.3	44.4	33.3	44.4	44.4	44.4	66.6	55.5	77.7	33.3	55.5	66.6	22.2	66.6	44.4	66.6		66.6
TVM	4	75	75	75	25	75	75	75	50	50	75	75	100	100	25	50	50	50	25	

Table 4.3c Spatial coherence of Severe Droughts (%)

Cochin and Quilon are key stations, only one station exhibits high spatial coherence. In general, the spatial coherence of severe droughts is higher than the coherence of severe droughts is higher than the coherence of large and moderate droughts.

<u>(d)Probabilities of spatial coherence of disastrous droughts</u>

Disastrous droughts, though the least frequent, exhibit the highest spatial coherence among all the categories of droughts (Table 4.3d) In other words, when any station experienced a disastrous drought, the probability of occurrence of a drought at any station was very high. From the study it is seen that when Kayamkulam was the key station, 12 stations showed 100% spatial coherence of disastrous droughts. While Thiruvalla exhibited 100% coherence with 5 stations and moderate coherence with 7 others. However when Sherthala was the key station, 15 auxiliary stations exhibited 100% coherence and 3 other stations moderate coherence. Vythiri did not experience any disastrous drought during the study period. Kasargode, Mannarghat, Trichur and Kayamkulam have high probability of drought occurrence when other stations have disastrous droughts.

Comparing the spatial coherence of all categories of droughts, it is seen that moderate droughts have the least coherence, though they are the most frequent. On an average, when any station experiences moderate droughts there is a moderate possibility of drought occurrence at 6 stations, however there are exceptional cases: Kasargode has 13 stations and Mannarghat only 1 station experiencing drought simultaneously In the case of large droughts, coherence is higher with 7

Auxiliary Stations

	NO OF DROUGHT IN KEY STN.	KSD	CNR	MTY	VYT	CLT	MRT	ATR	TCR	CGR	CHN	KKD	STL	KTM	ALP	TVL	KNI	KYM	QLN	TVM
KSD	2		100	50	50	50	50	100	50	0	0	50	50	100	50	100	50	100	0	100
CNR	2	100		100	0	100	100	50	50	100	100	0	0	100	0	50	0	50	100	50
MTY	2	100	100		100	50	100	50	100	100	100	50	50	100	50	100	50	100	100	50
VYT																				
CLT	1	100	100	100	0		100	100	100	0	100	100	100	100	100	100	100	100	100	100
MRT	2	50	50	50	50	0		100	100	100	50	50	100	50	50	50	50	50	50	50
ATR	1	100	100	0	100	100	100		100	0	0	100	100	100	100	100	0	100	0	100
TCR	1	100	100	100	0	0	100	100		100	100	100	100	100	100	0	100	100	100	100
CGR	3	100	66.6	33.3	66.6	66.6	66.6	66.6	100		100	66.6	100	66.6	33.3	100	66.6	100	100	66.6
CHN	2	100	100	100	50	0	100	100	100	100		100	100	100	100	50	100	100	100	100
KKD	2	100	50	100	100	0	100	100	100	100	50		100	100	100	50	100	100	100	100
STL	2	100	100	100	50	50	100	100	100	50	100	100		100	100	100	100	100	100	100
KTM	2	50	100	100	50	50	100	100	100	100	100	50	100		50	100	50	100	100	50
ALP	2	100	100	100	50	50	100	100	100	50	100	100	100	100		100	100	100	100	100
TVL	3	100	33.3	33.3	66.6	66.6	66.6	33.3	100	66.6	100	66.6	100	66.6	0		33.3	100	66.6	0
KNI	1	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100		100	100	100
KYM	1	100	100	100	0	100	100	100	100	100	0	100	0	0	100	100	100		0	0
QLN	1	100	100	100	100	0	100	100	100	100	100	100	100	100	100	100	100	100		100
TVM	2	100	100	100	100	0	50	50	50	100	100	100	100	50	100	100	100	50	50	

Table 4.3 d Spatial Coherence of Disastrous Droughts (%)

stations having moderate possibility of simultaneous drought incidence and atleast 1 station, high probability (>75%) When severe droughts affect any station, there is moderate coherence at 8 other stations and atleast 1 station shows high probability of drought incidence. Disastrous droughts have the highest spatial coherence: 3 stations, on the average, show moderate probabilities and as many as eleven stations, high probabilities.

Moderate droughts have the least spatial coherence since such droughts are a result of minor fluctuations or departures of the actual moisture regime from the average or climatic level of water balance. Large and severe droughts that exhibit increasing spatial coherence in that order, results due to water deficiency arising out of anomalies in the circulatory patterns of the atmosphere affecting the areas. Disastrous droughts, least frequent but with the highest spatial coherence, occur due to wide fluctuations of the water balances onto the drier side, arising out of very large water deficiencies and these must be the result of large-scale anomalies in the general circulation over the region as a whole: considering the widespread drought conditions of 1982-83 almost all the stations exhibited 100% spatial coherence

4.2.5 Climatic shifts

As a result of wide fluctuations of water budget parameters - both water deficiency and water surplus it is quite likely that the normal climatic regime are occasionally shifted into more humid or less humid categories. In order to study this aspect, climatic shifts have been studied by plotting the interannual variations of moisture index (I_m) for all the stations.

Of the 24 stations included in this study, results of only six representative stations representing per-humid, humid and moist-sub humid categories of climate are presented here (Table 4.4 & Fig 4.7 (a) to (f)) Kasargode had a total number of 21 shifts into the other climatic types. Of these, 20 were to the humid climates of different categories and one to the moist sub humid type.

Among the humid stations, Kottayam had 49 shifts, while, Calicut, Cochin and Alleppey had 47, 43 and 41 respectively. All these four stations had larger number of climatic shifts into the drier categories of the humid climate. In addition, Kottayam had two shifts into the moist sub humid climate while Alleppey had one.

Trivandrum, the only moist sub humid station studied here, had a total of 42 shifts of which 24 were to the dry subhumid and 1 to the semi arid category.

An overall study of the climatic shifts in the region in comparison to the occurrences of droughts reveals interesting results. As is to be expected during many of the years when the climate shifted to a drier category due to deficient rainfall, the stations experienced droughts of one or the other categories. However, there were many occasions when several stations did not experience droughts eventhough shifts in the climate to drier categories were observed. Similarly,there have also been years when droughts have occurred even when rainfall had been above normal and the climatic shifts were in the wetter directions.

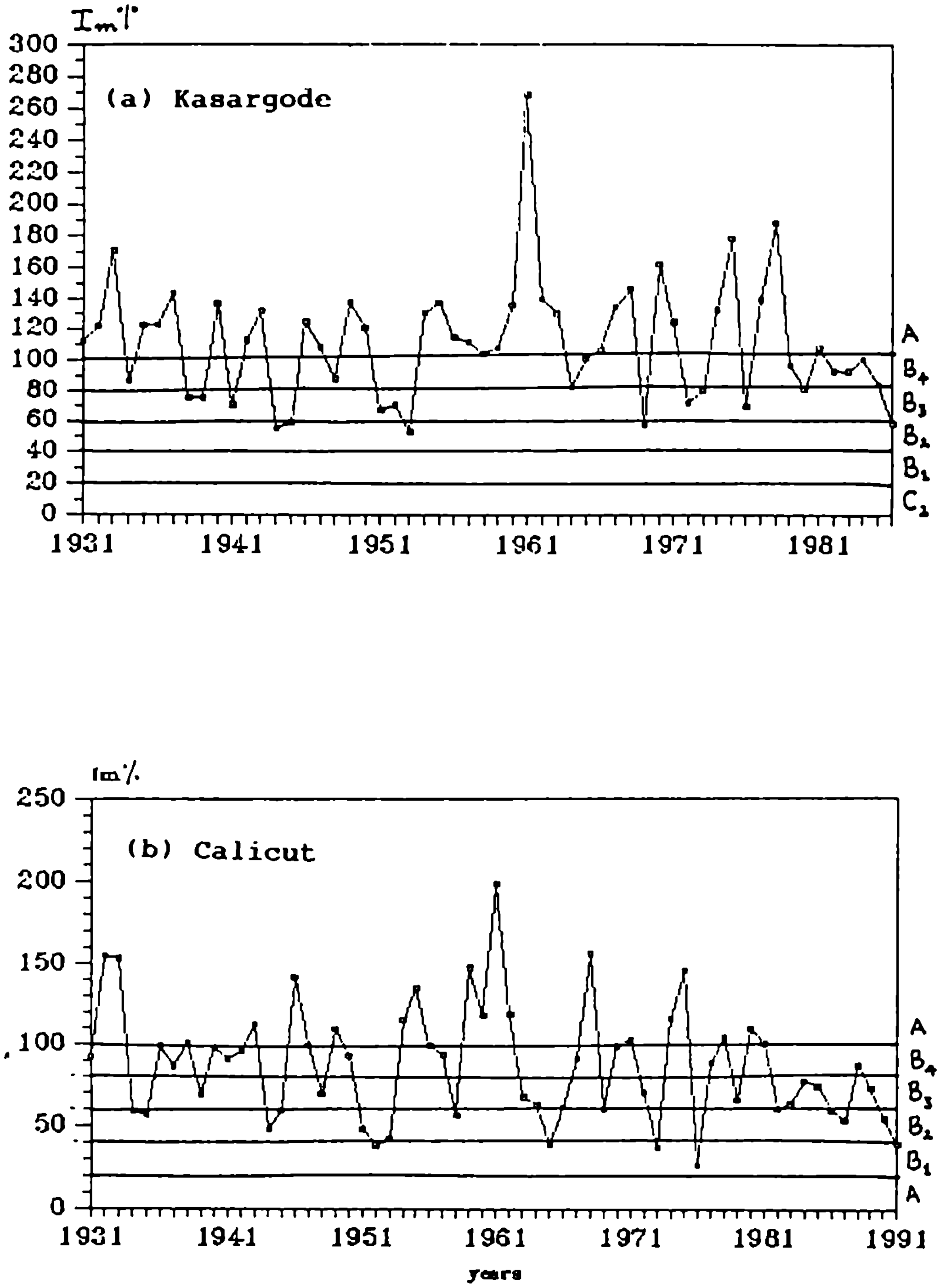
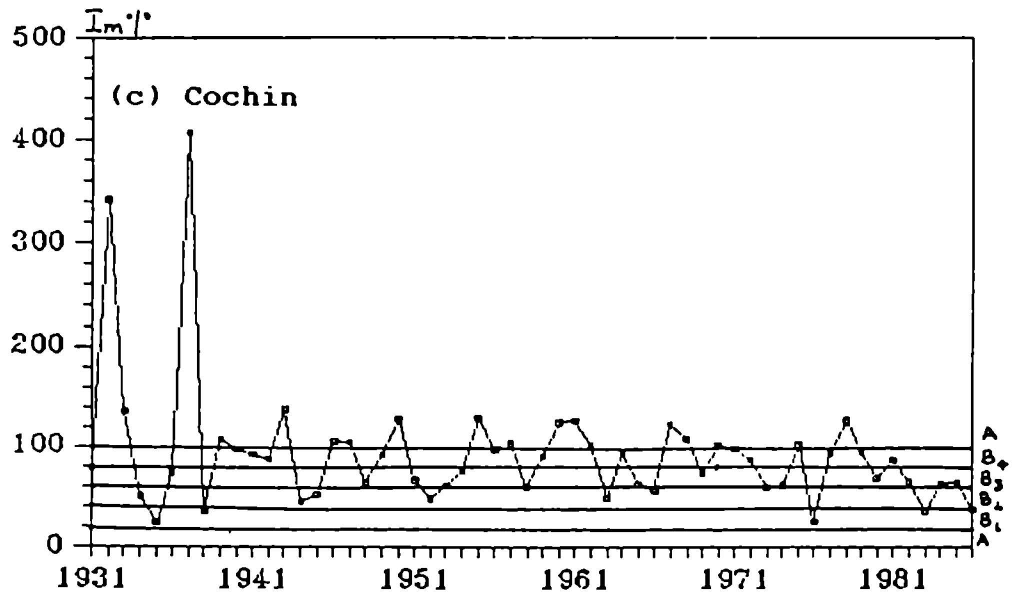


Fig 4.7 Yearly march of Moisture Index and climatic shifts



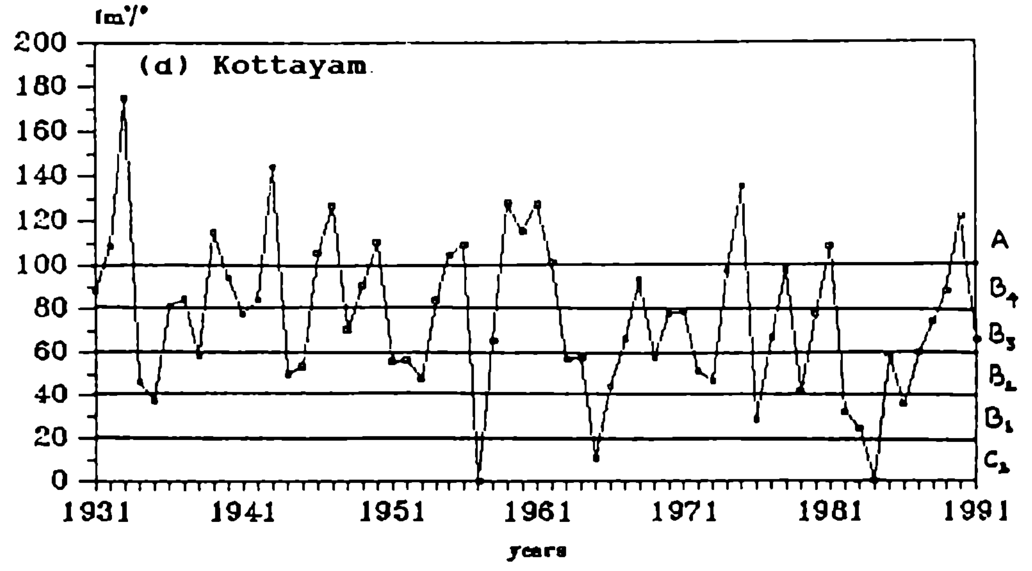
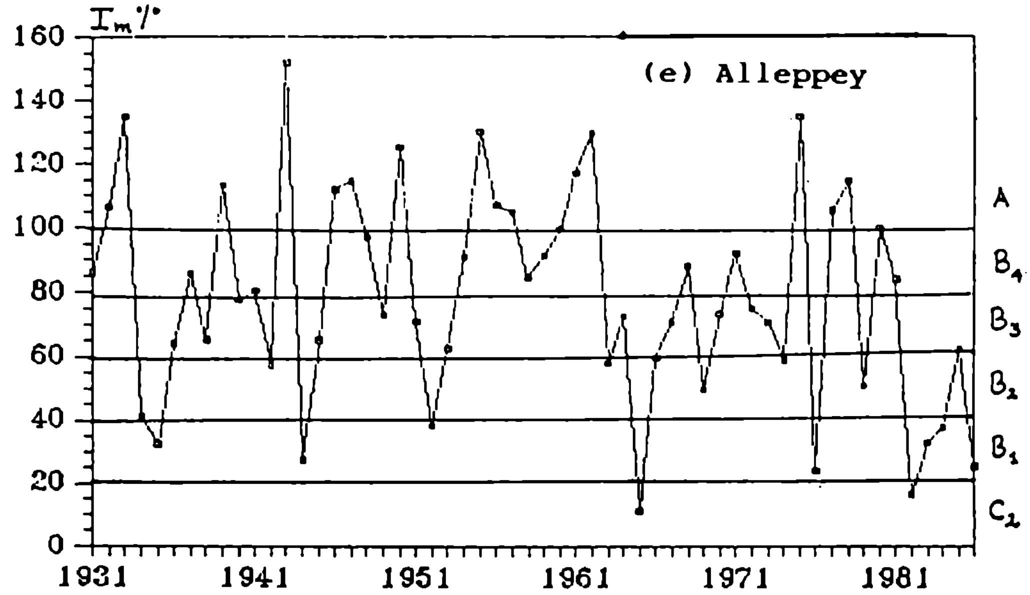


Fig 4.7 Yearly march of Moisture Index and climatic shifts (contd.)



