HYDROMETEOROLOGICAL STUDIES OF KERALA STATE IN RELATION TO THE WESTERN GHATS

THESIS SUBMITTED TO THE
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY
IN
METEOROLOGY

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SEPTEMBER 1987

DECLARATION

I hereby declare that this thesis entitled "Hydrometeorological Studies of Kerala State in relation to the Western Ghats" has not previously formed the basis of the award of any degree, diploma or associateship in any University.

Cochin - 682 016,
1st September, 1987.

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C E R T I F I C A T E

This is to certify that this thesis is an authentic **record** of research work carried out by Shri K. Shadananan Nair, M.Sc. under my supervision and guidance in the School of Marine Sciences for the Ph.D. Degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any University.

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PREFACE AND ACKNOWLEDGEMENT

One of the primary constraints to economic and social development of a region is the difficulty in getting reliable water supplies. The uncommitted supplies of water diminish when the demands for them increases. This necessitates the broadening of the objectives of water resources planning and the application of hydrometeorological techniques to make an intelligent and comprehensive evaluation of the availability of water.

The State of Kerala which is blessed with copious rainfall and sufficient water resources does experience periods of water deficiencies and even droughts. Shortage of water for hydel power generation, agriculture and for the use of local population has now become a serious threat to the development of the State. In the present thesis, detailed analysis of the rainfall and water balance of the State has been carried out in an attempt to make a hydrometeorological appraisal of the water potentialities of the region. In addition, detailed studies of droughts and climatic shifts have also been made. As the meteorology of the State is greatly influenced by the orography of the Western Ghats, the hydroclimatology of the entire Ghats region has also been studied, to project its contribution to the resources potential of the State.

I wish to express my profound and heartfelt indebtedness and gratitude to Dr.H.S. Ram Mohan, Reader, Physical Oceanography and Meteorology Division, School of Marine Sciences, Cochin University of Science and Technology, under whose guidance this investigation was carried out. Without his unfailing encouragement and suggestions, this investigation would not have taken the present form.

It is appropriate that I should acknowledge the authorities of the Cochin University of Science and Technology for providing me with the necessary facilities and a fellowship under the UGC sponsored Department Research Support Scheme. I am very thankful to Prof.Y.L. Dora, Director, School of Marine Sciences and Prof.P.G. Kurup, Head, Physical Oceanography and Meteorology Division, School of Marine Sciences for their encouragement and support.

I wish to express my sincere gratitude to Dr.M.M. Ali, Scientist, Space Applications Centre, Ahmedabad for the valuable help and suggestions he has made.

I am grateful to the India Meteorological Department, Poona & Trivandrum and the Directorate of Economics & Statistics, Trivandrum, for the supply of necessary data and relevant information.

The gratitude and indebtedness that are due to my good friends are great, for their co-operation and help given in the computations and calculations.

Thanks are also due to Mr.Mohan who typed the Thesis and Mr.Madhu who drew most of the figures.

CHAPTER I

GENERAL INTRODUCTION

The existence of all living beings on the earth's surface is primarily dependent on water and air. These two elements are closely interlinked, as all the water supplies over land originate from atmospheric moisture. The distribution of water over the land is of diverse nature - some regions receive abundant precipitation while some others are devoid of water. Of the total amount of water on the earth, 97% lies in oceans and a major portion of the remaining 3% lies in the form of permanent ice fields or below the land surface. Only a small fraction of this 3% of water is available for the direct utilization of mankind and all land based animals. It is here that the applications of Hydrometeorology, the study of the exchange of water between the atmosphere and the land surfaces, become important in the efficient use and proper management of the available water resources.

India is an agricultural country and its food production, in the absence of sufficient irrigation facilities over large areas, is vastly dependent on the mercy of the monsoons. Compounded to this, is the fact that in the regions of high rainfall occurrence like the Western Ghats, the present utilization of water potential is very small with the greater part wastefully flowing into the oceans before it can be gainfully utilized for the water requirements of those regions. In order to derive optimum benefit from the water resources, a realistic assessment of the water reserves in the different phases of the hydrologic cycle in comparison to the present and future demands of the different sectors of consumption is required.

A part of the total amount of rainfall falling on continental areas is returned to the atmosphere due to evapotranspiration, a fraction of the remaining part is retained in the soil depending on the edaphic factors of the place and any surplus may either flow off over the surface or through the subsurface and underground regions. This runoff water finally appears as stream flow and is the water resource of any region. Factors affecting all these processes are to be carefully studied before planning any hydrological project.

The water balance model of Thornthwaite (1948) is of great practical use in such regional studies of the climatic characteristics of a region. Water balance studies reveal that hydroclimatic characteristics of a region cannot be assessed from precipitation alone, but from its quantitative comparison with evaporation and transpiration. Though evaporation is a factor of great importance in water resources planning, its direct measurement is difficult which made several researchers to attempt at deriving empirical relations for its evaluation. In water balance studies, the total loss of water - evapotranspiration - is of great importance because of its ecological significance. Thornthwaite (1943) defined the term "Potential Evapotranspiration" (P.E.) which is the maximum amount of water which would be lost to the atmosphere from a surface completely covered with vegetation if there is sufficient water in the soil at all times for full use and he designed an "Evapotranspirometer" for its measurements. Later, he also developed a semiempirical formula for its evaluation from mean monthly temperature.

Since P.E. represents the entire water need of a region, comparison of the march of P.E. and precipitation provides information about the water balance of a region and thus, the wetness or dryness of its climate. The book-keeping procedure of Thornthwaite and Mather (1955) which is the modified version of the earlier one (Thornthwaite, 1948) gives a rational assessment of the water budget parameters - Actual Evapotranspiration, Water Surplus, Water Deficit and Soil Moisture conditions. Studies in hydrology and climatology using water balance concepts were first introduced to the Indian region by Subrahmanyam (1956). Since then, several researchers have made use of these concepts in studying various aspects of applied climatology in different regions.

Precipitation is the primary element in the water balance procedure and is the most important element to be analysed in any hydrometeorological study as it is variations in this that lead to all water surpluses and deficiencies. Precipitation varies widely, both annually and seasonally and is responsible for the occurrence of floods or droughts. India has a good density of rain-recording stations and a fairly long period of rainfall data.