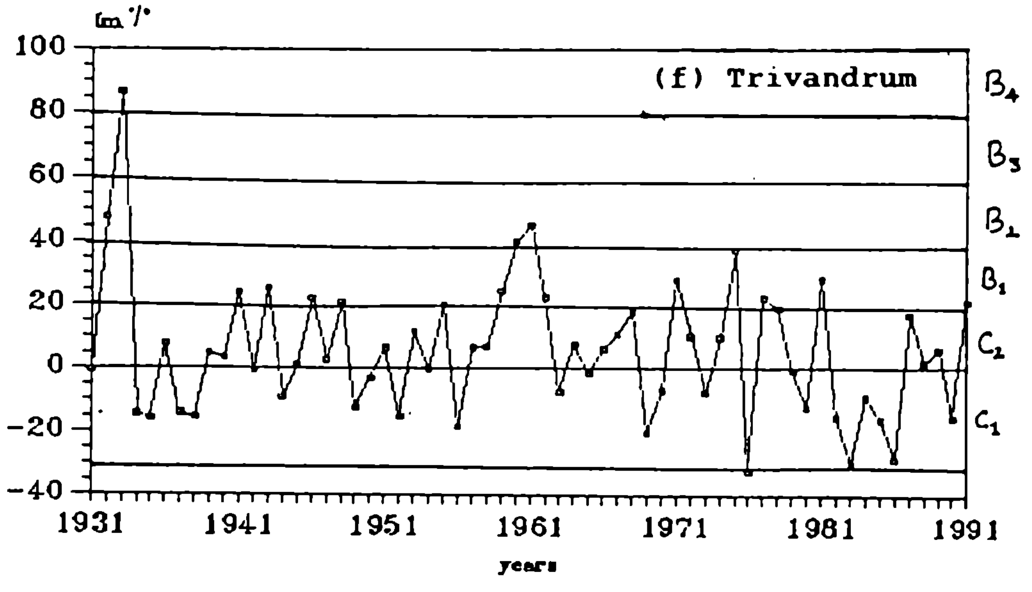


Fig 4.7 Yearly march of Moisture Index and climatic shifts (contd.)

CLIMATIC TYPE

Stations	A	B4	B3	B2	B1	C2	C1	D	Total
A Kasargode		8	7	5		1			21
B Calicut	21	1	11	11	3				47
Cochin	20		12	7	5				44
Kottayam	16	1	10	15	5	2			49
Alleppey	17		6	12	5	1			41
C Trivandrum		1		3	12	1	24	1	42

Table 4.4 Number of occasions of climatic shifts

These observations point to the inadequacy of rainfall data alone in delineating droughts. It is not monthly or the annual deficiency in rainfall that has to be considered in categorizing droughts, but rather its distribution in comparison to the water need of the place. As was seen in the study of the water budget elements, is the irregular distribution of rainfall that causes water deficiencies (and therefore droughts) and water surpluses. The water balance technique of comparing perception with the water need on a monthly, weekly or daily basis is thus well suited to the study of droughts and climatic shifts.

4.2.6 Moisture regime during climatic shifts

The study of the water balances of different locations in years of extreme climatic shifts is of immense practical utility in agroclimatology and hydrometeorology. A critical examination of the comparative values of elements of water balance would reveal the variability of water surplus and water deficit in years of such shifts. As all the stations studied in the State belong to the humid climates, analysis of water deficits is more important than water surpluses. Table 4.5 summarises the main elements of water balance at all the important stations in Kerala through a comparison of the important water budget parameters in the normal year with those of wettest year, driest year and disastrous drought years.

For example, during a normal year at Kasargode, a perhumid station, rainfall is 361cm., water deficit is 57cm. and surplus is 240cm. During the wet year 1961 the rainfall was above 170% of the normal and the water surplus was double the climatic

Kasargode

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year		360.9	56.6	246.9	109.8	A
Wettest year (1961)	167.6	613.1	50.36	500.0	468.3	A
Driest year (1938)	169.3	358.1	239.3	238.8	75.6	B_3
Disastrous drought years i (1968)	169.38	413.8	77.52	324.34	145.7	A
ii (1986)	174.03	273.91	76.52	177.58	58.1	B_2

Calicut

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	172.0	324.4	46.9	200.2	90.1	B_4
Wettest year (1961)	167.9	495.2	47.5	381.4	198.8	A
Driest year (1976)	171.4	216.3	46.1	91.9	26.7	B_1
Disastrous drought years i (1976)	171.41	216.27	46.14	91.85	26.7	B_1
ii (1982)	175.53	279.38	53.16	158.91	60.2	B_3

Table 4.5 Variability in water budget elements during climatic shifts.

value. However, water deficit decreased only marginally while the moisture index shot up to 468% On the other hand, during the driest year 1938, rainfall and water surplus were almost equal to the normal values but water deficit was about 420% of the climatic value and the climate shifted to B_3 humid category. In 1968 when a disastrous drought occurred at the station, rainfall was 15% above normal and water surplus increased by 31% However, water deficit was also higher by about 35% Paradoxically, the station exhibited a higher moisture index (145.7%) In an other disastrous drought year (1986) the climate shifted to B_2 category as a consequence of rainfall being only 76% of the normal. Water surplus was about 72% of the normal value while deficit was one third more than climatic.

Similarly, detailed analysis of the water budget elements in years of climatic shifts at other stations too has been made. As is to be expected during dry years, water deficits increased and water surpluses fell below normal, while in the case of wet years surpluses increased and deficits fell below normal. However, such simple relations are not always true. In the example detailed, about Kasargode experienced higher rainfall and water surplus but also had larger water deficits resulting in a disastrous drought in 1968. It is thus possible that increased water surpluses can coexist with increased water deficits even in disastrous drought years.

It is also observed that values of water deficits and water surpluses in years of extreme climatic shifts are not proportional to the changes in rainfall amounts. That is, increases or decreases in rainfall do not result in proportionate changes in water surpluses or water deficits. For example, at Calicut in the wettest year 1961, rainfall was 53% above normal and water surplus was 90% above normal. However, water deficit remained constant while the climate jumped to the perhumid category. Such a behaviour of the moisture regime is because water surpluses and water deficits are not determined by the magnitudes of rainfall but rather by its distribution through the year.

CHAPTER V

CROP - WEATHER RELATIONSHIPS - CASE STUDIES OF COCONUT AND RICE

5.1 Introduction

Every crop variety has its own optimum requirements of weather, climatic and other factors of the environment to which it selectively responds. These requirements and responses which effectively control the growth and development of any given crop in a given environment vary not only between crops or families but also from species in the same family and even from variety to variety in the same species. At times, in the same variety the responses may vary from one growth stage to another. Again, optimal requirements for total dry matter production may be quite different from that required for the maximal yield of the economically important parts of the crop. For example, in the case of grain crops, good vegetative development is generally conducive for good yield. However, this relationship is not valid above a limit and the yields are more influenced by the ear-head capacity and the ambient weather conditions. The influence of weather phenomena on crop growth and yield depends on the crop growth stage. For example, a moderate wind or a light rain, when the crop is near harvest, may do more damage than even heavy rains and high winds in the vegetative phase. Further, the weather requirements for maximum yield per plant are not the same as for maximum yield per unit area. Thus, the plants contributing to bumper crop yields, function, more often than not, much below their individual potentiality.

In the light of the above, the types of weather responses a crop ecologist can expect to encounter are really innumerable.

However, as pointed out by Went (1957), the problem of weather relations of crops is not so intractable as may seem at first.

Firstly, the crops are often influenced significantly by one or two factors that are more crucial for their growth and development. For example, during kharif, when the temperatures are equable, it is the distribution of the rainfall quantum that assumes paramount importance. Similarly, in the case of irrigated rabi crops,the temperature regime in the reproductive phase becomes crucial.

Secondly, crops belonging to the same family or related families may show a typical response towards a particular climatic element.

Thirdly, while differences in climatic responses between the species may be quite different and sometimes spectacular, the range of various climatic parameters to which a species shows a significant response is quite often not very wide. The intra-varietal weather responses in a species are much more limited.

Fourthly, as pointed out by Went(1957), the greater latitudinal coverage of plant species compared to their altitudinal distribution show that natural selection, while having a profound influence on the photoperiodic reponse, has very little influence on the temperature response of plants.

The above considerations should enable an investigator to arrive at the approximate climatic requirements of any crop species under examination. The technique to be explored for arriving at the climatic requirements of crop plants has been indicated by Went (1957) and De Villiers (1966) and has been referred to by Venkataraman (1968) and Venkataraman and Krishnan (1992)

As is well known, both thermal and hygric factors are equally important for the growth and development of any crop. The derived parameters of actual evapotranspiration (A.E.) from the water budget procedure used in the present study integrates these two factors through a comparison of water supply (precipitation) and water need (Potential Evapotranspiration (P.E.), computed using temperature and duration of sunlight) Correlation studies were carried out using annual values of the ratio A.E/P.E (I_{ma} used in drought studies earlier) and the yields of various crops at different districts of the State. In many cases, correlations were found to be positive and significant, that is adequate moisture for the growth and development of plants resulted in higher yields. On the other hand, there were also a large number of cases where the positive correlations were not significant and even cases where there were negative correlations. No definite conclusions could be drawm from these studies and hence are not being presented. Perhaps, the relationship between these parameters controls only a small fraction of the crops yields. It was felt that to gain a deeper insight into the relationship between yield and specific weather parameters, case studies of some crops should be undertaken. Therefore, in the present study two case studies - one each for coconut and paddy have been attempted and crop-weather models developed to forecast crop yields at different stages of crop-growth. The choice of coconut and paddy was made because these two are the most important of perennial and annual crops in the State respectively Moreover, availability of experimental data for coconut from Pilicode and for paddy from Pattambi also influenced the final choice.

5.2 Case study - Coconut:

5.2.1 Introduction

The coconut palm is one of the most useful plants in the world. Grown in more than 80 countries of the tropics, it is the most important of all cultivated palms.

The coconut palm has been known to exist in most regions of the tropics from pre-historic times. Although the original home of the coconut palm is not clearly known,it has been possible to trace the history of coconut culture in most of the countries. The major coconut growing countries of the world are found in Asia, Oceania, West Indies, Central and South America, East and West Africa.

Although India is the third largest coconut producing country in the world, the per capita availability of coconut is as low as 10 nuts per year, whereas it is as high as 282 nuts in Philippines, 53 nuts in Indonesia and 156 nuts in Sri Lanka. An important reason for this situation is that coconut is not grown in all the states of the country but is confined to the coastal states which ultimately have to meet the entire domestic demand. As much as 65 percent of the total coconut area is concentrated in Kerala, a small state accounting only for 1.18 percent of the total land area of the country

Coconut is the first ranking crop in the State. The area under the crop, the production and productivity of the crop in the State from (1975-1976) to (1991-1992) is given below (Status report)

	1975-'76	1980-'81	1985-'86	1992-'93
Area (ha.)	693	651	687	877
Production (million nuts)	3439	3296	3453	5124
Productivity (nuts/ha.)	4963	4617	5023	5843

The production in 1975-76 was 3,439 million nuts while in 1992-'93 it was 5,124 million nuts. Coconut is mostly grown in home steads and small farms in Kerala. There are about 25 million holdings, with an estimated total of 170million coconut palms, the palm density being 299/ha. Calicut is the leading district having about 56% of its total area under coconut crop, followed by Trivandrum (40%) and Alleppey (36%) The area under coconut is the lowest in Wynad (2.91%) The yield rate is maximum in the districts of Trichur (6264 nuts/ha), and minimum (1338 nuts/ha) in Wynad.

5.2.2 Characteristics of the coconut palm

The coconut palm is tall and stately in appearance and attains a height of about 15 to 30m when fully mature. It has a tall, stout somewhat flexible trunk, rising from a swollen base surrounded by a mass of roots. Its characteristics phenological phases and climatic requirements have been described in detail by Thampan (1981)

The genus 'Cocos' formerly included about 30 species, almost all American. These species have been subsequently assigned to several new genera and the genus Cocos is now considered as monotypic containing only one species, C.Nucifera L.

The adult palm usually carries 30 to 40 paripinnate leaves in its crown. The leaf consists of a central stalk, p to 6m long, with a row of over 200 narrow and tapering leaflets 1 to 1.5m in length. The life span of a leaf, from its emergence to shedding, is about 2.5 to 3 years and a new leaf appears in the crown every three or four weeks in a healthy palm.

In the adult palm, though the leaves are produced in succession, the interval between the opening of two successive leaves is influenced by the genetic make-up of the palm, soil fertility and seasonal conditions.

In a growing seedling, the trunk begins to form after the emergence of 12 to 18 leaves. In the first few years, it rapidly increases in thickness and thereafter, the girth is maintained at a steady level. The uniformity in the thickness of the trunk is very often influenced by the environmental factors, especially the availability of nutrients and moisture. Under normal situations the diameter of the stem is often 30 to 40cm, some times reaching 1m at the base.

The coconut palm has no tap root, but has a thick growth of a string- like root system emanating from the blunt bottom of the stem. The number of roots produced by a fully grown tree ranges from 1500 to 8000 depending on the soil conditions. The direction of the main roots is more or less horizontal. The normal length of the roots of a mature tree is about 5m in firm soil and 7m in sand.

In a coconut palm which has reached the normal bearing stage, every leaf axil produces a spadix or inflorescence. The annual production of spadices, therefore coincides with the number of leaves produced by the palm which under normal conditions ranges from 12 to 15. Under unfavourable circumstances, especially when the initial formation of the spadix coincides with the dry weather period, a few of the spadices fail to develop.

The inflorescence develops within a strong, tough, pointed double sheath called spathe. When the spathe is fully grown, it splits along its underside from top to bottom and releases the inflorescence. This usually occurs from 75 to 90 days after the first appearance of its top in the leaf axil. The primordium of the inflorescence begins to form in the leaf axil about 32m before the opening of the spathe and the formation of a leaf starts about 36 months before the appearance of spadix in its axil. The coconut palm is monoecious, producing both male and female flowers on the same inflorescence. The number of female flowers produced by an inflorescence is a highly variable factor and is influenced by the season, soil-conditions, the variety and the inherent yield potential of the palm. In India, the female flower production rate is generally high during the period March to May the highest being in May and the lowest from September to January In general, the number of female flowers per inflorescence varies within a wide range of 10 to 50, though figures outside the range are also not very uncommon.

In the coconut palm, especially in the tall variety, there is a gap between the male and female phases. The opening of the spathe coincides with the effective emission of pollen by the male flowers. The male flowers after opening shed pollen for about 24 hours and then drop off. Pollen discharge or anthesis will continue for about 18 to 20 days (male phase) because of the fact that maturation of inflorescence is a progressive process. The pollen remains viable for two to nine days after it is discharged.

Normally, the female flowers commence to open by the twenty-first day, but during the summer months the flowers may open even from the 18th day onwards. The female phase, ie., the period from the opening of the first female flower to the opening of the last female flower is from four to seven days. The period during which the female flower remains receptive varies in different places with a normal range of one to three days.

Overlapping of phases of two successive inflorescences is a characteristic conditioned by the interaction between genotype and environment. There is so far no consensus on the major agency responsible for pollination. Both wind and insects are considered to have equally important roles as carriers in the pollination.

After pollination, the unfertilized flowers turn brown and fall from the inflorescence. A number of fertilized flowers also fail to develop properly and they too are shed. Generally, not more than 25 to 40 percent of the female flowers reach maturity.

After fertilization it takes about 11 to 12 months for the flower to develop to maturity as large ovoid fruit which is popularly known as 'nut' The fleshy perianth leaves of the flower adhere at the base of the nut throughout this period.

It is possible to estimate the yield of a palm by counting the developing nuts in the crown. Leaving the buttons uncounted, all the nuts present should be available for harvest during the following 11 to 12 months. Very often immature nuts, three or four months old, drop off the bunches due to various reasons. Immature nut fall is heavy during prolonged spells of dry weather and also immediately after the first rain preceded by a dry period.

(a) Climatic requirements

The coconut palm is a tropical crop and grows best when favoured with a hot moist climate. Though not very fastidious or exacting in its climatic requirements, the palm does exhibit growth preferences.

The palm prefers an equable climate and does not tolerate extremes of temperature. Between the tropics of Cancer and Capricorn, the only places where the palm is not found are those which are either too cold or too dry. For vigorous growth and good yield, a mean annual temperature of 27^{o}C is stated to be the best. The palm fails to flourish in areas where the mean temperature falls below 21^{o}C and also where the temperature fluctuations are considerable. Occasional short spells of low temperatures and slightly higher temperature than the optimum is likely to be tolerated by the palm, if it is not associated with very low humidity, hot dry winds and inadequate soil moisture supply.

Heavy and well spread rainfall ranging from 100 to 300Cm is required by the palm. The distribution of rainfall, drainage status and moisture-holding capacity of the soil are more important than the quantum of total rainfall. In a study at the Central Plantation Crops Research Institute, Kasargode, India it was observed that the yield of coconuts in any year is profoundly influenced by the seasonal rains from January to April received two years prior to the harvest. In the coconut palm, the primordium of the spikelets of the inflorescence is formed about 15months before the opening of the spathe, and of the female flowers before 12 months. Even after the spathe is opened, the female flowers require about 11 to 12 months to reach full maturity. Therefore, severe drought during the early formative period of the inflorescence may kill the growing points due to desiccation resulting in the abortion of spadix. Rainfall has been found to influence not only the number of nuts produced by the palm but also the size and quality of nuts.

In an experiment in Trinidad (Smith,1966), it was found that the yield in a particular year was correlated with the integrated soil water deficit over the 29 months preceding the beginning of the season. It was found that for most coconut growing areas, coconut crops do not respond to any rain over 35.56cm in a month. Rainfall in excess of this limit does not become available to the palms because the surplus moisture is lost either by surface run-off or seepage. A study on the influence of rainfall on coconut crop revealed that during the period September- December any rain in excess of 35.56cm in a month was significantly harmful to the crop During this period of the year, the temperature is low and humidity is high and these climatic factors interfere with the normal transpiration process of the leaves, resulting in the accumulation of excessive moisture in the soil and a reduction in the effective period of sunshine. But excessive rainfall during the period January- April was not found harmful, probably due to the accelerated transpiration facilitated by high temperature and low humidity (Abeywardena, 1968) The experience in India is that there is a certain maximum rainfall beyond which any further precipitation will be of no practical use. But the critical range of rainfall or the effective rainfall is subject to variation from region to region and is mainly controlled by the soil types and microclimate.

Although a hot humid climate is good for the growth of the palm, very high humidity throughout the year interferes with the moisture and nutrient uptake of the palm and also encourages incidence of various pests and diseases. A dry and windy atmosphere is always beneficial provided the soil moisture availability is adequate. Under unfavourable soil moisture stress, only a light wind is desirable.

The coconut is more or less a coastal crop. The palms on the sea coast benefit from a humid climate which is less subject to wide fluctuations of temperature. They are also benefited by better supplies of sub-soil moisture due to the continuous seepage of fresh water to the sea from higher inland areas. Further, the constant movement of the sub-soil moisture near the coasts caused by the ebb and flow of the tide is also beneficial to the palms.

In the principal coconut growing countries, plantations are found established on a wide variety of soils ranging from littoral sands to the heaviest clays. In India, coconuts are found grown on almost all soil types. In general, the major soil types used for coconut in India are laterite, alluvial, red sandy loams, coastal sandy and reclaimed soils with a pH ranging from 5.2 to 8.0. Though coconut is grown on a wide range of soil types, water supply is the single important factor that determines the suitability of a particular soil type. In areas of heavy rainfall, well-drained soil types are the most ideal. On the other hand, in areas of poor rainfall or where long spells of dry periods are likely, it is always desirable to have deep and fine soil types possessing good water- holding capacity

(b) Varieties of Coconut

There are only two distinct varieties of coconut, the tall and dwarf. Owing to cross pollination, especially in the talls, a wide range of variations occur within the same variety.

The tall variety is extensively cultivated in all the coconut tracts of the world. This variety is characteristically tall, growing to a height of about 15 to 18m. The crown has 25-40 fronds and the length of a fully opened frond is about 6m. It is a comparatively hardy type, late bearing, and lives upto a ripe age of 80 to 90 years. West coast tall, Lakshadweep Ordinary, Andaman Ordinary, Kappadam, Laguna San Ramon, Macapuno, Spicata are the types which come under tall variety.

Dwarf coconuts are known to occur in most of the coconut growing countries. This variety is characterised by its short stature and earliness in bearing. Under normal conditions, the palm starts flowering in about three to four years when the tree is just above the ground, and a fully grown tree rarely exceeds 5m in height. Some of the important dwarf types grown in India and elsewhere are Chowghat 'Dwarf Green' Chowghat 'Dwarf Orange', Malayan Dwarf, Gangabondam, Coconino, Mangipod etc.

The manifestation of heterosis or hybrid vigor in a perennial crop like the coconut palm was first reported from India in 1932. The inter- varietal hybrids produced in these countries for commercial plantings are the Tall x Dwarf, Dwarf x Tall and Tall x Tall.

(c) Pests and Diseases

The coconut palm is susceptible to the attack of a large number of pests of major and minor importance. All these are capable of causing considerable damage to the palm resulting in reduced yields.

The Rhinoceros beetle is the most serious pest of the coconut palm and is found in all the coconut growing countries. The cock chaffer popularly known as 'white grub' which cause damage to the coconut palms by feeding on the root system, live inside the soil and usually occur in the sandy or sandy loam soil tracts of Kerala state in India. The grubs are active with the onset of monsoon, especially in the months of May and September Other pests which cause damage to the coconut palm are the red palm weevil, asiatic palm weevil, slug caterpillar, the flying fox, the robber crab etc.

Among the many diseases of the coconut palm, only those caused by fungi and hematodes have been fully understood. Some of the pathogenic diseases are Bud rot, Grey leaf spot or blight, the leaf rot, red ring disease etc. Stem bleeding, root wilt, tatipaka, Cadang-Cadang, Lethal yellowing etc. are some of the diseases of uncertain etiology.

5.2.3 Crop-weather relationships

The climatic requirements of coconut have been discussed by Copeland (1931), Menon and Pandalai (1958), Ochse et al. (1961), Papadakis (1970) and Domros (1974) Weather influence on the development and yield of coconut has been discussed by Krishnamarar and Pandalai (1957), Menon and Pandalai (1958)

It is seen from these that the coconut palm is more tropical than the other crops. Outside 20^{o} latitude on either side of the equator, fruit bearing is unsatisfactory (Menon and Pandalai, 1958) The main centres of coconut production are confined to the coastal area, in the latitudinal belts 15^{o}S to 15^{o}N (Ochse et al., 1961) Coconut requires a mean annual temperature of 27^{o}C, in which the coldest month has a mean temperature of 20^{o}C, hottest months has a mean temperature less than 35^{o}C, the lowest mean minimum temperature is greater than 10^{o}C and the diurnal variation is less than 6^{o} to 7^{o}C (Menon and Pandalai, 1958; Domros,1974) However, a very low maximum temperature brought about by cloudy conditions restricts production and may call for the use of growth regulators (Papadakis,1970) Coconut is grown at altitudes of less than 750m except near the equator where it is grown up to about 1,350m (Menon and Pandalai, 1958)

Earlier studies indicated that only rainfall influences coconut yields significantly Gadd (1922), reported that shedding of buttons-a phenomenon related to yield was high in the rainy season. Gadd (1923) gives explanation for the physiological droughts encountered by the crop during rainy season. Patel (1938) pointed out that coconut yield in any particular year is influenced by the January to April rains for two years prior to harvest, together with the rains received in January to April of the year of harvest. On the west coast of India, a well distributed annual rainfall of 2,500 mm is considered optimum (Radha et al., 1962) According to Wickramasuriya (1968) rainfall has no effect on the number of spadix. Abeywardena (1968) revealed that during the period September-December, any rain in excess of 35.56cm in a month was significantly harmful to the crop. When mean annual precipitaion is less than 1,000 mm or when monthly rainfall is less than 50 mm at a stretch, the crop would require to be irrigated. Coconut is light loving. A minimum of 4 hours of bright sunshine per day and an average of at least 6 hours per day for the year as a whole is required. A relative humidity regime of 80 to 90% is preferred by the crop. The relative humidity can go down to 60% but for brief periods only (Domros, 1974) Coconut crop can also stand stiff breezes and is felled only by cyclonic storms. Air containing salt spray is considered to be beneficial.

Since coastal areas have high humidity, equable warm temperatures and good subsurface feed of water on account of high water-table, they are the preferred habitat for the plants However, coconut can also be successfully raised in inland areas with irrigation and in non-coastal areas whwre water-table fluctuationms provide the crop with requisite amounts of aeration and soil moisture.

Though Kerala is known as the land of the coconut, the per palm production is much less (33 nuts/palm) when compared to that of the other coconut growing States. Within the State, the per palm production is much less in the northern districts. Higher nut yields are recorded in the southern districts despite the prevalence of root wilt disease.

The weather influences on the growth and yield of coconut at the Central Coconut Research Station, Kasargode, on the West Coast of India, have, been studied by a number of workers. The works of Sayeed and Narayana (1953), Gangooly and Nambiar (1953) and Sayeed (1955) have been summarised by Krishnamarar and Pandalai (1957) The works of Patel and Anandan (1936), Pillai and Satyabalan (1960), Lakshmanachar (1962) and Vijaylakshmi et al. (1962) can be summarised as follows. The main features emerging are as follows: (a) Leaves are produced most rapidly in September October while the rate of leaf production is low in summer, (b) leaf shedding is the least in the rainy season; (c) production of infloresences is highest in summer and the least in winter; (d) abortion of infloresences is rare in summer and more prevalent in rainy season; (e) in summer the male phase is of the shortest duration and more percentage of female flowers are produced; (f) shedding is high in the monsoon period and low in winter; (g) yield of good nuts is high in summer; (h) barren nuts are more in the hot weather and rainy season; (i) summer crop is of superior quality

Patel and Anandan (1936) found that the yield of coconut in any particular year was influenced by the rain fron January to April of the preceding two years as well as that of the year of harvest. Vijayalakshmi et al. (1962) found that in general the weight and volume of nuts were higher in those bunches that reaches the stage of stigmatic receptivity during summer Lakshmanachar (1962) found that rainfall received from the third to seventh month after inflorescence had the greatest impact on production.

The coconut gardens in the northern region of Kerala which grow under the rainfed and good management conditions do suffer due to lack of soil moisture in summer. If the pre-monsoon showers fail, the effect of prolonged dry spell or drought on coconut production is much more severe. Prasada Rao (1982) enunciated in Kerala that a the continuous dry spell for six months with high moisture deficit and high water surplus during July decreased the coconut yields in the subsequent year considerably. The effect of drought incident, intensity, and duration on coconut palm was studied by Prasada Rao (1985), based on the visual symptoms like drooping of leaves, immature nut fall, and button shedding etc., under the drought condition in 1983. Investigation of the impact of drought on nut yield (Prasada Rao, 1986) led to the conclusion that, decline in annual nut yield was seen only in the subsequent year, while decline in monthly nut yield commenced in the eight month after the drought was over, and continued for twelve months with the maximum effect at the thirteenth month. The association of increasing trend in intensity and frequency of agricultural drought in the recent years with the decreasing trend in nut yield in coconut in the district of Kasargode was studied by Prasada Rao (1990) Thirty to fifty percent yield decline in coconut was seen in the subsequent year due to severe soil moisture stress that occurred during summer 1983,1985 and 1989 (Prasada Rao et al., 1993) Park (1934) found that the severe drought experienced in Puttalam (Ceylon) in 1931 affected the yield of nuts for a period of about two years with the maximum effect at about thirteen months after the conclusion of drought.

Being a perennial crop with long phenophases of 44 months, advance information on behaviour of coconut yields is of great importance to Government agencies as well as planners and related agencies. Several workers (Balasubrahmanian,1956; George,1988; Jacob Mathew et al, 1986; Jacob Mathew et al., 1988; Nayar and Unnithan,1988; Vijaya Kumar et al., 1988 a & b; Saraswathi and Mathew, 1988; Pillai et al, 1988; and Abraham Varughese and Mohamed Kunju,1988) have attempted crop weather relationships of coconut for forecasting nut yield. In an outstanding paper Abeyawardena (1983) developed a forecasting model for forecasting nut yield a year ahead based on the drought index (R^2 = 0.98) for the entire Sri Lanka. Attempts were made by Prasada Rao (1990) in developing a model to assess the yield a year ahead employing yield moisture index and index of moisture adequacy during the summer. A multiple regression equation was developed by Prasada Rao (1996) using the index of moisture adequacy from December to May during the same year of harvest, one year prior to harvest, and two years prior to harvest to estimate the annual nut yield.

5.2.4 Crop-weather model

(a) Experimental data used for study

Details of crop and weather data collected from the Regional Agricultural Research Station, Pilicode, (12^{O} 12'N 75^{O} 10'E) is given below.

Parameter	Years of data
Crop	
Coconut monthly production	September 1986-December 1990.
Meteorological (monthly data)	
Maximum temperature (TMAX)	January 1983-December 1990.
Minimum temperature (TMIN)	-do-
Soil temperature (5cm depth) (STI)	-do-
Soil temperature (70cm depth) (STII)	-do-
Morning relative humidity (RHI)	-do-
Evening relative humidity (RHII)	-do-
Evaporation (EVP)	-do-
Rainfall (RF)	-do-
Rainy days (RD)	-do-
Solar radiation hours (SRH)	-do-

The soil type at the research station is laterite. The monthly nut yields have been collected from all the species of the coconut palm available at the station. The meteorological data has been measured at the station observatory as part of the ongoing research programs. All the data for this study has been obtained from the records maintained at the station.

The monthly data of rainfall and temperature were used to compute the monthly water balance using Thornthwaite and Mather (1948,1955) procedure. Potential evapotranspiration was computed using the formula given by Thornthwaite (1948) While Actual Evapotranspiration (A.E.) and Moisture Deficit (MDEF) values were derived from the water budget procedure. As explained earlier (Section Three of Chapter Two) the Index of Moisture Adequacy (I_{ma}) was computed as A.E/P.E * 100.

(b)Methodology employed

The methods of correlation and regression analysis are most widely used for studying crop-weather relationships and weather based yield prediction. PCA is usually employed to nullify the inter-correlation between the variables. Before applying these techniques ,it is necessary to process the available agro-climatic data to a suitable form.

The yields of agricultural field crops are the result of growth and development processes extending over a long period of time. Within the growing season, the type of weather required may be subjected to considerable changes. The whole of the growing season must, therefore, be divided into smaller periods which are closely linked to the yield development processes.

In the present study, the time interval for nut development from primordium of the inflorescence to harvest was divided into four different periods such as primordium of the inflorescence to initiation of spikes (44 to 28 months before harvest), initiation of spikes to female flowers initiation (27 to 24 months before harvest), female flower initiation to opening of spathe (23 to 12 months before harvest) and the opening of the spathe to harvest. Correlations were worked out between each month's coconut production and the weather parameters influencing the yield 44 months prior to the harvest. Variables which showed a significance of 99% and above were selected to form the independent variables for the multiple regression equation. These variables were subjected to PCA and the PC scores were calculated. The PC scores of the selected PC's were the independent variables in the multiple regression models, explained in Section 2 of Chapter 2 developed to predict the monthly coconut production.

(c) Results

(i) Results of correlation analysis

When the weather parameters of the first 3 periods (44 to 28 months before harvest, 27 to24 months before harvest, 23 to 12 months before harvest) were correlated with the corresponding monthly nut yield, the following results were obtained

During the first stage, only three weather parameters significantly influence the development, and in turn affect the final nut yield. These are total amount of rainfall, morning relative humidity and minimum temperature (Table 5.1) Rainfall and minimum temperature are negatively correlated and morning relative humidity, positively correlated with production. During the second stage the weather parameters positively correlated are moisture deficit, maximum temperature and soil temperature while actual evapotranspiration (AE) ratio of actual

Variables	Stage I Coefficients	Stage II Coefficients	Stage III Coefficents	Stage IV Coefficents
AE	-0.0690	-0.4187 *	0.3922 *	-0.2088
AE/PE	-0.0288	-0.4086 *	0.4095 *	-0.2361
MDEF	0.0146	0.4193 *	-0.3653 *	0.1613
RF	-0.4120 *	-0.0240	0.1015	-0.3826 *
RHI	0.3885 *	-0.4206 *	-0.0728	0.0899
RHI	-0.0554	-0.2177	-0.3417	-0.1127
TMAX	-0.2240	0.4069	0.3218	-0.2111
TMIN	-0.4492	0.0829	0.4334	-0.4115
STI	-0.2040	0.3837	-0.2724	0.0720
STII	-0.2040	0.4114	-0.0949	0.0679
SRH	0.1041	0.2166	0.0917	0.2425
RD	-0.2627	0.1216	0.0755	-0.3130
EVP	-0.1142	0.3560	0.730	-0.0221

* - Significant at 95% level

Table 5.1 Results of correlation analysis - Coconut

(Contd.)

Cochin

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.1	311.3	31.00	167.0	92.5	B_4
Wettest year (1937)	168.3	314.2	34.00	178.1	85.6	B_4
Driest year (1976)	174.3	217.0	48.80	91.4	24.45	B_1
Disastrous drought years i (1935)	169.27	211.56	57.23	976.9	23.9	B_1
ii (1983)	182.50	254.30	61.44	125.84	35.3	B_1

Kottayam

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year						
Wettest year (1933)	166.96	457.71	27.43	319.17	174.7	A
Driest year (1965)	175.41	201.6	37.99	56.98	10.8	C_2
Disastrous drought years i (1979)	179.24	255.37	51.71	126.44	41.7	B_2
ii (1983)	181.73	233.20	56.79	101.45	24.6	B_1

(Contd.)

Alleppey

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.8	310.0	21.70	160.0	85.0	B_4
Wettest year (1977)	177.6	364.7	21.50	208.9	105.5	A
Driest year (1973)	173.3	289.2	30.10	152.6	70.7	B_3
Disastrous drought years i (1982)	180.07	205.74	58.69	88.44	16.5	C_2
ii (1983)	182.64	249761	65.67	126.23	33.2	B_1

Trivandrum

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.9	183.9	29.9	51.9		
Wettest year	164.4	303.6	29.7	171.9	86.5	B_4
Driest year	172.3	112.7	55.6	00.0	-32.25	B_1
Disastrous drought years i (1976)	172.26	112.73	55.55	00.0	-32.2	C_1
ii (1983)	180.99	135.61	53.63	00.0	-29.6	C_1

evapotranspiration to potential evaporation (AE/PE) and morning relative humidity are negatively correlated. In the third stage, the parameters positively correlated are AE, AE/PE and minimum temperature, while moisture deficit is negatively correlated. The correlations of other parameters are not significant.