The runoff from a region is estimated as a percentage of the total water surplus. The runoff at any place is determined by the surface and underground characteristics such as slope, soil type and vegetation. In the absence of reliable information about these factors, Thornthwaite (1948) assumed that only 50% of the water surplus runs off in any month and the remaining is detained in the ground for further contribution to runoff and detention again giving equal weightage to surface and underground flows. In this investigation, the monthly water surpluses have been converted into runoff values using a runoff coefficient based on the above three factors. In addition, the water surpluses have been further segregated into surface flow and underground flow, using two other coefficients. This enables the estimation of the surface and underground flows suitable for the conjunctive utilization of the surface and groundwater of any region. Using this technique, areas of exploitable groundwater and areas where surface waters can be stored or articicially recharged to groundwater are suggested.

The State of Kerala receives abundant rainfall from both monsoons and has enough utilizable water potential. The present utilization is very small, only about 10% of the net area sown is irrigated. There exist arable lands and large undercultivated areas only because of the lack of irrigation facilities. For the development of hydel power, industry or any other activity which may depend on water, a proper assessment and management of the available water resources is of utmost importance as the need for water is always increasing with the increase of population.

In spite of the heavy rainfall and large water surpluses, the State of Kerala in recent years has experienced large water deficiencies and conditions of droughts. This has led to the present study of the rainfall characteristics, moisture conditions and drought occurrences which seriously influence the economy of the State. As most of the rainfall occurrences are due to the orography of the Western Ghats, emphasis is given to the study of the hydrometeorology of the Ghats region.

The present investigation is an attempt to analyse the meteorological and hydrological conditions of Kerala State for suggesting measures for the overall development of the State. In spite of some drawbacks due to non-availability of reliable and complete data sets, it is hoped that the present study would be a contribution towards planned growth and development of the State of Kerala.

CHAPTER II

WATER BALANCE APPROACH TO HYDROMETEOROLOGY

SECTION I. STUDIES IN HYDROMETEOROLOGY

Hydrometeorology is the study of the occurrence, movement and changes in the state of water in the atmosphere. In a restricted sense, it is the study of the exchange of water between the atmosphere and continental surfaces which includes the processes of precipitation and direct condensation, and of evaporation and transpiration from natural surfaces.

ATMOSPHERIC WATER CYCLE

Water occurs in the atmosphere primarily in the vapour form. The average amount of vapour present in the atmosphere decreases with increasing elevation and latitude and varies strongly with season and type of surface. Precipitable water, the mass of vapour per unit area contained in a column of air extending from the surface to the outer limit of the atmosphere, varies from zero in continental arctic air to about 6 gm/cm^2 in humid, tropical air. Its average value over the Northern Hemisphere varies from around 2 gm/cm^2 in January/February to around 3.7 gm/cm^2 in July. Nearly 50% of this vapour is contained within the first 1.5 km. of the atmosphere and 80% within 3 km. (Ency. Sci. & Tech., Vol. 6).

The rate of exchange of water between the atmosphere and the continents and the oceans is significant. The average water molecule remains in the atmosphere only about 10 days, but is precipitated hundreds of kilometers away from the place at which it entered the atmosphere, because of the extreme mobility of the atmosphere. Evaporation from the ocean surface and evaporation and transpiration from land areas are the sources of water vapour for the atmosphere. Water vapour is removed from the atmosphere by condensation and subsequent precipitation in different forms, including rain, snow, sleet and dew.

A major feature of the atmospheric water cycle is the meridional net flux of water vapour (Table 2.1). The average precipitation exceeds evaporation in a narrow band extending from 10^{o}S to 15^{o}N and in the temperate and polar regions of the two hemispheres, poleward of about 40^{o} Lat. and evaporation exceeds the average precipitation in the subtropical regions. To balance this, the general circulation of the atmosphere carries water vapour equatorward in the tropics and poleward in the temperate and polar regions. For the earth as a whole, the average amount of evaporation must balance the precipitation.

TABLE 2.1

Meridional Flux of Water Vapour in the Atmosphere

(Source : Ency. Sci. and Tech., Vol. 6)

Latitude	Flux (10^{10} gm/sec.) of water vapour
90°N	0
70°N	4
40°N	71
10°N	-61
Equator	45
10°S	71
40°S	-75
70°S	1
90°S	0

At any given time, the oceans contain about 97% of the total water occurring over the earth. Rest of it is fresh water, of which about 2% occurs in snow-fields and glaciers and nearly 1% in fresh-water bodies and as groundwater (Ryabchikov, 1975). The atmosphere contains only a very small quantity which is equivalent to a layer of water 2.5 cms. deep over the entire globe.

The Earth's interior contains 20,000 million cu.km. of chemically combined water of which 340 million cu.km. is in the lithosphere and the oceans contain 1370 million cu.km. of salt water. The total reserves of fresh-water on the Earth, including glaciers, lakes, rivers and groundwater are 32 million cu.km.. The Earth's development in its interiof releases 320 million cu.m. of free water to the surface. 520,000 cu.km. of water is included in the annual water cycle, of which 109,000 cu.km. falls on the land and provides a runoff of 37,000 cu.km. Presently, man consumes about 10% of this runoff water. The world production of free water is estimated to be 100 million cu.km. in an year. By the year 2000, man will be using one-half of the water being renewed on the land (18,700 cu.km.) of which 7000 cu.km. would be for irrigation, 1700 cu.km. for industrial use, 9000 cu.km. for dilution of sewage and pollution and 1000 cu.km.

for domestic use. The annual growth of irretrievable water mass is 4 to 5% and if this continues, by the year 2230, man will have exhausted all the water reserves of the geosphere and will have to be satisfied with precipitation which is 520,000 cu.km./year or artificially produced water. These assumptions are conditional and only go to show that with the present rate of growth of population and production, the free natural resources on the Earth are not so great.