From the entire data period, the month which gave the highest production was April, 1987 and the lowest production was in December,1987 In both the cases correlation analysis points to a negative correlation between rainfall during the first stage and production.

Coming to the second stage, which is only four months out of the entire development stage of the nut, in the case of highest production month, this period falls from January to April 1985, with rainfall only in the month of April, while for the lowest production month it was from September to December 1985, having rainfall during all the months. A negative correlation with AE and AE/PE and a positive correlation with moisture deficit, soil temperature and maximum temperature are observed

From the third stage correlation results, we can come to a conclusion that more rainfall is favoured during this stage. In both the cases (highest and lowest production), a good rainfall period is encountered by the nuts. But, in the highest production case, rainfall is received during the former phase and in the lowest production, during the latter phase of the stage.

Coming to the fourth stage, according to correlation results high rainfall amount and rainy days do not favour a good production. From the figures it is evident that, in the case of highest production, the nuts come across heavy rainfall (south west monsoon) during the early stages, while for the lowest production case heavy rainfall is in the latter phase of the stage The developing nuts might have come across drought conditions during its opening of spathe which resulted in button shedding.

(ii) Development of a crop-weather model Coconut

Only the parameters which are significantly correlated at each stage of the development of the coconut are considered for Principal Component Regression (PCR) The variables considered for Principal Component Regression (PCR) after Ist stage are rainfall (RF1), morning relative humidity (RHI1) and minimum temperature (TMIN1) Application of PCA reduced the number of variables from three to one (Table 5.2) since only those components which have eigen values of 1.000 or greater were selected for further computations. In this case, the first principal component which had an eigen value of more than one was selected to calculate the PC scores (PC1) employing the eigen vectors, following the procedure explained in Section Three of Chapter Two.

The linear multiple regression equation developed to predict the monthly coconut production after the Ist stage (PROD1) is

PROD1 = 13920 + (-2417.8) * PC1

where PC1 is the independent variable

It is clear from Table 5 5 that, 17% (R^2 = 0 1699) of the variance of monthly coconut production is explained by first

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.058E+06	100.0	100.0
2	8.063E-01	0.0	100.0
3	6.904E-02	0.0	100.0

FACTOR	VECTORS
RFI	1.0000
RHII	-0.0001
TMINI	0.0002

Table 5.2 Eigen values and eigen vectors of Stage I weather parameters - Coconut

stage variables. 83% of the variance is due to other factors such as cultural practices, pests and diseases etc. The standard deviation was 5398.

For the development of prediction model after the IInd stage the variables considered are the three significant variables, RF1, RHI1, TMIN1 of the first stage and the seven significant variables of the second stage - actual evapotranspiration (AE2), ratio of actual evapotranspiration to potential evapotranspiration (AE/PE2), moisture deficit (MDEF2), morning relative humidity (RHI2), soil temperature at 70 cms. (STII2) and maximum temperature (TMAX2) Application of PCA reduced the number of variables from ten to four (Table 5.3), following the same conditions as stated above.

The linear multiple regression equation developed to predict the monthly coconut production after the IInd stage (PROD2) following similar procedure is

$$PROD2 = 13920 + (3083.2 * PC1) + (3228.6 * PC2) + (4209.1 * PC3) + (-2181.7 * PC4)$$

When the first and second stage variables are considered for the development of the model the R squared obtained is 0.3595 (Table 5.5) That is 36% of the variance of coconut production can be explained by the selected weather variables. The standard deviation in this case is 3792, lower than that obtained after first stage.

Finally, all the three stages ie. from primordium of the inflorescence to opening of spathe are considered to develop a linear model. The variables included for the Principal Component

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.058E+06	96.5	96.5
2	3.846E+04	3.5	100.0
3	127.4	0.0	100.0
4	1.410	0.0	100.0
5	6.603E-01	0.0	100.0
6	2.359E-02	0.0	100.0
7	8.197E-02	0.0	100.0
8	4.825E-02	0.0	100.0
9	1.042E-05	0.0	100.0
10	4.374E-055	0.0	100.0

Vectors

Factor	1	2	3	4
RF1	1.0000	0.0023	0.0019	0.0010
RHI1	-0.0001	0.0035	-0.0161	-0.0566
TMIN1	0.0002	-0.0010	-0.0044	-0.0920
AE2	0.0002	-0.6635	0.7440	-0.0707
AE/PE2	-0.0000	-0.0013	-0.0003	0.0016
MDEF2	-0.0029	0.7479	0.6568	-0.0856
RHI2	0.0012	-0.0132	-0.0865	-0.9340
STI2	-0.0001	0.0126	0.0643	0.1958
STII2	-0.0004	0.0083	0.0486	0.2335
TMAx2	0.0000	0.0052	0.0273	0.1037

Table 5.3 Eigen values and eigen vectors of Stage II weather parameters - Coconut

Regression model for the prediction of monthly coconut production 11 months before harvest are RF1, RHI1, TMIN1, of the Ist stage, AE2, AE/PE2, MDEF2, RHI2, STI2, STII2, TMAX2 of the IInd stage and the four significant variables of stage III-Actual evapotranspiration (AE3), ratio of actual evapotranspiration to potential evapotranspiration (AE/PE3), moisture deficit (MDEF3) and minimum temperature (TMIN3) of third stage. Application of Principal Component Analysis reduced the number of variables to be included in the model from fourteen to six (Table 5.4)

The regression model to predict the monthly coconut production 11 months prior to harvest (PROD3) is

$$PROD3 = 13921 + (4608.6 * PC1) + (-5996.8 * PC3) + (-2347.1 * PC3) + (-6776.0 * PC4) + (14244 * PC5) + (-5930.8 * PC6)$$

The R squared obtained is 0.6314 (Table 5.5) with a standard deviation of 3792 nuts. That is 63.14% of the variance of monthly coconut production can be explained by the weather changes which take place during 44 to 11 months prior to harvest. It is evident from the three experiments that the impact of weather parameters on the monthly production is increasing after each stage, and therefore the estimated yield after the third stage (PROD3) is closest to the observed yield.

The observed and estimated monthly nut production was in good agreement in a majority of the cases (Table 5.6) Out of 52 sets of monthly production values only 6 cases showed more than 50% deviation. However, the percentage deviation in nut production was within permissible limits as the deviation stayed within one standard deviation in most of the cases Hence, the

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.059E+06	95.0	95.0
2	3.884E+04	3.5	98.5
3	1.671E+04	1.5	100.0
4	171.0	0.0	100.0
5	81.78	0.0	100.0
6	1.261	0.0	100.0
7	5.597E-01	0.0	100.0
8	2.187E-01	0.0	100.0
9	8.042E-02	0.0	100.0
10	3.315E-03	0.0	100.0
11	7.308E-03	0.0	100.0
12	1.929E-03	0.0	100.0
13	2.914E-05	0.0	100.0
14	1.491E-05	0.0	100.0

Vectors

Factor	1	2	3	4	5	6
RF1	-0.9995	0.0020	0.0316	-0.0001	0.0030	0.0010
RHI1	0.0001	-0.0034	0.0022	0.0154	0.0023	-0.0158
TMIN1	-0.0002	0.0010	0.0003	0.0011	-0.0056	-0.0813
AE2	-0.0001	0.6572	-0.0960	-0.5188	0.5320	-0.0763
AE/PE2	0.0000	0.0013	-0.0002	0.0003	-0.0003	0.0010
MDEF2	0.0028	-0.7418	0.0905	-0.4578	0.4711	-0.0919
RHI2	-0.0011	0.0133	0.0022	0.0474	-0.0782	-0.8955
STI2	0.0001	-0.0125	0.0017	-0.0408	0.0571	0.2613
STII2	0.0004	-0.0083	0.0012	-0.0348	0.0354	0.3101
TMAx2	-0.0000	-0.0052	-0.0000	-0.0168	0.0230	0.1094
AE3	-0.0232	-0.1011	-0.7688	0.4594	0.4321	-0.0154
AE/PE3	-0.0000	-0.0001	-0.0004	0.0001	0.0000	-0.0016
MDEF3	0.0215	0.0039	0.6249	0.5518	0.5450	-0.0155
TMIN3	-0.0008	-0.0001	-0.0016	0.0079	0.0085	0.0046

Table 5.4 Eigen values and eigen vectors of Stage III

Weather parameters - Coconut.

Stage	Predictor Variables	Coefficients	R Square	Standard deviation
I	Constant	13920.0	0.1699	5398
	PC1	- 2417.8		
II	Constant	13920.0	0.3595	4891
	PC1	- 3083.2		
	PC2	3228.6		
	PC3	4209.1		
	PC4	- 2181.7		
III	Constant	13921.0	0.6314	3792
	PC1	4608.6		
	PC2	- 5996.8		
	PC3	- 2347.1		
	PC4	- 6776.0		
	PC5	14244.0		
	PC6	- 5930.8		

Table 5.5 - Coefficients of Coconut production prediction model - Coconut

σ = 3792

Months	observed	estimated	deviation	percentage deviation
1	8947.00	11212.64	.25	25.3
2	7413.00	12354.26	.67	66.7
3	6325.00	11958.50	.89	89.1
4	7496.00	11513.52	.54	53.6
5	9895.00	13102.32	.32	32.4
6	17596.00	14291.01	-.19	-18.8
7	23366.00	18706.95	-.20	-19.9
8	27457.00	23913.20	-.13	-12.9
9	24251.00	19385.24	-.20	-20.1
10	16274.00	19388.57	.19	19.1
11	20426.00	17788.01	-.13	-12.9
12	22504.00	16596.15	-.26	-26.3
13	20394.00	19307.21	-.05	-5.3
14	16009.00	15636.73	-.02	-2.3
15	12206.00	11561.71	-.05	-5.3
16	9598.00	10817.95	.13	12.7
17	8638.00	12127.05	.40	40.4
18	12633.00	12759.81	.01	1.0
19	12523.00	16429.86	.31	31.2
20	13573.00	17536.46	.29	29.2
21	11565.00	18756.15	.62	62.2
22	9355.00	16459.45	.76	75.9
23	15282.00	15853.19	.04	3.7
24	12489.00	13891.70	.11	11.2
25	14555.00	15255.69	.05	4.8
26	9699.00	11875.95	.22	22.4
27	10615.00	9794.12	-.08	-7.7
28	7826.00	9695.19	.24	23.9
29	9498.00	9421.02	-.01	-.8
30	16344.00	12009.08	-.27	-26.5
31	25841.00	16907.49	-.35	-34.6
32	23857.00	22789.19	-.04	-4.5
33	18913.00	21698.57	.15	14.7
34	21861.00	19252.33	-.12	-11.9
35	17683.00	19242.65	.09	8.8
36	24163.00	17572.75	-.27	-27.3
37	16637.00	20883.27	.26	25.5
38	17498.00	17664.84	.01	1.0
39	15239.00	13434.89	-.12	-11.8
40	8716.00	9129.08	.05	4.7
41	11699.00	8026.64	-.31	-31.4
42	11999.00	7499.79	-.37	-37.5
43	15768.00	13974.31	-.11	-11.4
44	11660.00	13461.41	.15	15.4
45	14321.00	10622.73	-.26	-25.8
46	6172.00	8687.40	.41	40.8
47	8792.00	7731.52	-.12	-12.1
48	11386.00	8378.71	-.26	-26.4
49	6249.00	10591.64	.69	69.5
50	10675.00	8047.90	-.25	-24.6
51	5575.00	4794.79	-.14	-14.0
52	4369.00	4025.50	-.08	-7.9

Table 5.6 Comparison between actual and estimated - monthly coconut production

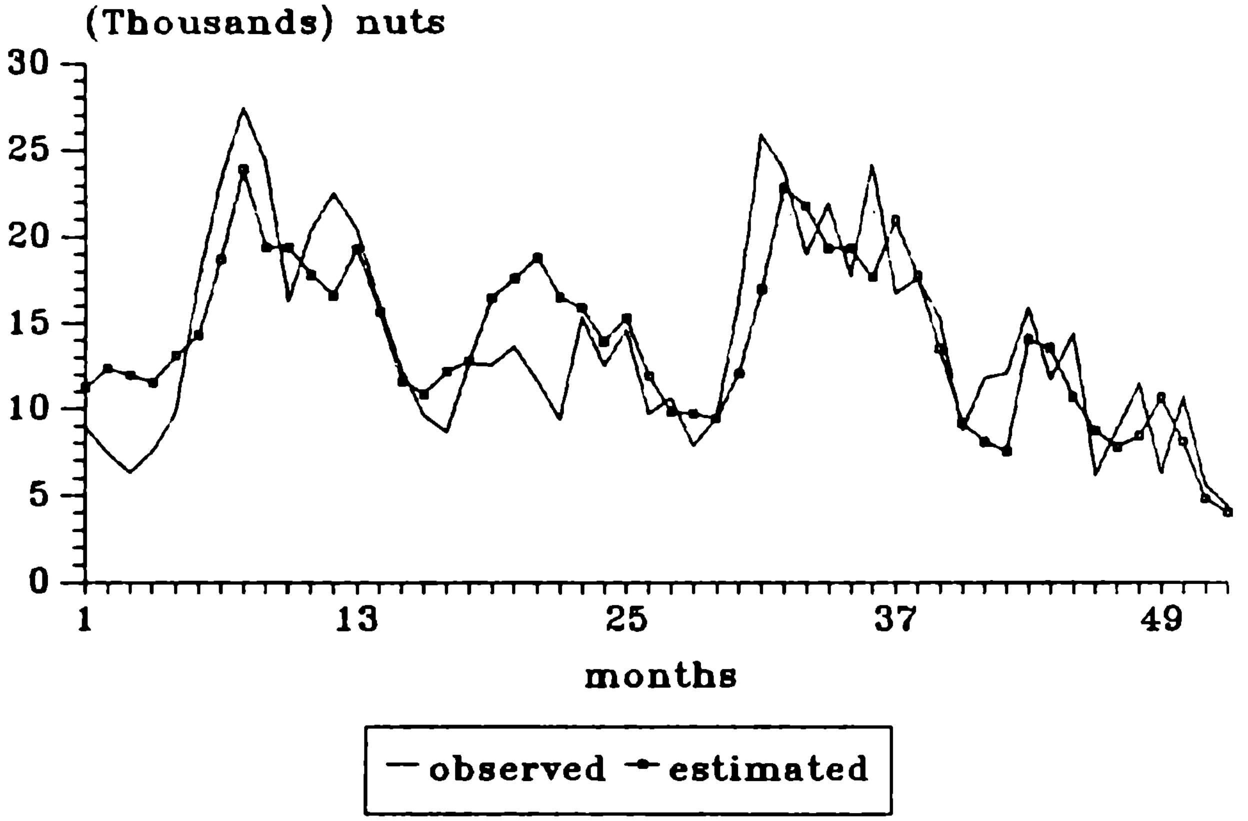


Fig 5.1 Observed and predicted monthly coconut production

equation is a good fit for estimating coconut production eleven months ahead. Fig 5.1 gives the fit between observed and estimated values.

5.3 Case study - Rice:

5.3.1 Introduction

The cultivation of rice certainly fate to the earliest age of man, and long before the era of which we have historical evidence rice was probably the staple food and the first cultivated crop in Asia. Hogan(1970) reported that,, according to the Archaeological Survey of India, four terraces for rice cultivation on the banks of the Ravi River in South -west Kashmir date to the Pleistocene or Ice Age.If this be so, it would appear that rice is an older cereal grain than is generally recorded by historians.

Carbonized paddy grains and husks, estimated to date 1000 to 800 BC, have been found in Lothal in Gujarat, which is considered to be the southward extension of the Harappa and Mohenjadaro culture of the Indus Valley civilization assigned to 2300 BC(CSIR 1966) Excavations at Mohenjadaro brought to light rice grains on earthen vessels, thus providing evidence that this cereal was an important food in this region some 2500 years BC (Andrirs and Mohammed,1958)

The ancient Indian name for rice, 'dhanya' meaning 'sustainer of the human race', indicates its age-old importance. Some of the very ancient Tamil puranas contain descriptions of particular varieties of rice which are used in certain religious offerings, showing that even in ancient times, varieties with definite grain characteristics were recognized, and Susrutha (1000 BC) in his Ayurvedic Matera Medica recognized the differences among rices that existed in India, separating them into groups based on their growth periods, water requirements and nutritional values (Ramiah and Rao,1953)

The varieties of cultivated rice are legion and the variation of characters exhibited by them enables the crop to be grown with success over a wide range of climatic and cultural conditions; from dry land in more or less arid conditions with irrigation, to deep undrained swamps, and varying depths of water. In 1982 the IRRI collection of rice species includes 67000 Asian cultivars, 2000 African rices, 1100 wild rices and 690 genetic testers.