HYDROMETEOROLOGICAL STUDIES IN INDIA

The application of hydrometeorological techniques in the study of water resources is important in the light of the increasing need for water. Hydrometeorology which deals with the occurrence and distribution of water on the earth's surface helps to assess the variation of water resource potential in space and time.

Rainfall is the major important hydrometeorological parameter to be studied for the development of the water resources of a region. In a country such as India, whose economy is dependent on the monsoonal rainfall and its variability, hydrometeorological studies are of utmost importance in assessing the water potential of any region, so that optimal utilization of the existing resources could be judiciously planned. Such hydrometeorological studies have been carried out by several researchers, some of which are reviewed here.

i. Rainfall studies

Dhar et al.,(1974) estimated the mean annual rainfall over India for the period 1901 to 1950 to be 119 cms. of which 75% occurred in the southwest monsoon season (90 cm.). The year 1917 was the year of highest rainfall (145 cm.) when the rainfall was 22% above normal and 1918 was the year of lowest rainfall (96 cm.) when the deficiency was 19%. Monsoon rainfall was the highest in coastal Karnataka (289 cm.) which was 87% of mean annual and the lowest in Tamil Nadu (35 cm.) which was only 19% of the mean annual. For Kerala, mean annual rainfall for the period was 297.1 cm. and 198.2 cm. (67%) of it occurred during the southwest monsoon season, the coefficient of variability of monsoon rainfall being 23.5%. Some stations at high altitudes in the Ghats region received very high rainfall (upto 600 cm.), but the rainfall sharply decreased towards the east of the Ghats where the amounts were as low as 50 cms. Similarly the southern slopes of the Himalayas were found to receive rainfall upto 150-250 cm. which decreased rapidly across the Himalayas.

Parthasarathy and Dhar (1974) studied the trends and periodicities in annual rainfall of 31 meteorological sub-divisions of India for the period 1901 to 1960. They found a positive trend (increasing rainfall) over central and adjoining peninsular India and over two smaller areas north-west and north-east of India, and a negative trend (decreasing rainfall) in some parts on the eastern side. The mean annual rainfall increases on the western side of the Western Ghats and decreases rapidly eastwards. They found a cycle of 8.5 to 12 years in and around arid and semi-arid regions of Rajastan, parts of central India and extreme south Peninsula. A cycle of 2 to 3.5 years was found over large parts of the country, mainly over central parts of Peninsular India and parts of north-east India. Of the various sub-divisions in the country, rainfall was the highest in coastal Mysore and the lowest in West Rajastan. The variability was the lowest in Assam and the highest in Sourashtra and Kutch. Dhar and Bhattacharya (1974) found that maximum rainfall in the Himalayas occurred at 2 to 2.4 km. But,high peaks like the Mount Everest were almost semi-arid (Dhar & Narayanan, 1965). Rainiest region in the country was the southern slopes of Khasi-Jainter hills where Cherrapunji and Mawsynaran got an annual rainfall of 1100 cm. Using data for 70 years, Jagannathan and Parthasarathy (1973) also studied the trends and periodicities in the annual rainfall of India. Dhar (1978) made a list of heavy rainfall stations in India while Dhar et al., (1978) made an appraisal of the heavy rainfall stations of India and found that such regions are mainly located in north-east India and in the Western Ghats region. Seasonal variation of precipitable water vapour in the atmosphere over India was studied by Ananthakrishnan et al., (1965). On the basis of mean annual rainfall, Dhar et al., (1974) estimated that total available annual volume of water precipitated over India was 3.9×10^6 million cu.m.

Rainfall over the west coast of India and the influence of the Western Ghats has also been studied by various workers. Ananthakrishnan et al., (1979) studied the features of hourly southwest monsoon rainfall along the west coast of India. Relation between cumulative percentage of rainfall and of rainfall hours and intensity of rainfall were studied in detail. Ananthakrishnan et al., (1979) studied the rainfall of Kerala and the space-time distribution statistics of seasonal and annual rainfall were presented district-wise. Dikshit (1979) discussed the anomalies in the distribution of rainfall on the west coast of India.

ii. Studies of point maximum precipitation

Studies of the point maximum precipitation (P.M.P.) and of the intensity, frequency and duration of rainfall have been made for almost all regions of the country by several researchers. Dhar and Kamte (1969) studied the P.M.P. over Uttar Pradesh using Hershfield's techniques. Dhar and Kulkarni (1970) found that P.M.P. estimates over North India vary from 37 cms. to 100 cms. for one-day duration. Based on the rainfall data from 1891 to 1920, Iyer and Zafar (1938) prepared charts of one-day rainfall. Rao (1959) and Parthasarathy (1959) studied frequency distribution of one-day rainfall of 25 cms. and above. Krishnan et al., (1959) studied the maximum one-day rainfall for various return periods. Parthasarathy and Singh (1961) prepared generalised 2-year rainfall charts of 1,2,3,6 and 24 hrs. duration. Dhar and Kulkarni (1971) studied the maximum one-hour rainfall of southern half of Peninsular India. They also prepared frequency interpolation nomograms for estimating maximum one-day point rainfall for different return periods for North Indian States. Harihara Ayyar and Prasad (1971) prepared generalised charts of one-hour rainfall for different return periods. Harihara Ayyar and Tripathy (1971) examined the heaviest one-day point rainfall for 50 stations to determine the probability of occurrence of such intense rainfalls.