Oryza sativa L. is divided into four subspecies as follows Vasconcellos (1953) (1) Indica (2)Japonica (3)Brevindica and (4) Brevis Gustchin. The last two are not generally recognized. The Japonica forms are typical of the more northerly (and southerly)areas of paddy cultivation and flourish under very long photo periods. Seedlings of cold water-tolerant japonica varieties may grow and develop faster than seedlings of indica varieties when the temperature of soil or water is low (Adair et al. 1966) The grain of japonicas is commonly shorter and broader than is usual for indicas; japonicas usually have broad leaves rather hairy glumes and translucent endosperm.

The types of rice favoured in a country depend on climatic and cultural conditions, and whether the rice is destined for export or local consumption. Of the total production in India and

Pakistan, about 13 percent is long grain, 32 percent medium-grain and 55 percent short- grain rice.

No expert can, by visiting and area, or by examining climatic conditions and the chemical nature of the soil, prescribe with any certainty the variety of paddy to which the situation is suited. The many factors influencing the growth of paddy are so complex and so much is incompletely understood, that the vagaries of the crop can only be countered by the process of trial and error.

5.3.2 Characteristics of the plant

Rice is a grass (Gramineae) belonging to the genus Oryza Linn. of which two species are cultivated, O. sativa Linn. and O. glaberrima Steud.

Oryza sativa is widely grown in tropical and subtropical regions, either as a dry land (upland) crop but more usually in water. The ripe seed is the staple food in many Eastern countries. It is not, however, and aquatic plant, for the roots of aquatics produce but few branches and no root hairs, whereas the roots of paddy- whether grown as a dry land crop or in water- are much branched and possess a profusion of root hairs.

Under normal conditions the root system of the plant is fairly compact, tending to develop horizontally rather than vertically, the plant therefore draws its nutrients from near the surface of the soil (Sasaki,1932) showed that under standard conditions after transplanting the roots develop at first near the soil surface, then gradually penetrate deeper in the soil.

The extreme depth reached by mature root system was 90 cm. Root development is influenced by soil texture, cultivation, water and air in the soil, the amount of available food supply and the system of transplanting.

Sato (1938) observed that the number of roots increases gradually from the early period of growth towards tillering, and the shooting period reaches the maximum at heading time, gradually deceasing until harvest time.

The main stem or culm is differentiated from the growing point of the embryo, enclosed at first by the coleoptile. The ultimate height of the stem depends on the number of internodes and their length and may be much affected by environment but under comparable growth conditions is characteristic of varieties.

The leaves are alternate and borne in two ranks along the stem. The leaf consists of two parts, a sheath enveloping the stem and a blade or lamina. The number of leaves borne on an axis is equal to the number of nodes. Leaf structure, a varietal character, allows increased light absorption and utilization of light energy by the plant, resulting in increased yield potential (Purseglove,1968)

The blade is long and narrow, usually pubescent or hispid, or (less usually) glabrous. Japanese scientists, and especially Matsushima (1969 b) have shown that high yield of grain is positively correlated with the uppermost two or three leaf blades being short and erect to increase the photosynthetic efficiency of the plant.

The angle of the flat leaf is important, since it affects shading of lower leaves. Radiation capture and hence carbon assimilation is hindered by mutual shaking by the plants leaves. A high final angle of the flag leaf, from which much of the carbohydrate in the grain is derived, is an important yield component. Singh(1981) showed that the flag leaf plays an important role in assimilation of plant nutrients and thus influences grain yield.

Varieties in various regions are designated as kharif, winter, spring and summer crops and each class is sub-divided into early and late types purely on the basis of the local normal time of harvest.

5.3.3 Rice in Kerala

Over a very large part of the rice growing areas in India and other countries, single crop of rice alone is raised from June-July to November-December. Two and sometimes three crops are raised in Kerala on the same land, the cultivating seasons corresponding to the rainy periods of the tract. The three main seasons for rice are fairly well defined, the virippu or the autumn crop is raised from April- May to September - October followed by the Mundakkan crop (winter crop) from September October to December- January while the typical Punja (Summer crop) is raised from December-January to March-April (Sahadevan, 1966)

Any account of the rice seasons will not be complete without a mention of the age-old astronomical basis on which agricultural seasons and calendar of operations are prescribed for raising rice and various other crops in Kerala. The year is divided into 12 months, the names of the month corresponding to the 12 signs of the Zodiac (Rasis) The Agricultural year commencing on 1st of Medam (Aries) is again divided into 27 parts (on an average 13.5 days each) and each part known as 'nattuvela meaning period of the sun is given the name of each of 27 nakshatras or lunar mansions through the moon passes in her monthly journey through the stars.

The period prescribed for the sowing of autumn rice is Bharani and Karthika nattuvelas, (about April 27 to May 23), the period of sowing sprouted seeds in puddle is the Makayiram nattuvela corresponding to June 8 to June 20 and the best period for transplanting is the Thiruvathira nattuvela (June 22nd to July 4) similarly the nursery for winter crop is to be raised in Ayilyam and Makam nattuvela (August 3 to August 29) and transplanting completed before October 10. The summer crop has to be planted before the end of February at the latest.

It is now well established that within any season long days and humid conditions with adequate rains or water supply help towards satisfactory vegetative growth of the rice plant while bright weather and short days with a diminishing supply of water favour the flowering phase. These requirements are very nearly met during the periods specified in terms of natuvelas as given above.

The success of the autumn crop depends on the timely and adequate premonsoon showers received from April to June before the south-west monsoon breaks out in June. The winter crop usually is affected by drought in the post-flowering period in November-December, if north-east monsoon rains are either in adequate in quantity or ill-distributed. The largest area under summer crop is grown by dewatering flooded areas. Very often breaching of bunds and intrusion of salinity affect the crop adversely

The varieties could be broadly grouped into upland and low land varieties. The upland varieties would thrive under low land conditions but the converse is not true. Among the low land varieties, salt tolerant types and deep water types (floating rices) come under district categories. These and the upland varieties are grown in the autumn season (viruppu) in Kerala like the typical autumn varieties. The winter varieties (mundakkan) come under a different group. Varieties grown during summer season (Punja) can also be raised in both autumn and winter seasons.

Photo-sensitivity brings about still another distinction among the varieties particularly in regard to those having long (about 150 days) and medium (130 days) duration. Being photo-sensitive, these varieties flower only at a particular time of the year irrespective of the time of sowing. They should therefore be grown only in the season for which they are recommended. Short-term varieties (about 100 days) are generally photo-insensitive and can be grown in all the three seasons, whatever the season, these come to maturity within the same period, the duration remaining more or less unchanged except in high altitude areas. For upland and summer varieties the duration does not go above 115 days while the medium and long term rices are exclusively grown in wet lands during autumn and winter season.

5.3.4 Crop weather relationships

The weather conditions during the crop growth period of paddy greatly decide the crop's response to added inputs (Tanaka et al.,1964; Mahapatra and Badekar, 1969) Among the various weather factors that affect the growth and yield of rice, air temperature plays an important part. Each development stage and growth process response differently to the same temperature conditions (Izhizuka et al., 1973) Low temperature slows down the rate of germination and root development. High temperature during the vegetative stage increase the tiller number and retards the rate of development For rice, unlike the other crops, both water temperature and air temperature are important. At germinating seedlings stages, water temperature is more influencial than air temperature. And at later stages, both the day time and night time temperatures are important. For upland rice, the optimum temperature for germination is 30^{o}C (Hall, 1966) while the lower limit is 20^{o}C (Downey and Wells, 1974) Dedatta (1970) attributed low average yield in the tropic's warm climate during early growth periods. Sreedharan (1975) reported that a minimum air temperature of 25^{o}C to 26^{o}C is ideal for shoot and root growth. The optimum temperatures for elongation and leaf emergence are 25^{o}C and 30^{o}C respectively (Robertson, 1975) Kang and Heu (1976) also observed that lower temperature during nursery period of rice resulted in higher plant height.

Yield reduction in rice due to low temperature was recorded in North India due to cold injury Due to cold weather, significant yield reduction (20 40%) was noticed on account of high spikelets sterility during the rabi season. The most comprehensive work on the effect of cold injury to rice crop has been done in Japan where low temperature is the main limiting factor in rice production. Nishiyama et al., (1969) showed that the critical low temperature for inducing sterility is 15°C - 17°C in highly cold tolerant varieties at meiotic stage of crop growth. Their studies suggested that the critical temperature for sterility is about 15°C 20°C. A significant negative correlation between yield and the minimum temperature 30 days after transplanting and significant correlation between yield and maximum temperature over the 45 days before maturity are reported by Datta and Zrate (1970)

During reproductive stage, within a temperature range of 22 to 31°C, spikelets number per plant increases as the temperature crops (Yoshida,1973) He also suggested that the optimum temperature for rice shifts from high to low as the growth advances from vegetative to reproductive stages. The rice plant is very sensitive to low temperature about 9 days before flowering (Satake, 1976) and high temperature at flowering (Satake and Yoshida, 1978)

Variability of rainfall affects the rice crop generally at the reproductive stage. If the variability is associated with an untimely cessation at the reproductive or ripening stage, yield reduction is severe. Rainfall variability is more critical for upland rice than for low land rice. Venkateswarlu et al., (1976) reported high pannicle number in rabi (500) compared to kharif

(400) season, thus being responsible for high yields in the former.

Solar energy is the major governing factor for photosynthesis and hence dry matter production and yields are dependent on solar radiation to a considerable extent. The low light intensity upto flowering in kharif, imposes a ceiling on tillering and reduces dry matter production as compared to rabi season (Venkateswarlu,1977; Venkateswarlu et al., 1977)

Several workers pointed out the positive influence of solar radiation received during different critical growth stages on grain yield. Stansel (1966), and Murata and Togari (1973) reported it to be the three weeks before and after flowering. Ghildyal and Jan (1967), and De Datta and Zarate, (1970) reported it to be the one week before harvest and according to Matsushima (1970) it is fifteen days before and twenty five days after flowering. Evans (1972) reported that grain filling was very poor in the absence of light. Low light intensity during the reproductive phase has a pronounced effect on spikelet number and, hence, on yield.

Rice is generally a short day plant and sensitive to photo period. The observations of Venkataraman and Narasimhamurthy (1973) showed that the variation of only 30minutes in photo period can significantly affect crop development. The photo periods insensitive rice varieties enable the farmers in the tropics and subtropics to plant rice at any time of the year without great changes in duration.

Flowering of rice does not occur below 40% Relative humidity and is best at 70 to 80 % Relative humidity High humidity during post flowering stage appeared to have a detrimental effect on yield.

Estimation of rice yield before harvest is of immense help for planning purposes. On the basis of rainfall, IMD divided the country into 33 meteorological subdivisions and developed equations to forecast wheat and rice yields on a subdivisional basis. Regression models were developed by Das (1970) for the Bihar plains and by Das and Mehra (1971) for Kerala. Rao and Das (1971) made a comprehensive survey of weather and rice crop yield. Srinivasan and Banerjee (1973) applied Fisher's technique to find out effect of rainfall on rice crop at Karjat (Maharashtra) Adopting this technique at Adhutarai and Coimbatore (Tamil Nadu), Srinivasan and Banerjee (1978) found that additional rainfall above the normal, exerts negative influence during sowing, tillering and flowering stages of rice.

Appa Rao et al (1977) modified the equations developed for the Bihar Plains and Kerala. They found that pre-planting rainfall increase the yield but minimum temperature during flowering leads to yield reduction. Effects of weather variables on rice yield and its forecast at Raipur district, Madhya Pradesh was done by Jain et al (1980) and Agarwal et al(1983) Crop-weather relationships of rice at Ankapalle, Andhra Pradesh was investigated by Rupa Kumar et al (1984) Studies on water balance and rice production in Cannanore District of North Kerala was done by Prasada Rao and Nair (1984) The study showed that water surplus during the crop growth period results in heavy flooding and this leads to low crop productivity

High humidity and high temperature during the rainy season often favour pests and diseases outbreak, IRRI (1986) in three trials conducted at Pattambi reported that low yields are the results of heavy infestation of pest and disease which occur more dominantly in later part of the wet season. Joseph(1991) observed that weight of 100 grain was significantly higher for planting done on 20 July at Pattambi. Chowdhury and Gore (1991) applied Curvilinear technique to rice crop in Bhandara district (Maharashtra) and observed that combination of seasonal mean maximum temperature of 30.5° C, 81% relative humidity and rainfall of 1000mm during physiological growth phases, ie., between elongation and grain formation gives optimum rice yield. Effect of temperature on the duration of vegetative phase of rice varieties in low lands of Kasargode district, Kerala was investigated by Prasada Rao (1994) Studies on effect of weather on paddy yield by Curvilinear technique at Pattambi, Kerala were carried out by Samui and Chowdhury (1994) The study brought out clearly that maximum and minimum temperatures play an important role towards rice production at Pattambi.

5.3.5 Crop-weather model

(a) Experimental data used for study

Details of crop and weather data collected from the Regional Agricultural Research station Pattambi ($10^{o}48'N$, $76^{o}12'E$) of Kerala Agricultural University located 25m amsl is given below.

Parameters	Years of data
Crop	
Crop yield of Tall Indica (Viruppu and Mundakkan)	1961 - 1990
Meteorological (Weekly)	
Rainfall (RF)	1961 - 1990
Maximum temperature (TMAX)	-do-
Minimum temperature (TMIN)	-do-
Soil temperature 5cm. depth (STI)	-do-
Soil temperature 15cm. depth (STII)	-do-
Morning relative humidity (RHI)	-do-
Evening relative humidity (RHII)	-do-
Solar radiation hours (SRH)	-do-

The crop yield data of Tall Indica has been obtained from permanent manurial experiment (Cattle manure - 4485 kg/ha + Ammonium sulphate - 22.4 kg/ha. + P_2O_5 and K_2O each 22.4 kg/ha.) conducted in the lowland laterite soils of the research station.

(b) Methodology employed

The crop growth period from seedling stage to harvest is considered to be 22 weeks and 20 weeks in the case of Viruppu and Mundakkan crop respectively The entire growth period was divided into 6 stages (Table 5 7) which appear to be the most appropriate growth stage divisions for the paddy crop in Kerala.

Viruppu Crop	
crop stage	weeks
nursery	(20th-23rd week) (4 weeks)
tiller initiation	(24th -25th week) (2 weeks)
active tillering	(26th - 29th week) (4 weeks)
panicle initiation	(30th -32nd week) (3 weeks)
flowering stage	(33rd 35th week) (3 weeks)
flowering to harvest	(36th -41st week) (6 weeks)

Table 5.7 Growth stages in rice crop- Viruppu.

As in the case of the coconut crop in the case of the rice crop too, the methods of correlation and regression analysis are widely used to study crop weather relationships. Firstly the rainfall amount from 17th to 19 th week is correlated with the final crop yield and a regression model is developed to predict the final yield using the sowing rains. The average of the weather parameters and total rainfall in the six stages is computed. These parameters constitute the independent variables that are to be related with the dependent variable, yield. But as a matter of fact, all the weather parameters are inter-correlated. Principal Component Analysis (PCA) is usually employed to nullify the inter-correlation between the variables. In the first instance correlations were worked out between the rice yield and the eight meteorological parameters pertaining to each stage of the crop growth. All the variables were subjected to PCA. Only those components which have eigen values of 1.000

or greater were selected for further computation. The PC scores were computed for each stage. Based on the scores some components were selected as the independent variables in the multiple regression model. The crop yield is predicted at the end of each stage. Further the crop yield of each stage is included as one of the independent variable for the computation of yield of the following stage. Thus, the model for Stage II will include the yield value estimated at the end of Stage I. While that of Stage V will include estimated yield at the end of Stage IV. This physico-statistical approach to crop-weather modelling is similar to the model developed by Robertson (1974) This approach enables a better insight into the influence of the weather during the growing season on the production of rice and to develop a numerical model for assessing the influence of advancing weather conditions on the final yield. The aim of this model is to make it applicable for ultimate use in crop yield forecasting from meteorological parameters.

In the case of the Mundakkan crop,its period is taken to be the 39th week to the 6th week of the following year.The sowing rains considered to be from the 36th to the 38th week. The division of crop stages in the present study given in Table 5.8.

Mundakkan Crop crop stage	weeks	
nursery	(39th-42nd week)	(4 weeks)
tiller initiation	(43rd -44th week)	(2 weeks)
active tillering	(45th 48th week)	(4 weeks)
panicle initiation	(49th -51st week)	(3 weeks)
flowering to harvest	(52nd - 6th week)	(7 weeks)

Table 5.8 Growth stages in rice crop- Mundakan.

The methodology followed by Viruppu crop is repeated in the case of Mundakkan too.

5.3.6 Results

(a) Viruppu crop

(i) Results of correlation studies

The results of correlation analysis between viruppu crop yield and weather parameters in the different stages of crop development is given in Table 5.9 From the table, it is observed that in all the stages excepting the last (ripening phase), soil temperature shows significant negative correlation with the yield. During the nursery period of the crop, higher relative humidity favours a better yield. Even though, several workers pointed out the positive influence of solar radiation received during different growth stages on grain yield, in the present study, a negative correlation is exhibited during active tillering stage. In none of the stages rainfall exhibits any significant correlation with yield. This can be attributed to the fact that deficiency in moisture is rarely encountered by the crop, during viruppu season.