Parthasarathy and Dhar (1976) studied the trends and periodicities of seasonal and annual rainfall of India (1901 to 1960) using latest statistical techniques.

iii. Rainfall variability studies

Rao and Mishra (1971) calculated the variability of rainfall during various seasons and showed that annual rainfall of the country is quite stable. India Meteorological Department (1971) has published a rainfall Atlas for India which includes maps of monthly, seasonal and annual distribution of rainfall and its coefficient of variability based on data from 1901 to 1960.

iv. Rainfall-runoff studies

Characteristics of rainfall and the occurrences of floods and droughts have been studied for different river basins, even about 100 years back. Blanford (1889) made detailed studies of frequency distribution and short duration distribution of daily rainfall, the proportion of surface drainage to rainfall and the evaporation from free water surface. Binnie (1925) prepared rainfall-runoff curves based on the rainfall and runoff data of Ambajhari reservoir. Strange (1928) classified river basins into bad, average and good based on the capability of a basin to produce runoff and prepared tables of estimated runoff as percentage of monsoon rainfall for the basins. Inglis and De'souza (1930) studied the rainfall and runoff of the Bombay-Deccan area and based on the 25 years' rainfall-runoff record they derived empirical relations connecting the rainfall and runoff of Ghat and non-Ghat basins. Lacey (1942) and Khosla (1949) also did similar work. Khosla estimated the total water potential of the country to be 1.7×10^6 million cubic metres by dividing the country into six major regions and 66 large river basins. He calculated the total volume of water generated to be 3.9×10^6 million cubic metres, assuming the mean annual rainfall to be 119 cm. He found that mean annual runoff through rivers was 1.7×10^6 million cubic metres. This means 43% of annual rainfall is converted into surface runoff and 57% is lost by evaporation and transpiration. Satakopan (1948) employed techniques of depth-area-duration and storm transportation to estimate maximum basin rainfall. Pramanik & Rao (1950) and Satakopan & Parthasarathy (1955) made systematic studies of the hydrometeorology of different river basins. Similar studies were carried out by Parthasarathy (1955) for Bihar, Bengal and Assam, Bose (1958) for basins of West Bengal and West Uttar Pradesh and Bhan (1958) for Jhelum basin. Banerji & Anand (1962), Banerji & Narayanan (1966), Parthasarathy

& Sarker (1966) and Abbi & colleagues (1970, 71) also carried out similar studies for different river basins. Features of rainstorms were studied by Pant et al., (1970) for Brahmaputra basin and Changrain et al., (1970) for Barak basin. Parthasarathy et al.,(1959) analysed the rainfall distribution of a number of storms in different parts of India and derived an equation for area-intensity of rainfall. Parthasarathy & Singh (1960) studied the intensity, duration and frequencies of rainfall for the whole of India for local drainage design.

v. Studies on floods and droughts

Before planning the construction of any river project, it is necessary to make a careful assessment of the past rainfall, especially of the heavy rainstorms. Flood discharges through the spillway and flood and drought conditions of the area drained by the river are to be studied in detail. Such studies have been carried out for almost all dam sites and river basins in India. According to Parthasarathy (1959) who analysed five biggest rainstorms in different parts of the country, rainstorms of high magnitude occur in regions of low rainfall. Raman and Chhabra (1966) worked out empirical relations between maximum and central raindepth and its areal extent based on depth-area-duration statistics. Dhar and Bhattacharya (1974) found another relation for the plain areas of North India. Dhar and Rakhecha (1974) determined a three-dimensional relation between maximum raindepth area and return period for a three-day duration for the rainstorms of Bihar region, using data from 1897 to 1961 and prepared a nomogram for this. Dhar and Rakhecha (1973) studied the efficiency factors of severemost rainstorms and Dhar et al.,(1974) analysed the severemost rainstorm over north Indian plains. Ramdas (1950) studied the vagaries of monsoon from 1875 to 1950 for north India and their liability to floods and droughts.

The brief review of hydrometeorological studies in India given above, though not exhaustive, is representative of the enormous amount of work done in this field. Hydrometeorological investigations based on the concept of water balance have not been included here, as they have been discussed in the next section separately.

SECTION II. CONCEPT OF WATER BALANCE AND ITS APPLICATIONS IN CLIMATOLOGY

THE HYDROLOGIC CYCLE

Water occurs in the solid, liquid and gaseous forms in the earth's surface and in the atmosphere. The interdependence of the three states and the continuous movement of water provide the basis for the hydrologic cycle. The flux of vapour from the oceans to the continents through the atmosphere, and its ultimate return to the atmosphere or ocean by evaporation, transpiration or runoff is known as the hydrologic cycle. It is an intricate combination of evaporation, transpiration, air mass movements, condensation, precipiration, runoff and groundwater movements.

The hydrologic cycle may be considered to begin with evaporation from the oceans into the atmosphere. This vapour condenses and falls to the earth as precipitation. A part of the precipitation falls directly on the seas and the remaining part on the land surface. A portion of the water falling over the land is intercepted by the vegetation cover and other objects and is retained as interception storage. The water may later evaporate into the atmosphere. The other part falling over the land unintercepted, infiltrates into the soil to form a thin layer of water close to the surface, called soil moisture. This may evaporate into the atmosphere or when the capacity of the soil (field capacity) is exceeded, percolate down to become groundwater; when the rate of precipitation is heavy and exceeds infiltration rate, runoff occurs. This water flows through surface channels as rivers, lakes or streams and finally joins the sea. Of course, evaporation does occur from surface water bodies. Groundwater too, flows through the subsurface channels to join the sea ultimately. A part of the groundwater is absorbed by the root systems of the vegetation which return it to the atmosphere by transpiration.

Therefore, ultimately all the water precipitated from the atmosphere is returned to the system, completing the hydrologic cycle. This closed chain of events determines the water balance of a region by taking into account the various ways in which its water supply and water use are balanced against each other. This concept is expressed by the basic hydrologic equation,

$$P = E + \Delta S + G + R,$$

where P is the precipitation; E is the evapotranspiration including the transpiration from vegetation; ΔS is the change in water storage on or below the surface within the region; G is the groundwater loss or leakage from the region and R is the runoff. G is negligible, if the region is large and free from unusual geologic formations. Precipitation, evapotranspiration, water surplus (W.S.) and water deficit (W.D.) resulting from the change in storage and runoff are the fundamental elements of water balance.

i. Precipitation

Precipitation is the most widely measured water balance element and its measurements are within acceptable limits of accuracy. A fairly well-distributed network of rainfall measuring stations with records for long periods exists in India. Precipitation data, therefore, is not a constraint to water balance studies in general and over the Western Ghats region in particular.

In the present thesis, apart from making use of the required precipitation data for water balance computations, detailed analysis of rainfall has also been carried out.

Seasonal distribution of rainfall and number of rainy days are studied in comparison to annual values for the entire Western Ghats region. Rainfall intensity, precipitation ratio and rainfall variability are also studied for the State and its vicinity, using standard statistical techniques.

To study the probable limits of maximum and minimum rainfall, the method suggested by Sanderson (1972) is used. Theoretically, the rainfall cannot exceed an amount equal to the mean annual rainfall(P) plus 2 times the standard deviation ($P+2\sigma$) and the minimum rainfall cannot be less than an amount equal to the mean annual rainfall minus 2 times the standard deviation ($P - 2\sigma$) in 97.5 years out of 100.

For the planning of agriculture, hydro-electric power generation and irrigation, a study of the departures of rainfall is very important. An analysis of rainfall of the State for the years 1901 to 1986 is made by calculating the annual rainfall departures for some selected stations, using the method suggested by Nicholson (1983). A transformed, annual rainfall departure x_{ij} is derived for each station and year as

$$x_{ij} = (r_{ij} - \bar{r}_i)/\sigma_i,$$

where x_{ij} is the annual rainfall for station i and year j, $\bar{r}_i$ is the mean annual rainfall at station j, and σ i is the standard deviation of the rainfall at station i. For the State as a whole, the areally integrated rainfall for the year j,

$$R_j = I_j^{-1} \sum x_{ij},$$

where I_j is the number of stations available for year j.

Temporal distribution of rainfall is important in many agrometeorological and hydrological investigations. A simple index developed by Walsh and Lawler (1981) is used in the present thesis, to quantify the rainfall seasonality in the Western Ghats region. The degree of variability in monthly rainfall which assesses seasonal contrasts in rainfall amounts is defined as the relative seasonality. Walsh and Lawler have developed a seasonality index ($\overline{SI}$), which is the sum of the absolute deviations of mean monthly rainfall from the overall mean, divided by the mean annual rainfall.

$$\overline{SI} = \frac{1}{\bar{R}} \sum_{n=1}^{12} |\bar{x}_n - \bar{R}/12|$$

where $\bar{R}$ = mean annual rainfall,

$\bar{x}_n$ = mean monthly rainfall of month 'n'.

The index can be zero if all the months have equal rainfall and can be a maximum value of 1.83 if all the rain occurs in a single month. The index values are classified into 7 categories as follows:

TABLE 2.2

Seasonality Index Classes

Rainfall regime	$\overline{SI}$ class limits
Very equable	$\leqslant$ 0.19
Equable with a definite wetter season	0.20-0.39
Rather seasonal with a short drier season	0.40-0.59
Seasonal	0.60-0.79
Markedly seasonal with a long drier season	0.80-0.99
Most rain in 3 months or less	1.00-1.19
Extreme, almost all rain in 1-2 months	$\geqslant$ 1.20

To suit the general conditions in the Western Ghats region and to simplify the classification, the limits are modified in the present thesis as follows:

0 to 0.6 - equable, 0.6 to 1.2 - moderately seasonal and above 1.2 - highly seasonal.

Use of climatic data in calculating the seasonality tends to underestimate seasonality. This can be rectified to a certain extent by calculating the seasonality indices of individual years (SI_i) which are then averaged to get the conservative value of seasonality index ($\overline{SI_i}$).

If the mean rainfall regime occurs every year, $\overline{SI}$ becomes equal to $\overline{SI_i}$ and the timing of the rainfall peaks and troughs does not change from year to year. The degree of variability of rainfall regimes can then be assessed by examining the ratios of $\overline{SI}/\overline{SI_i}$ and assessing the percentage frequency of months with maximum rainfall and investigating the range of SI values in individual years. If the ratio is high, the maximum rainfall occurs in a small spread of months; when it is low, peak rainfall may occur in a larger spread of months. When the range of SI_i values is low, replicability of the mean rainfall regime is high.

ii. Evapotranspiration

Evapotranspiration is the key element in the water budget which is the link between moisture and energy exchanges. It includes evaporation from water, snow, soil surfaces, water intercepted by vegetation and transpiration from vegetation. It has an important role in the global heat balance, as it releases vast amount of heat energy when it condenses. Evapotranspiration depends upon a number of conditions like soil moisture, nature and properties of soil and vegetation, air temperature and humidity.

An idea about the exchange of water between earth and atmosphere can be obtained by the comparison of precipitation and evapotranspiration. Depletion and recharge of the moisture content of the soil depends on the duration, intensity and amount of precipitation. The relative magnitudes and periods of occurrence of rainfall and evapotranspiration determine the moisture status of the soil. If evapotranspiration exceeds precipitation for a prolonged time, the moisture content of the soil may reach the wilting point. When the precipitation exceeds evapotranspiration and the water holding capacity of the soil, the surplus water runs off to feed the streams and rivers and also raises the groundwater levels.

Unfortunately, of all climatic parameters, evapotranspiration is least understood even to this day and has eluded attempts at precise measurements. Therefore, indirect methods of its measurement and estimation are being resorted to. Earlier, evaporation was mainly measured using evaporimeters and natural evaporation was estimated by reducing the observed values using a coefficient. The practical limitations of such reduction factors were discussed by Mcllroy (1957) and Deacon et al.,(1958). Rohwer (1931) developed an empirical formula for estimating the evaporation from other meteorological parameters. Thornthwaite and Holzman (1942) employed an evaporation equation that required specific humidity, wind velocity and temperature at two levels over a point which were not easy to measure. Hickox (1946) developed a formula for evaporation into air in motion, by considering the transport of moisture analogous to heat transfer. Khosla's (1951) empirical formula for measuring evaporation involves only temperature and this has been widely used for the estimation of river basin yields in India. Vapour pressure and wind velocity were used by Sutton (1943) and Pasquill (1943) in their formulae. Bowen (1926), McEven (1930), Richardson (1931) and Cummings (1936) used formulae based on heat-balance methods.