(ii) Development of crop-weather model - Viruppu

The rainfall amount during the two weeks preceding sowing is employed to predict the yield (YIELD 1) The linear regression equation developed to predict the yield for sowing rains is

YIELD1 = 2909.7 + (-0.48716 * SRF)

where SRF is the sowing rains

From Table 5.15 it is clear that only 0.2% of the variance of Viruppu crop yield can be attributed to sowing rains.

Coefficients

Variables	Stage I	Stage II	Stage III	Stage IV	Stage V
Rainfall (RF)	0.1078	0.0534	0.0832	-0.1838	-0.0586
Morning Relative Humidity(RHI)	0.3165*	0.2367	0.0748	0.1196	-0.0086
Evening Relative Humidity (RHII)	0.3244*	0.2399	-0.0001	-0.1642	-0.0537
Solar radiation hour (SRH)	-0.3138*	-0.2490	-0.3015*	0.0413	-0.0072
Soil temperature at 5cm (ST I)	-0.3914*	-0.3352*	-0.5606*	-0.3326*	-0.3153*
Soil temperature at 15cm (ST II)	-0.2867	-0.2709	-0.4530*	-0.2442	-0.1508
Maximum temp-erature(TMAX)	0.0074	0.1268	-0.2366	0.0932	-0.0580
Minimum temp-erature (TMIN)	-0.2482	-0.1278	0.0577	0.0889	0.1433

* Significant at 95% level

Table 5.9 Results of Correlation analysis between weather Parameters and yield - Viruppu Crop

Prediction after Ist stage

All the eight varables, rainfall (RF) maximum temperature (TMAX), minimum temperature (TMIN),soil temperature at 5cm (ST I) soil temperature at 15cm (ST II), morning relative humidity (RHI) evening relative humidity (RHII) and solar radiation hours (SRH) of the Ist stage are subjected to Principal Component Analysis and components exhibiting eigen values more than 1.00 are selected. Application of PCA reduces the number of variables from eight to five (Table 5.10) Employing the eigen vectors in table the five PC scores are calculated. The PC scores thus obtained and the predicted yield from the previous stage (YIELD I) form the input variables in the linear multiple regression equation.

The linear multiple regression model developed to predict the paddy yield of Viruppu season, 18 weeks before harvest (YIELD 2) is

YIELD 2 = -3439.0 + (-118.04) * PC1 + (83.808)*PC2 + (-108.86) * PC3 + (-72.97) * PC4 + (-223.38) * PC5 + (2.1966) * YIELD 1

It is clear from Table 5.15, which presents the results, that 18% of the variance of Viruppu yield is explained by first stage weather parameters and YIELD 1.

Prediction after IInd stage

When all the eight variables of IInd stage are subjected to PCA, and components exhibiting eigen value more than 1.00 are selected, the number of variables is reduced to five (Table 5.11) Employing the eigen vectors in table the PC scores thus obtained and the predicted yield of previous stage (YIELD 2) form

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.383E+04	99.2	99.2
2	271.1	0.8	100.0
3	5.638	0.0	100.0
4	1.432	0.0	100.0
5	1.087	0.0	100.0
6	6.340E-01	0.0	100.0
7	3.466E-01	0.0	100.0
8	1.126E-01	0.0	100.0

VECTORS

FACTOR	1	2	3	4	5
TMAX	-0.0031	0.0672	0.3208	-0.3863	0.5017
TMIN	-0.0027	-0.1022	-0.0283	-0.3174	-0.0505
STI	-0.0056	-0.0762	0.1408	-0.3337	0.5981
STII	-0.0142	-0.5873	-0.6666	-0.1442	0.1033
RHI	0.0117	0.3877	-0.1396	-0.7205	-0.4725
RHII	0.0371	0.6402	-0.6192	0.1343	0.3925
SRH	-0.0088	-0.2694	-0.1704	-0.2843	0.0033
RF	0.9991	-0.0396	0.0153	-0.0050	-0.0028

Table 5.10 Eigen values and eigen vectors of Stage I weather parameters - Viruppu Crop.

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	2.558E+04	98.1	98.1
2	467.0	1.8	99.9
3	13.58	0.1	100.0
4	2.508	0.0	100.0
5	1.387	0.0	100.0
6	6.454E-01	0.0	100.0
7	2.554E-01	0.0	100.0
8	6.024E-02	0.0	100.0

VECTORS

FACTOR	1	2	3	4	5
TMAX	-0.0023	0.0543	0.1282	0.2798	0.1651
TMIN	-0.0034	-0.0512	-0.0338	0.3047	0.5542
STI	-0.0067	-0.0296	0.0518	0.4394	0.3543
STII	-0.0318	-0.4616	-0.2072	0.2644	0.2871
RHI	0.0111	0.1151	0.1357	-0.6961	0.6682
RHII	0.0619	0.5351	-0.8312	0.0405	0.0924
SRH	-0.0457	-0.6888	-0.4764	-0.2822	-0.0521
RF	0.9964	-0.0811	0.0222	0.0054	-0.0018

Table 5.11 Eigen values and eigen vectors of Stage II weather parameters - Viruppu Crop

the input variables for the multiple regression model at this stage.

The linear multiple regression model developed to predict the Viruppu yield 16weeks before harvest is

YIELD 3 = -617.21 + (-53.493) * PC1 + (58.223) * PC2 + (-387.1) * PC3 + (64.274) * PC4 + (6.1998) * PC5 + (1.2147) * YIELD 2

The R square value is 0.2163 ie. 21% of the variance of Viruppu crop yield (Table 5.15) can be explained by the eight weather parameters of IInd stage selected for analysis and the yield predicted after the previous stage.

Prediction after IIIrd stage

As a result of further application of PCA to all the eight weather parameters of the IIIrd stage, and selection of components which exhibit eigen value more than 1.00, the number of variables reduces to three in this case (Table 5.12) Employing the eigen vectors given in table the three PC scores and the yield obtained from the previous stage model (YIELD 3), form the independent variables in the linear regression model to predict the Viruppu crop yield 12 weeks before harvest (YIELD 4)

The regression model developed to predict YIELD 4 is

YIELD4 = -568.05 + (154.61) * PC1 + (133.58) * PC2 + (66.34) * PC3 + (1.1977) * YIELD 3

The R squared value obtained is now 0.2691, which shows that 26.9% of the variance of Viruppu crop yield 12 weeks before harvest can be explained by the eight weather parameters of IIIrd stage and the yield predicted after previous stage.

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	5.473E+04	100.0	100.0
2	5.431	0.0	100.0
3	1.406	0.0	100.0
4	8.981E-01	0.0	100.0
5	6.816E-01	0.0	100.0
6	3.030E-01	0.0	100.0
7	5.428E-02	0.0	100.0
8	3.520E-02	0.0	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.0019	0.1521	-0.1101
TMIN	-0.0002	0.1317	-0.3741
STI	-0.0011	0.1482	-0.2876
STII	-0.0025	0.1389	-0.4234
RHI	0.0013	-0.1288	-0.7145
RHII	0.0110	-0.9252	-0.1365
SRH	-0.0026	0.2136	-0.2384
RF	0.9999	0.0118	0.0002

Table 5.12 Eigen values and eigen vectors of Stage III weather parameters - Viruppu Crop

Prediction after IVth stage

Application of PCA once again to all the eight weather parameters of stage IV, reduces the number of variables to three (Table 5.13) Employing the eigen vectors given in the table the three PC scores are calculated. The three PC scores and the yield obtained from the previous stage model (YIELD 4), form the independant variables in the linear regression model to predict the Viruppu crop yield 9 weeks before harvest (YIELD 5)

The regression model which can predict YIELD 5 is

$$\text{YIELD 5} = 170.72 + (-86.127) * \text{PC1} + (41.279) * \text{PC2} + (112.50) * \text{PC3} + (0.9406) * \text{YIELD 4}$$

It is clear from Table 5.15 that, 32% of variance of Viruppu crop yield is explained by IVth stage weather parameters and predicted yield (YIELD 4) of previous stage

Prediction after Vth stage

Finally, the eight weather parameters of Stage V, selected for analysis are subjected to PCA, and .employing the criteria of eigen value greater than one, only four components are selected for further analysis. The eigen vectors shown in Table 5.14 are used to compute the four PC scores. The four PC scores thus obtained and the yield predicted after the previous stage (YIELD 5) form the independent variables of the prediction model of Viruppu crop yield 6 weeks before harvest (YIELD 6) The prediction model to predict YIELD 6 is

$$\text{YIELD 6} = 43.784 + (-7.6113) * \text{PC1} + (30.779) * \text{PC2} + (38.163) * \text{PC3} + (-17.519) * \text{PC4} + (0.9854) * \text{YIELD5}$$

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	2.668E+04	99.9	99.9
2	13.24	0.0	100.0
3	1.154	0.0	100.0
4	9.257E-01	0.0	100.0
5	4.383E-01	0.0	100.0
6	3.601E-01	0.0	100.0
7	1.257E-01	0.0	100.0
8	5.974E-02	0.0	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.0030	0.0372	-0.0988
TMIN	-0.0021	0.0202	0.3376
STI	-0.0028	0.0441	-0.2095
STII	-0.0035	0.0662	-0.3470
RHI	0.0031	-0.1034	-0.3387
RHII	0.0164	-0.9798	-0.1069
SRH	-0.0062	0.1446	-0.7654
RF	0.9998	0.0178	-0.0033

Table 5.13 Eigen values and eigen vectors of Stage IV weather parameters - Viruppu Crop

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.048E+04	99.9	99.9
2	9.243	0.1	100.0
3	1.870	0.0	100.0
4	1.092	0.0	100.0
5	5.826E-01	0.0	100.0
6	5.246E-01	0.0	100.0
7	1.233E-01	0.0	100.0
8	8.859E-02	0.0	100.0

VECTORS

FACTOR	1	2	3	4
TMAX	-0.0034	0.1020	-0.0139	0.1443
TMIN	0.0004	0.0124	-0.1148	0.3024
STI	-0.0032	0.0462	-0.0948	0.6196
STII	-0.0057	0.1333	0.1279	0.6741
RHI	0.0086	-0.1199	0.9452	0.0664
RHII	0.0297	-0.9592	-0.1492	0.1611
SRH	-0.0095	0.1845	-0.2137	0.1381
RF	0.9994	0.0325	-0.0053	0.0022

Table 5.14 Eigen values and eigen vectors of Stage V weather parameters - Viruppu Crop

STAGE	PREDICTOR VARIABLES	COEFFICIENTS	R SQUARE	STANDARD DEVIATION
Sowing rains	Constant	2909.7	0.0020	528.7
	SRF	- 0.48716		
Stage I	Constant	-3439.0	0.1808	528.5
	PC1	- 118.04		
	PC2	83.808		
	PC3	- 108.86		
	PC4	- 72.97		
	PC5	- 223.38		
	Yield 1	2.1966		
Stage II	Constant	- 617.21	0.2163	516.9
	PC1	- 53.493		
	PC2	58.223		
	PC3	- 387.1		
	PC4	64.274		
	PC5	6.1998		
	Yield 2	1.2147		
Stage III	Constant	- 568.05	0.2691	478.8
	PC1	- 154.61		
	PC2	133.58		
	PC3	66.34		
	Yield 3	1.1977		
Stage IV	Constant	170.72	0.3199	461.9
	PC1	- 86.127		
	PC2	41.279		
	PC3	112.50		
	Yield 4	0.9406		
Stage V	Constant	43.784	0.3255	469.5
	PC1	- 7.6113		
	PC2	30.779		
	PC3	38.163		
	PC4	- 17.519		
	Yield 5	0.9854		

Table 5.15 Coefficients of Crop yield prediction model

(Viruppu crop)

σ = 469.5

Years	Observed	Estsimated	Deviation	Percentage deviation over actual
1961	3505.00	2741.77	- .22	-21.8
1962	3568.00	2805.09	- .21	-21.4
1963	3153.00	2849.18	- .10	- 9.6
1964	3477.00	2891.64	- .17	-16.8
1965	3950.00	2994.28	- .24	-24.2
1966	3314.00	2929.03	- .12	-11.6
1967	2543.00	2771.22	.09	9.0
1968	3193.00	2903.62	- .09	- 9.1
1969	3166.00	2903.62	- .08	- 8.3
1970	2611.00	2808.50	.08	7.6
1971	2848.00	2842.66	.00	- 0.2
1972	2814.00	3045.29	.08	8.2
1973	2868.00	3070.75	.07	7.1
1974	2814.00	2576.38	- .08	- 8.4
1975	3186.00	2676.61	- .16	-16.0
1976	2692.00	2863.56	.06	6.4
1977	3017.00	2961.37	- .02	- 1.8
1978	2854.00	2933.52	.03	2.8
1979	2083.00	2802.21	.35	34.5
1980	2097.00	2947.03	.41	40.5
1981	2461.00	2701.30	.10	9.8
1982	3220.00	2860.33	- .11	-11.2
1983	2173.00	2754.45	.27	26.8
1984	2802.00	3011.19	.07	7.5
1985	3134.00	3031.95	- .03	- 3.3
1986	3382.00	2901.49	- .14	-14.2
1987	2923.00	3040.68	.04	4.0
1988	1799.00	2695.02	.50	49.8
1989	1810.00	2844.39	.57	57.1
1990	2765.00	3064.01	.11	10.8

Table 5.16 Comparison between actual and estimated Viruppu crop yield

The R square value obtained is 0.3255 ie. 32.55% of the variance of the Viruppu crop yield can be explained by the Vth stage weather parameters and predicted yield after the fifth stage (YIELD 5)

From Table 5.15 it is seen that with each advancing stage the predicted yield is improving: R^2 value is increasing and standard deviation reducing. However, observed and estimated viruppu crop yield were not in good agreement in a majority of the cases (Table 5.16) Out of 30 years of yield prediction, the percentage deviation in the yield was above 15% in 12 years. Moreover, the percentage deviation was found to be high in the later years of study period, which may be due to sensitivity of the crop to cultural practices, pests and diseases etc. However, the deviation of yield was within permissible limits of one standard deviation in most of the cases. Fig 5.2 gives the fit between the observed and estimated values of viruppu crop yield.

(b) Mundakkan crop

(i)Results of correlation studies

The results of correlation analysis between Mundakkan crop yield and weather parameters in the different stages of crop development is given in Table.5.17 From the table it is observed that both air temperature and soil temperature are important for rice. Soil temperature is influential during all the stages except panicle initiation, whereas air temperature (maximum and minimum temperature) is influential during active tillering phase of the crop period. During the nursery period of the crop, reduction in solar radiation hours and soil temperature favour a better yields. This may be attributed to the fact that lower

Coefficients

Variables	Stage I	Stage II	Stage III	Stage IV	Stage V
Rainfall (RF)	0.0471	0.0275	0.1062	-0.3353*	0.3817
Morning Relative Humidity(RHI)	0.0657	0.0669	0.1308	-0.1215	0.0055
Evening Relative Humidity (RHII)	0.3835*	0.2078	0.1804	-0.2893	0.0436
Solar radiation hour (SRH)	-0.3732*	0.0063	-0.1354	0.4866*	-0.0444
Soil temperature at 5cm(STI)	-0.4799*	-0.2976	-0.4785*	0.1944	-0.3817*
Soil temperature at 15cm (ST II)	-0.5345	-0.3449*	-0.5405*	0.0598	-0.3053
Maximum temp-erature (TMAX)	-0.2618	-0.0450	-0.3346	0.2046	-0.1826
Minimum temp-erature (TMIN)	-0.2206	-0.2322	0.4058*	-0.3085	-0.0742

* Significant at 95% level

Table 5.17 Results of Correlation analysis between weather parameters and yield - Mundakan Crop temperature during nursery period results in increased plant heights. The table ascertains the results of studies carried out on rainfall variability and yield. Significant correlation between rainfall and yield is seen only in the panicle initiation and flowering stages. When relation between solar radiation hours and crop yield were looked into it is seen that a high value of radiation hours during panicle initiation stage favours high yield.

(ii) Development of crop-weather model- Mundakan crop

Employing the rainfall amount during the two weeks preceding sowing the final yield (YIELD 1) is predicted. From

YIELD 1 = 3155.1 + 1.31 * SRF

From Table 5.22 it is clear that only 6.32% of the variance of Mundakan crop yield can be attributed to sowing rains.