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 uninhabited use. This concept gives good results when the growth and distribution of vegetation are also considered. The spread and growth of vegetation varies directly with the water available in the soil, if the other factors determining vegetational development are constant. Evapotranspiration under a given environmental condition increases with the increase of water supply, until it reaches a maximum value which is equal to the P.E.. Studies with the use of evaporimeters in different climates of the world have revealed that P.E. depends mainly on the meteorological parameters of the atmosphere above and is independent of the nature of the soil, vegetation or cultural practices. Since experimental measurement of P.E. in different parts of the world under different meteorological conditions is scarce, attempts have been made to develop empirical formulae for evaluating P.E. from other meteorological parameters. The formulae based on energy balance approach are popular for their sound theoretical basis, but their practical application face observational and instrumental problems. Penman (1956), Budyko (1958), Blaney and Criddle (1950), Lowry and Johnson (1941) Halstead (1951) and Ramdas (1957) have all formulated methods to estimate P.E., of which only Penman's formula has found worldwide applications.

Thornthwaite (1948) established a relation between mean monthly temperature and P.E. from extensive records of observation. The relation was adjusted to a month of 30 days and 12 hours of bright sunshine per day, which is given by the equation:

$$e = 1.6 \left(\frac{10\,t}{I}\right)^{a}$$

where e = monthly P.E. in cms,

t = mean monthly temperature in $^{\circ}C$,

I = annual heat index being equal to

$$\sum_{n=1}^{n=12} i_n$$

where i_n = mean heat index of the n^{th} month equals $\left(\frac{t_n}{5}\right)$ 1,514, where t is the mean temperature of n^{th} month

and $a = (6.75 \times 10^{-7} \times I^3) - (7.71 \times 10^{-5} \times I^2) + (1.792 \times 10^{-2} \times I) + (4.9239 \times 10^{-1})$

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

$$e = -41.586 + 3.2233\,t - 0.043254\,t^2.$$

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. The heat index can be obtained from the table prepared and the unadjusted P.E. from the nomogram which is based on the fact that there is a linear relation between the logarithm of temperature and the logarithm of unadjusted P.E..

Before any further discussions of the concept of P.E., it would be proper and worthwhile to dwell on its limitations. 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). Many researchers are of the view that the concept is an approximate one because (a) different crops use different quantity of water (b) sensible and turbulent heat transfer affecting P.E. is different for different crops and (c) humidity and wind speed affect P.E., but they are not considered. The Thornthwaite formula, according to Van Wijk et al.,(1959), gives good results in similar humid climate in which it was developed, but the values obtained for semiarid climates are very low. Mather (1954) feels that the formula is an underestimate of P.E. in winter and overestimate in summer. Hare's (1959) opinion is that no method developed after Thornthwaite's original equation was an improvement of it. According to Penman (1956), the method is quite acceptable, considering its simplicity and limitations.

The study of Bailey and Johnson (1972) reveals that noticeable errors occur in the tropics where the annual march of temperature is controlled more by the cloud variations than the insolation received. In the midlatitudes, the values of P.E. calculated are reasonable, except near the glacial limits. Problems also arise in the very warm climates where variation of P.E. with temperature is not agreeable with the temperature-evaporation relation in the middle of the temperature scale. Despite these drawbacks, numerical tests carried out in the study revealed that the method is internally consistent over a wider range of annual heat indices (17 to 146) rather than the range suggested (25 to 140) by Thornthwaite and Mather (1956).

Thornthwaite modified the book-keeping procedure in 1955, but he did not try to modify the formula for evaluating P.E.. According to him, a modified formula may give more accurate results in a single location for a particular season, but it may not work better in all places in all seasons. His idea was first to realize the physical reasons of evapotranspiration fully and then to develop a new expression for P.E., and for this purpose he studied the role of net radiation in evapotranspiration.

Though there are varying opinions about the concept and limitations of the formula for evaluating P.E., it has still its vital role in climatology and hydrology. The computed values have agreed well with actual measurements in different climatic regions of the world. Hence, the ever increasing need for water makes such rational computations more important today than ever before.

Data of actually measured P.E. are scarce in India. Subrahmanyam (1956) computed average annual P.E. from Thornthwaite's formula for the first time in India. After that Subba Rao (1961), Subramaniam (1961), Sastri (1969), Ramasastri (1973) and Sarma (1974) calculated P.E. for different climatic zones of India. Computations of water balance parameters on a regional basis have been made for Assam and neighbourhood by Bora (1976) and for Tamil Nadu and vicinity by Ram Mohan (1978). Hence, the formula and procedures of water balance computations have attained universal recognition.

COMPUTATION OF WATER BALANCE PARAMETERS

Water balance of a station is computed by comparing precipitation (water supply) with potential evapotranspiration (water need), making allowance for soil moisture storage and its evapotranspiration. For a particular station, if precipitation is always greater than P.E., the soil remains full of water and water surplus (W.S.) occurs. When precipitation is less than P.E. for months together, water deficit (W.D.) occurs. As the soil dries out, evaporation and transpiration decreases. The rate of evapotranspiration is proportional to the amount of water remaining in the soil (Thornthwaite and Halstead, 1954).

According to the 1948 procedure of Thornthwaite, the average moisture-holding capacity of the soil is 100 mm. and the moisture would be removed at the potential rate. This procedure worked fairly well, but with the availability of more experimental data on soil moisture in relation to P.E., it was realized that the assumption did not fully portray the actual physical processes. Thornthwaite and Mather (1955) modified the procedure by assuming 300 mm. as average moisture-holding capacity of soil and that 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. These more rational assumption made the procedure to be widely accepted replacing the older approach. The modified book-keeping procedure are detailed in the publications of Thornthwaite and Mather (1955, 57), Mather (1973) and Subrahmanyam (1982). As the water holding capacity 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 different types of soil and vegetation.

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 (W.D.) and water surplus (W.S.) are the derived elements.

Actual Evapotranspiration is the amount of water that is actually available for evaporation and transpiration and depends on P.E., precipitation 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.

In the present thesis, water balance elements of 32 stations in the Western Ghats region have been worked out on a climatic basis, using the modified procedure of Thornthwaite and Mather (1955). A more detailed study using monthly data for the period 1901 - 1979 have been made for Kerala and its vicinity, to study the influence of the Western Ghats on the water balance of this region. Of the 13 stations chosen, 6 are inside Kerala and the rest in the vicinity - 4 in Tamil Nadu and 3 in Karnataka.