Prediction after Ist stage

All the eight variables, rainfall (RF) maximum temperature (TMAX), minimum temperature (TMIN), soil temperature at 5cm (ST I) soil temperature at 15cm (ST II), morning relative humidity (RHI) evening relative humidity (RHII) and solar radiation hours (SRH) of the Ist stage are subjected to Principal Component Analysis and components exhibiting eigen value more than 1.00 are selected. Application of PCA reduces the number of variables from eight to two (Table 5.18) Employing the eigen vectors in table the two PC scores are calculated. The PC scores thus obtained and predicted yield of the previous stage YIELD 1, form the input

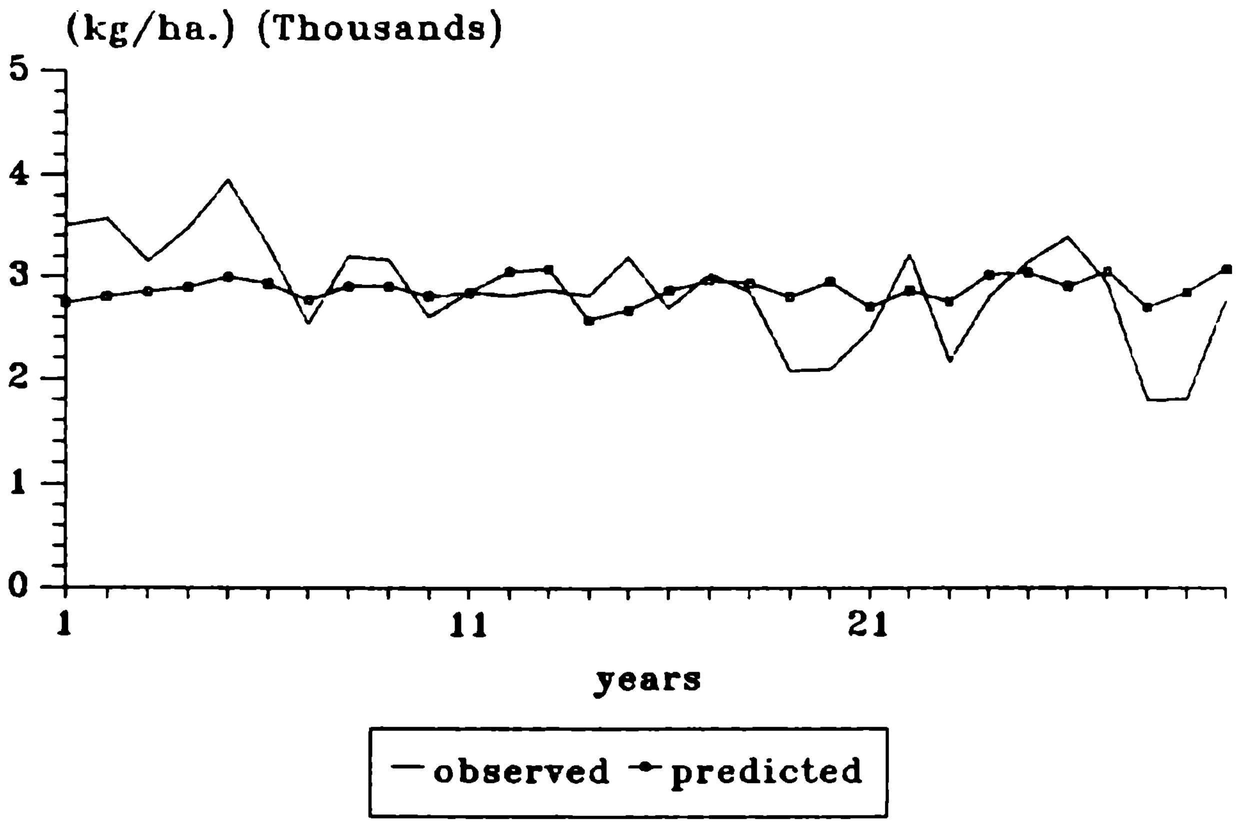


Fig 5.2 Observed and predicted Viruppu crop yield

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.931	49.1	49.1
2	1.538	19.2	68.4
3	0.955	11.9	80.3
4	6.162E-01	7.7	88.0
5	3.647E-01	4.6	92.6
6	3.364E-01	4.2	96.8
7	2.026E-01	2.5	99.3
8	5.610E-02	0.7	100.0

VECTORS

FACTOR	1	2
TMAX	-0.4293	0.2516
TMIN	-0.0204	0.6099
STI	-0.4493	0.0503
STII	-0.4551	0.0833
RHI	0.0437	-0.4492
RHII	0.4470	-0.1120
SRH	-0.3744	-0.3556
	0.2538	0.4631

Table 5.18 Eigen values and eigen vectors of Stage I weather parameters - Mundakan crop

variables in the linear multiple regression equation to predict yield of Mundakan crop 16 weeks before harvest.

The linear multiple regression model developed to predict the paddy yield of Mundakan season, 16 weeks before harvest (YIELD 2) is

$$\text{YIELD 2} = -2023.7 + (67.156)\,\text{PC1} + (-38.055)\,\text{PC2} + (0.2757)\,\text{YIELD 1}$$

It is clear from Table 5.22 which projects the results that, 23.1% of the variance of Mundakan yield is explained by first stage weather parameters and YIELD 1.

Prediction after IInd stage

When all the eight variables of IInd stage are subjected to PCA, and components exhibiting eigen value more than 1.00 are selected, the number of variables is reduced to five (Table 5.19) Employing the eigen vectors in table the PC scores thus obtained and the predicted yield of previous stage (YIELD 2) form the input variables for the multiple regression model at the IInd stage.

The linear multiple regression model developed to predict the Mundakan yield 14weeks before harvest is

$$\text{YIELD 3} = 864.48 + (28.445) * \text{PC1} + (45.597) * \text{PC2} + (0.89167)\,\text{YIELD2}$$

The R square value is 0.2597 ie. 25.97% of the variance of Mundakan crop yield can be explained by the eight weather parameters of IInd stage selected for analysis and the yield predicted at the end of Stage I

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	4.482	56.0	56.0
2	1.287	16.1	72.1
3	8.731E-01	10.9	83.0
4	5.124E-01	6.4	89.4
5	4.052E-01	5.1	94.5
6	2.610E-01	3.3	97.7
7	1.365E-01	1.7	99.5
8	4.360E-02	0.5	100.0

VECTORS

FACTOR	1	2
TMAX	-0.3898	-0.2167
TMIN	0.0440	-0.8249
STI	-0.3883	-0.2881
STII	-0.4200	0.0072
RHI	0.2402	0.2730
RHII	0.4471	-0.1674
SRH	-0.3742	0.1715
EVP	0.3483	-0.2398

Table 5.19 Eigen values and eigen vectors of Stage II weather parameters - Mundakan crop

Prediction after IIIrd stage

Once again ,the application of PCA to all the eight weather parameters of the IIIrd stage, and selection of components which exhibit eigen value more than 1.00 has been carried out. The number of variables reduces to two in this case (Table 5.20) Employing the eigen vectors given in the table, the two PC scores and the yield obtained from the previous stage model (YIELD 3), form the independent variables in the linear regression model to predict the Mundakan crop yield 10 weeks before harvest (YIELD 4)

The regression model developed to predict YIELD 4 is

YIELD 4 = -735.1 +(17.045) * PC1 +(17.653)*PC2 + (1.2487)*YIELD 3

The R squared value obtained in this case is 0.4114, which shows that 41.14% of the variance of Mundakan crop yield 10weeks before harvest can be explained by the eight weather parameters of IIIrd stage and the yield predicted at the end of IInd stage.

Prediction after IVth stage

Application of PCA once more to all the eight weather parameters of stage IV, reduces the number of variables to three (Table 5.21) Employing the eigen vectors given in the table the three PC scores are calculated. The three PC scores and the yield obtained from the previous stage model (YIELD 4), form the independant variables in the linear regression model to predict the Mundakan crop yield 7 weeks before harvest (YIELD 5)

The regression model to predict YIELD 5 is

YIELD 5 = 419.2 + (-4.8463) * PC1 + (8.3669) * PC2 + (17.529) * PC3 + (0.8862) * YIELD 4

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	4.423	55.3	55.3
2	1.308	16.4	71.6
3	0.989	12.4	84.0
4	4.977E-01	6.2	90.2
5	3.862E-01	4.8	95.0
6	2.091E-01	2.6	97.7
7	1.325E-01	1.7	99.3
8	5.484E-02	0.7	100.0

VECTORS

FACTOR	1	2
TMAX	-0.3965	-0.2594
TMIN	0.0004	-0.7629
STI	-0.3696	-0.2872
STII	-0.3749	-0.1301
RHI	0.3414	0.1169
RHII	0.4368	-0.1539
SRH	-0.3498	0.3800
RF	0.3687	-0.2636

Table 5.20 Eigen values and eigen vectors of Stage III weather parameters - Mundakan crop

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.980	49.8	49.8
2	1.655	20.7	70.4
3	1.013	12.7	83.1
4	4.408E-01	5.5	88.6
5	3.521E-01	4.4	93.0
6	3.293E-01	4.1	97.1
7	1.615E-01	2.0	99.2
8	6.767E-02	0.8	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.3062	-0.4680	0.1439
TMIN	0.1417	-0.4742	-0.6832
STI	-0.3966	-0.3873	-0.0597
STII	-0.4066	-0.2681	-0.0108
RHI	0.2841	-0.4002	0.5782
RHII	0.3863	-0.3978	0.2173
SRH	-0.3933	0.1010	0.3567
RF	0.4231	-0.0748	0.0116

Table 5.21 Eigen values and eigen vectors of Stage IV weather parameters - Mundakan crop

It is clear from the Table 5.22 that now 43.8% of variance of Mundakan crop yield is explained by IVth stage weather parameters and yield predicted (YIELD 4) at the end of Stage III.

From the Table 5.22 it is evident that with each advancing stage the R square value is improving. The observed and predicted yield was in good agreement in a majority of the cases (Table 5.23) unlike in the case of the viruppu crop. Out of 27 years of yield prediction, the percentage deviation in the yield was above 15% in only 8 of the cases. Moreover, the percentage deviation was found to be low in the later years of study period. The deviation of yield was within permissible limits as the deviations were always within one standard deviation in most of the cases.

The advantages of the physico- statistical model developed here over simple empirical statistical models is that the final crop yield can be predicted at any stage of the crop growth period employing the predicted yield at the end of the previous stage and the antecedent weather parameters. In the present model, the multi collinearity between the independent variables is eliminated and the dimensionality of the input variables is reduced. Fig. 5.3 gives the fit between the observed and estimated yields by the model.

These two case studies of the coconut and rice crops confirm that the crop yields are dependent to a large extent on weather parameters. The statistical model employed in the case of coconut and physico-statistical model employed in the case of rice can be applied for estimating yield with a fairly high

STAGE	PREDICTOR VARIABLES	COEFFICIENTS	R SQUARE	STANDARD DEVIATION
Sowing rains	Constant	3155.1	0.0632	568.1
	RF	1.31		
	Constant	2023.7		
	PC1	67.156		
Stage I	PC2	-38.055	0.2310	536.6
	Yield 1	0.2757		
	Constant	864.48		
	PC1	28.445		
Stage II	PC2	45.597	0.2597	526.5
	Yield 2	0.89167		
	Constant	- 735.10		
	PC1	17.045		
Stage III	PC2	17.653	0.4114	469.4
	Yield 3	1.2487		
	Constant	419.22		
	PC1	- 4.8463		
Stage IV	PC2	8.3669	0.4380	469.0
	PC3	17.529		
	Yield 4	0.88616		

Table 5.22 Coefficients of Crop yield prediction model

(Mundakan crop)

σ = 469

Years	Observed	Estsimated	Deviation	Percentage deviation over actual
1	2888.00	3067.86	.06	6.2
2	3790.00	3534.22	- .07	- 6.7
3	3066.00	3171.09	.03	3.4
4	5060.00	4511.87	- .11	-10.8
5	2232.00	2548.87	.14	14.2
6	3964.00	3651.91	- .08	- 7.9
7	3484.00	2687.17	- .23	-22.9
8	2624.00	3123.30	.19	19.0
9	2976.00	3082.07	.04	3.6
10	3044.00	3282.41	.08	7.8
11	2949.00	3583.18	.21	21.5
12	2706.00	2876.92	.06	6.3
13	3148.00	3164.23	.01	0.5
14	3030.00	3779.72	.25	24.7
15	3632.00	3946.57	.09	8.7
16	3869.00	3208.94	- .17	-17.1
17	3314.00	3133.65	- .05	- 5.4
18	3463.00	3612.51	.04	4.3
19	2530.00	3115.53	.23	23.1
20	3502.00	3027.01	- .14	-13.6
21	3206.00	3467.78	.08	8.2
22	3117.00	3292.71	.06	5.6
23	3981.00	3358.60	- .16	-15.6
24	3929.00	3651.97	- .07	- 7.1
25	3425.00	3578.05	.04	4.5
26	3804.00	3446.10	- .09	- 9.4
27	3295.00	3124.65	- .05	- 5.2

Table 5.23 Comparison between actual and estimated Mundakan crop yield - Mundakan crop yield

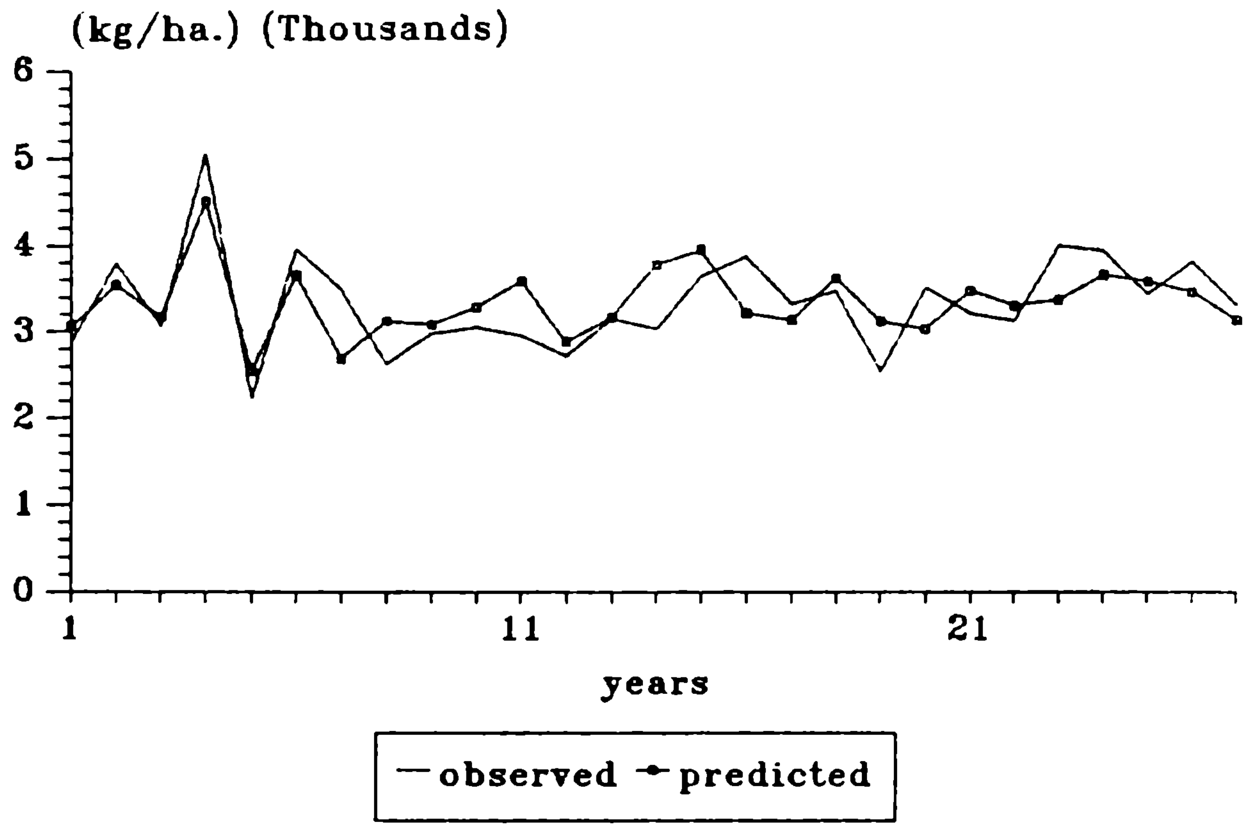


Fig 5.3 Observed and predicted Mundakan crop yield

degree of confidence. However, it should be noted that the equations developed are specific to the locations and to the concerned crops.These models can be applied at other sites and for other crops as well, if sufficiently long period data is available.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Kerala State lies in the south-west corner of the Indian peninsula between 8^{O} 18' and 12^{O} 48' north latitudes and 74^{O} 52' and 77^{O} 22' east longitudes, as a long narrow strip of land, 32 to 133 km. wide between the Western Ghats in the east and the Arabian Sea in the west with a 580 km long coastal line. The most conspicuous feature of the State is the rich diversity in the various physico-climatic features which significantly influence the climate, vegetation and the land use of the region. Even though, the State is blessed with abundant water resources, short-term variabilities in the rainfall and other weather parameters result in variations in the availability of these resources.