The monthly mean temperature and monthly rainfall data for a period of 79 years (1901-1979) are available for 3 stations and 75 years (1901-1975) for 5 stations. For the other stations, data are available only for a period ranging from 20 to 30 years. Most of the stations selected lie either in the Ghats region or in its close vicinity. The topography, soil type and vegetation are entirely different for the various stations. This fact has been considered in determining the water holding capacity and deriving the elements of water balance for each station.

Climatic water balance computations for two representative stations - Mysore and Calicut are presented here (Tables 2.3 and 2.4). These two stations are two extreme cases because Mysore has an annual water deficiency of 371 mm., while Calicut has an annual water surplus of 1869 mm.. Value of annual P.E. (1302 mm.) is much higher than that of P (837 mm.) for Mysore while the value of P (3283 mm.) exceeds greatly the value of P.E. (1739 mm.) for Calicut. Mysore experiences no water surplus in any of the months. Surprisingly, Calicut experiences a water deficit of 325 mm., from January to April and in December.

TABLE 2.3

Climatic Water Balance of Mysore

(All values in millimeters)

Lat. 12° 18'N. Lng. 76° 42'E. Ht. 767 m. Field capacity 200 mm.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
P.E.	95	98	142	150	150	96	106	103	101	100	87	74	1302
P	3	6	12	68	157	61	72	80	116	180	67	15	837
P-P.E.	92	-92	-130	-82	7	-35	-34	-23	15	80	-20	-59	-425
A.P.W.L.	-210	-302	-432	-514	-117	-152	-186	-209	-171	-39	-59	-118	
St	69	43	22	15	116	93	78	69	84	164	148	110	
Δ St	-41	-26	-21	-7	101	-23	-15	-9	15	80	-16	-38	
A.E.	44	32	33	75	150	84	87	89	101	100	83	53	931
D	51	66	109	75	0	12	19	14	0	0	4	21	371

P.E. : Potential Evapotranspiration
P : Precipitation
A.P.W.L. : Accumulated Potential Water Loss
St : Soil Moisture Storage
A.E. : Actual Evapotranspiration
D : Water Deficit

TABLE 2.4

Climatic Water Balance of Calicut

(All values in millimeters)

Lat. 11° 15'N. Long. 75° 47'E. Ht. 5 m. Field capacity 250 mm.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
P.E.	137	131	158	164	170	146	136	141	138	144	137	137	1739
P	6	11	21	111	323	871	860	405	215	290	140	30	3283
P-P.E.	-131	-120	-137	-53	153	725	724	264	77	146	3	-107	
A.P.W.L.	-238	-358	-495	-518								-107	
St	96	59	34	27	180	250	250	250	250	250	250	163	
Δ St	-67	-37	-25	-7	153	70	0	0	0	0	0	-87	
A.E.	73	48	46	118	170	146	136	141	138	144	137	117	1414
D	64	83	112	46	0	0	0	0	0	0	0	20	325
S	0	0	0	0	0	655	724	264	77	146	3	0	1869
RO	64	42	28	18	12	231	398	353	259	220	147	97	1869
Dt	100	58	30	12	0	424	750	661	479	495	261	164	
S.F.	0	0	0	0	0	223	246	90	26	50	1	0	636
G.R.	0	0	0	0	0	432	478	174	51	96	2		1234
T.G.	640	553	478	413	357	740	1117	1140	1036	991	858	741	
U.F.	87	75	65	56	49	100	152	155	141	136	117	101	1234
G.S.	553	478	413	357	308	639	965	985	895	856	741	640	
T.D.	87	75	65	56	49	323	398	245	167	185	118	101	1869

P.E. : Potential Evapotranspiration
P : Precipitation
A.P.W.L. : Accumulated Potential Water Loss
St : Soil Moisture Storage
A.E. : Actual Evapotranspiration
D : Water Deficit
S : Water Surplus
RO : Runoff

Dt : Water Detention
S.F. : Surface Flow
G.F. : Groundwater Flow
T.G. : Total Groundwater
U.F. : Underground Flow
G.S. : Groundwater Storage
T.D. : Total Discharge

When the amount of moisture in the soil reaches the field capacity, the surplus water appears as either surface runoff which joins water courses or as subsurface runoff which percolates down to join groundwater, depending on the surface and underground characteristics. Thornthwaite (1948), in the absence of detailed information regarding these characteristics assumed that only 50% of the water surplus in a month runs off and the remaining is detained in the underground regions for further contribution to runoff and detention again. The 50% detention factor has not been found suitable to South Indian catchments and a 2/3 of water surplus as runoff and 1/3 as detention gave good results when compared to actually measured values (Subba Rao, 1958 and Subba Rao and Subrahmanyam, 1961). Actually, the detention factor varies from station to station depending upon the physiographic features. Further, all the water that detains cannot be added to the surplus of the next month since water slowly flows out of the region as underground runoff. However, the runoff and detention does not depend only on the size and shape of the basin, but also on the slope, soil type and vegetation. Considering these factors, Subrahmaniam and Pardhasaradhy (1980) developed a runoff coefficient which was further modified by Ali

(1982) for the estimation of climatic runoff from the Godavari river basin. The estimated values were found in fairly good agreement with measured values. The modified runoff coefficients are detailed below (Table 2.5).

TABLE 2.5

Modified Runoff Factors (After Ali, 1982)

	Runoff factor	Detention factor
Station slope		
i. 10 m/km (Gentle)	0.70	0.30
ii. 10-20 m/km (Moderate)	0.85	0.15
iii. 20 m/km (Steep)	1.00	0
Soil Type		
i. Sandy (High permeability)	0.70	0.30
ii. Silt (Medium permeability)	0.85	0.15
iii. Clay (Low permeability)	1.00	0
Vegetation		
i. Tropical rainforest (Low flow)	0.70	0.30
ii. Monsoon forest (Medium flow)	0.85	0.15
iii. Open jungle (High flow)	1.00	0

The runoff coefficient of a station is the product of its runoff factors for station slope, soil type and vegetation. The detention coefficient is the complement of the runoff coefficient. These coefficients are used in the present thesis for converting the water surplus into runoff and detention. For example, the runoff coefficient for Calicut is 0.34 which is the product its runoff factors for slope (0.7), soil type (0.7) and vegetation (0.7).