Furthermore, such variabilities influence the yields of many crops in the State. Under these circumstances, a detailed analysis of the variability of climatic parameters and the impacts of such variabilities is essential for agricultural planning. Therefore, these aspects have been focused upon and analyzed in the present study The thesis consist of six Chapters with a general introduction as the first one. The first two Sections of the second Chapter reviews the literature available on the various aspects covered in the present investigation. The third Section presents the methodology followed in studying droughts, climatic shifts and crop-weather relationships.

The third Chapter consists of a discussion of the important physico-climatic features and the agricultural status of the State. The location, extent, physiography, soil types, vegetation and drainage pattern over the State are discussed in the first Section, while details about the different climatological parameters are discussed in the second. The agricultural status of the State is presented in detail in the third Section. Some of the important features discussed in the Chapter are presented now.

The undulating topography of the State falls generally into three well defined natural divisions- lowlands, midlands and highlands. The high lands stretched along the east, are intersected by numerous streams and rivers - the State has a well - distributed drainage network consisting of 44 rivers.

Kerala has a unique cropping pattern. Owing to historical and climatic reasons, the State has developed commercial agriculture more than food crops. Now-a-days rubber is the most flourishing crop of the State. Though rice is the staple food of the people of the State, the high cost of the cultivation and comparatively low return on rice now-a-days has forced the State to depend upon the Central Government and neighboring States for their food needs. For a State such as Kerala, whose welfare depends very much on agriculture, a qualitative knowledge of the productivity and area under each crop is essential to pursue agroclimatic studies of the State. Physico-climatic features and agricultural status of the State is discussed in the third Chapter of the thesis.

Taking into consideration the physiography, climate, soil characteristics, sea water intrusion, irrigation facilities, land use pattern and the recommendation of the committee on Agro Climatic Regions and Cropping Patterns constituted by the Government of Kerala in 1974, the State was divided into five Agroclimatic regions such as Northern, Central, Southern, High Ranges and Problem areas. The special zone of "Problem Areas" comprises of 5 areas viz. Onattukara, Kuttanad, Pokkali, Kole and sugar cane lands spread over the six districts of Kerala viz. Alleppey, Quilon, Kottayam, Ernakulam, Trichur and Malappuram. The first four areas, in the past, witnessed luxurious paddy cultivation and coconut plantation, now is in the verge of devastation due to salt water intrusion and root wilt disease.

Copious rainfall during monsoon, a well-spread drainage pattern and temperature ranging between 22°C and 30°C, has elevated the State to a land of luxurious vegetation. The suitability of land and climate for a number of crops tempted the farmers to cultivate a host of crops in the State, and resulted in an intensive cultivation of dry land in the State. The overall intensity of cropping in Kerala is fairly high. 57.89% of land in the State is contributed for agriculture purpose, followed by forest (27.83%) Only 7 79% of the land falls under non-agricultural category.

Paddy, coconut, arecanut, tapioca, pepper and rubber are the most important crops of the State. Unfortunately, the State is short of food grains, especially rice which is the staple food of the people. In this context, distribution and productivity of cereals and millets, pulses, sugar crops, spices and condiments, fruits and vegetables are grouped under food crops and oil seeds, drugs and narcotics, plantation crops, fodder grass etc. are grouped under non-food crops. 46.09% of the total cropped area of the State is under food crops and 51.75% under non-food crops. The districts Alleppey, Trichur, Palghat Cannanore and Kasargode contribute more than 50% of their total cropped area for food crops, while Kottayam, Pathanamthitta and Calicut contributed more than 60% of their cropped area for non-food crops.

Even though a wide variety of crops are cultivated in the State, rice, tapioca, coconut, pepper and rubber are considered as the principal crops. About 5.37 lakh ha. of the State is under paddy cultivation with a productivity of 2.02 kg/ha. While Palghat ranks first, considering the area under under the crop, productivity-wise Pathanamthitta is the first with 2.62 kg/ha. Coming to the area and productivity of tapioca in the State, 1.35 lakh ha. land is under tapioca cultivation with productivity 19.5 kg/ha. Eventhough, Trivandrum ranks first, considering the area under the crop, Kottayam, Idukki and Wynad contribute the most in the case of productivity (more than 25 kg/ha.)

India with 1.1 million hectares of land under coconut plantation accounts nearly for 1/8th of area under coconut in the world. 8.77 lakh ha. of land in the State is under coconut cultivation with a productivity of 5843 nuts/ha. The three districts Calicut,Trichur and Ernakulam having a long coast line rank high in the case of coconut productivity. About 1.8 lakh ha. of the State is under pepper cultivation. Looking into productivity of the crop, the districts Idukki,Quilon and Pathanamthitta contribute the most. Rubber is the one crop which has registered an increase in area of about 50.7%. More than 50% of the land in the districts Kottayam, Ernakulam and Pathanamthitta is under rubber plantation. About 25% of the State area is in Kottayam district itself.

Every year the fate of agriculture in the State oscillates with the vagaries of south west monsoon, pre-monsoon and post-monsoon rainfall. As drought is a consequence of aberration in the distribution of rainfall, a detailed knowledge of the distribution of rainfall and nature of variability is a pre-requisite for drought studies of a region. The next Chapter focuses on the variability of rainfall over the region and the consequent climatic shifts. It also projects the drought climatology of the State employing the water balance procedures outlined by Thorntwaite and Mather(1955) and the drought criteria enunciated by Ram Mohan (1984)

Results of previous studies pertaining to spatial and temporal distribution of annual as well as seasonal rainfall over the State is presented in the first Section of Chapter Four. The second Section deals with appraisal of agroclimatic droughts over the State. Analysis of occurrence of different categories of droughts at selected stations over the State during the study period reveals that, the number of drought years of various categories vary widely from station to station. Alleppey experienced the least number of droughts and Kasargode the most. Vythiri was free from disastrous droughts during the entire study period. Konni experienced the largest number of moderate droughts (13), followed by Sherthala and Cranganore (12) Kasargode experienced the most number of large droughts (12)

Trivandrum, Cochin and Trichur experienced 10 large droughts each. Alathur and Calicut experienced 10 severe droughts during the study period. The stations which experienced largest number of disastrous drought years (3) are Thiruvalla, Sherthala, Marayur, Cranganore, Kuttiyadi and Irikkur. From the study it is evident that the frequency of occurrence of severe and disastrous droughts is more in the sixth and seventh decade and in the first half of the eight decade. In the years 1982 and 1983, most of the stations studied, experienced either a severe or disastrous drought, stations especially in south Kerala experienced disastrous droughts. Significantly, the year 1984 was in strong contrast to the previous year, with most of the stations being drought free.

Since drought is a large scale rather than a local phenomenon, there is a distinct possibility of its simultaneous incidence over neighbouring and adjoining areas. When probabilities of spatial coherence of moderate droughts were looked into, it was found that when Kasargode, Karikode and Thiruvalla experienced moderate drought, the probabilities of drought occurrence in the other areas of the State are comparatively high. When Kasargode is the key station, thirteen other stations show moderate coherence. In the case of Karikode, ten other stations and in the case of Alleppey twelve stations show moderate coherence. When Manantoddy, Calicut, Mannarghat, Kottayam, Konni and Quilon experience moderate droughts, the probabilities of drought occurrence in the other areas of the State are generally low. Out of the nineteen stations only four stations show high coherence in the occurrence of moderate drought, simultaneous with other stations.

Coming to spatial coherence of large droughts when Mannarghat, Trichur and Kayamkulam are considered as the key station, moderate coherence is observed at 14,12 and 12 stations respectively, while in the case of Kottayam, only Cranganore and Cochin show moderate coherence. Seven stations in the State show high coherence with Quilon. No station showed high coherence with occurrence of large droughts in Cochin, Karikode, Kayamkulam or Trivandrum.

When the probabilities of spatial coherence of severe droughts were considered, the following results were obtained. Trichur exhibited moderate spatial coherence with 14 stations, the highest for any key station. Kasargode and Cochin had moderate coherence with 12 other stations. Trivandrum and Sherthala experienced high spatial coherence with 10 other stations. In general, the spatial coherence of severe droughts is higher than the coherence of large and moderate droughts.

Disastrous droughts, though the least frequent, exhibit the highest spatial coherence among all the categories of droughts. From the study it is seen that when Kayamkulam was the key station 12 stations showed 100% spatial coherence of disastrous droughts. When Sherthala was the key station 18 auxiliary stations exhibited spatial coherence of disastrous drought.

Comparing the spatial coherence of all categories of droughts, it is seen that moderate droughts have the least coherence, though they are the most frequent.

In order to study climatic shifts, the inter-annual variations of moisture index (I_m) were plotted. Kasargode had a total number of 21 shifts into the other climatic types. Humid stations Kottayam, Calicut, Cochin and Alleppey had 47,43 and 41 shifts respectively. Trivandrum, the only moist subhumid station studied, had a total of 42 shifts.

In order to analyse the impacts of these climatic shifts on the moisture regimes of different stations in the State a critical examination of the elements of water balance in such years was carried out. As is to be expected during dry years at most locations, water deficits increased and water surpluses fell below normal, while in the case of wet years surpluses increased and deficits fell below normal. However, such simple relationships are not always true. In some years water surpluses increased along with increased water deficits. Such a behaviour of the moisture regime is because water surpluses and water deficits are determined by the temporal distribution of rainfall and not by its magnitude.

The fifth Chapter deals with the impact of climatic variability on agricultural yields. Since correlation studies between yields of all the crops in the State and the derived parameter of Index of Moisture Adequacy have been inconclusive, case studies were taken up for coconut and rice crops. Data from experiments conducted at Regional Agricultural Research Station (RARS), Pilicode, was used for studying the crop-weather relationships of coconut, while data from RARS, Pattambi was used for studying the rice crop. After establishing correlations of different parameters with the observed yields, Principal Component Analysis (PCA) was carried out to eliminate inter-correlation amongst them. Meteorological parameters were thus selected after PCA to form a multiple regression statistical model in the case of coconut. In the case of rice, a physico-statistical model was developed using similar methodology. The salient features of the study and the models are presented.

For the study of crop-weather relationships of coconut, the time interval for nut development from primordium of the inflorescence to harvest was divided into four different periods.

The results of correlations worked out between each month's coconut production and the weather parameters influencing the yield 44 months prior to the harvest is as follows. During the first stage, only rainfall, minimum temperature and relative humidity were significantly correlated- the first two negatively and the latter one positively. During the second stage, the weather parameters positively correlated were moisture deficit, maximum temperature and soil temperature while actual evaporation, Index of moisture adequacy and morning relative humidity were negatively correlated. In the third stage, the parameters positively correlated were actual evapotranspiration, Index of moisture adequacy and minimum temperature, while moisture deficit was negatively correlated.

The method of Principal Component Regression (PCR) was employed for the development of the crop-weather model to predict monthly coconut production using the weather parameters of each stage. Only the significantly correlated weather parameters were considered for this.

Application of Principal Component Analysis reduced the number of variables from three to one in the case of Stage I, ten to four in the case of Stage II and fourteen to six in the case of Stage III prediction. Model equations were developed to predict yields at the end of each stage.

The regression model to predict the monthly coconut production at the end of last stage, 11 months prior to harvest (PROD 3) is

$$PROD\ 3 = 13921 + (4608.6 * PC1) + (-5996.8 * PC3) + (-2347.1 * PC3) + (-6776.0 * PC4) + (14244 * PC5) + (-5930.8 * PC6)$$

The R squared obtained was 0.6314 with a standard deviation of 3792 nuts.

The observed and estimated monthly nut production was in good agreement in a majority of the cases. Out of 52 sets of monthly production values, only 6 cases showed more than 50% deviation. However, the percentage deviation in nut production was within permissible limits as the deviation stayed within one standard deviation in most of the cases.

For the study of Crop-weather relationship of rice, the crop growth period from seedling stage to harvest was divided into 6 stages. The average of the weather parameters constitute the independent variables that are to be related with the dependent variable, yield.

In the first instance, correlations were worked out between the rice yield and the eight meteorological parameters pertaining to each stage of the crop growth. In the case of the Viruppu crop, in all the stages excepting the last (ripening phase), soil temperature shows significant negative correlation with the yield. During the nursery period of the crop, higher relative humidity favours a better yield.

Employing the method of Principal Component Regression, the PC scores were computed for each stage. These PC scores form the independent variables in the multiple regression model. The crop yield was predicted at the end of each stage. Further, the crop yield of each stage was included as one of the independent variables for the computation of yield of the following stage. The physico-statistical approach to crop-weather modelling is similar to the model developed by Robertson (1974)

The multiple regression model for the prediction of Viruppu crop yield 6 weeks before harvest (YIELD 6) is

$$YIELD6 = 43.784 + (-7.6113) * PC1 + (30.779) * PC2 + (38.163) PC3 + (-17.519) * PC4 + (0.9854) * YIELD5$$

where PC1,PC2,PC3,PC4 are the PC scores of the fifth stage and YIELD5 is the yield predicted after Stage IV.

The R square value obtained was 0.3255 It was seen that with each advancing stage the predicted yield was improving. Out of 30 years of yield prediction, the percentage deviation in the yield was above 15% in 12 years. However, the deviation of yield was within permissible limits of one standard deviation in most of the cases.

According to correlation studies of Mundakan crop yield and weather parmameters during each stage, both air temperature and soil temperature are important. Soil temperature is influential during all the stages except panicle initiation, whereas air temperature (maximum and minimum temperature) is influential during active tillering phase of the crop period. During the nursery period of the crop, solar radiation hours and soil temperature was negatively correlated with yield. Significant correlation between rainfall and yield is seen only in the panicle initiation and flowering stages. Multiple regression models were developed to predict yields at the end of each stage.

The model developed to predict Mundakan crop yield at the end of the last stage, 7 weeks before harvest (YIELD 5) is

$$YIELD5 = 419.2 + (-4.8463) * PC1 + (8.3669) * PC2 + (17.529) * PC3 + (0.8862) * YIELD4.$$

where PC1, PC2 and PC3 are the PC scores of the fourth stage.

The R square obtained was 0.438, ie. 43.8% of variance of Mundakan crop yield is explained by IVth stage weather parameters and yield predicted (YIELD4) at the end of Stage III.

With each advancing stage, the R square value improved. The observed and predicted yield were in good agreement in a majority of the cases. Moreover, the percentage deviation was found to be low in the later years of study period. The deviation of yield was within permissible limits as the deviations were always within one standard deviation in most of the cases.

The advantages of the physico-statistical model developed here over simple empirical statistical models is that the final crop yield can be predicted at any stage of the crop growth period employing the predicted yield at the end of the previous stage and the antecedent weather parameters.

The results of the study revealed that Kerala State is well endowed with more than sufficient natural resources-physiography, vegetation, soil types, and river systems. The State also experiences heavy rainfall and large water surpluses during the southwest monsoon months every year. The annual average rainfall is about three times the national average. However, water deficits also do occur in many locations in the drier months of the year. The average annual water surplus is about 6 times the deficit. However 80% of the water surplus occur in the monsoon months and during December to February there is hardly any surplus anywhere in the State. The coexistence of water surplus and water deficit at different times of the year in the same region is a significant aspect of the agroclimatology of the State. During many years when the southwest monsoon rainfall is above normal, there is a sharp increase in water surpluses.

By a judicious conservation and management of the surplus water, the effects of water deficit can be mitigated. The large quantities of surplus water that now freely flow into the Arabian sea can be harnessed to a large extent by the construction of dams and reservoirs at proper locations. Since construction of large projects entail heavy capital outlay and large gestation periods and can cause environmental degradation, it is advisable to plan mini hydel projects at suitable locations.

By proper management and optimum utilization of the available water resources-both surface and subsurface- it should be possible to convert large areas of cultivable waste land into productive agricultural land, as also lands presently under non-agricultural use into agricultural use. By this process, agricultural development can be accelerated by increasing the area of cropping and the intensity of cropping and therefore the net sown area These steps would also mitigate the hazardous impact of water deficit and drought by making available water for supplemental irrigation in the required quantities at required locations.

As has been well documented, climatic variability is an integral part of the climate of any area. The short term variabilities are generally larger than the long term changes. It is these fluctuations that cause droughts in some years and floods in others. Temporary climatic shifts are also a result of such inter-annual and inter-seasonal variations in weather parameters, particularly rainfall.

Inter-annual climatic variability has distinct effects on agricultural productivity and yields mainly due to variations in rainfall and hence available soil moisture. In the present study, the influence of various weather parameters over two important crops over the State has been studied through the development of appropriate models.

If such models have to be used on a real time basis for forecasting yields of any crop a proper data base of meteorological and agricultural parameters has to be established. A better network of agrometeorological observatories has to be designed so as to make such exercises possible in more areas. One of the draw backs of such models is that they are generally location specific, crop specific and some times even species specific. Yet another general problem encountered in such studies is that meteorological data are from specific sites where as agricultural data are from large areas.

In conclusion, it may be said that the development of the State is linked to the harnessing of the large water surpluses that occur during the southwest monsoon season. Optimum utilization of the available resources throughout the year for agricultural purposes would have to be planned for improving the agricultural productivity of the various food and non-food crops. Only then can the agricultural development of Kerala be ensured paving the way for the overall development of the State into "God's own Country"

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