In the procedure detailed above, it is assumed that all the detention water is added to next month's water surplus without any provision for its flow as underground runoff. Actually, the groundwater is always in motion. A portion of the detained water flows slowly depending upon the geological conditions of the area and the rest of it is only available as groundwater storage in any month which contributes to the underground out-flow of the next month. The distribution of surface flow, underground flow and the groundwater storage at the six representative stations in Kerala have been studied in detail.

The excess of monthly water surplus over the surface flow is considered as groundwater recharge (Table 2.4). To evaluate the underground flow, a figure of 40% of the coefficient for surface flow has been used. This figure of 40% was arrived at from the computed values of the surface flow, base flow and total runoff of the North Fabius river at Tailor, M.O. (USA) during the flood season from July 25 to August 17, 1932 (Sherman, 1942). During this period, the ratio of surface flow coefficient to underground flow coefficient was found to be only 25%. To suit the general conditions in the Godavari river basin, Ali (1983) has worked out a coefficient of 40% which is employed in the present study. The computational procedure for the station Calicut is shown in Table 2.4.

As detailed earlier, the surface runoff coefficient for Calicut is 0.34 and therefore, the coefficient for underground flow is 0.14 (40% of 0.34). Computations for surface and underground flow start from the first month in which water surplus is observed. An amount of 655 mm. of water surplus occurs in June and out of this 231 mm. (0.34 x 655) appears as surface flow and the remaining 424 mm. is contributed to the groundwater. The sum of this groundwater recharge and the groundwater storage of previous month is the total groundwater available for underground flow in the month. In the beginning of the first month of water surplus, the groundwater storage of previous month is considered sero. Thus, in the first iteration, the groundwater storage in May is zero and therefore the total groundwater in June is 432 mm.. After the final iteration, these figures change to 357 mm. and 740 mm. respectively. The underground flow in June is then 101 mm. (0.14 x 740) and its difference from total groundwater (639 mm) is the groundwater storage in June. The total stream discharge in June (323 mm) is then the sum of surface flow (223 mm) and underground flow (100 mm). Similarly, the flow components for other months are also calculated.

APPLICATIONS OF WATER BALANCE IN CLIMATIC CLASSIFICATION

The purpose of climatic classification is to characterise climatic regions in terms of principal elements which are more decisive in the determination for the purpose. Therefore, there can be no universal classification for it in the purpose which determines the validity of a particular scheme. Systematic division of the earth into various climatic zones using temperature distribution was attempted by Humboldt (1817) and Köppen (1884). Later, Köppen evolved a general scheme of climatic classification based mainly on critical temperatures for the growth and maintenance of different kinds of vegetation.

Where distribution of vegetation is the primary concern, precipitation is also an important factor and both temperature and precipitation must be taken into consideration to determine whether a climate is dry or moist. Where temperatures are quite high and uniform throughout the year, as in tropical and equatorial regions, moisture availability is the sole determining factor while in higher latitudes where moisture is low due to low temperature, the actual temperature may limit the growing season for vegetation. Though the importance of the moisture factor was realized by earlier workers, they had no clear idea of how to obtain a measure of the water need. Transeau (1905), Lang (1920), Martonne (1926), Szymkiewiez (1925), Thornthwaite (1931 and 1933), Wilson & Savage (1936) and others have defined various indices for the determination of climates. Leighly (1949), Thornthwaite (1943), Budyko (1958), Gentilli (1950) and Meher-Homji (1963) have all revised the various moisture index formulae invented repeatedly under different names and have attempted to determine the active factors in the classification of climates. A rational scheme for climate classification was developed by Thornthwaite (1948) which was later modified by Carter and Mather (1966) following the modified water budget procedure of Thornthwaite & Mather (1955). In this scheme, heat and moisture which are the active factors in the growth and development of vegetation have been taken into account. In short, the moisture and thermal regimes of climates have been blended together to evolve indices for identifying different climates. (Subrahmanyam & Sastri, 1969). Since the details of the classification are available in several publications (Subrahmanyam, 1956, 1982; Subba Rao & Subrahmaniam 1965 and Carter & Mather 1966), only a bare outline of the revised scheme which is followed in the present study is given here.

The modified expression for the moisture index, $I_m = I_h - I_a$

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.

The limits of various climatic types in the moisture regime and the subclassifications of these climates based on seasonal variation of effective moisture are presented in Tables 2.6 and 2.7.

The potential evapotranspiration, since it is derived from the temperature and length of the day, is also an index of thermal efficiency, expressing plant growth and development in terms of water need. Climatic regions based on thermal efficiency are analogous to those derived from moisture index and are represented by similar symbolic notations (Table 2.8).

In the equatorial regions, where the length of the day is the same throughout the year with uniform high temperatures, seasonal variations of P.E. are small or even negligible. There is thus no "summer" in these regions and the total P.E. for any three months will

TABLE 2.6

Moisture Index and Climatic Types

(After Thornthwaite, 1948 and Carter & Mather, 1966)

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 2.7

Seasonal Variation of Effective Moisture

MOIST CLIMATES (A, B and C_2)	ARIDITY INDEX, I_a(%)
r Little or no water deficiency	0 to 10
s_1 Moderate summer water deficiency	10 to 20
w_1 Moderate winter water deficiency	10 to 20
s_2 Large summer water deficiency	20+
w_2 Large winter water deficiency	20+
DRY CLIMATES (C_1, D and E)	**HUMIDITY INDEX I_a(%)**
d Little or no water surplus	0 to 16.7
s_1 Moderate winter water surplus	16.7 to 33.3
w_1 Moderate summer water surplus	16.7 to 33.3
s_2 Large winter water surplus	33.3+
w_2 Large summer water surplus	33.3+

TABLE 2.8

Thermal Efficiency and Climatic Types

Thermal Efficiency (Cm.)	Symbol	Climatic type
	E'	Frost
14.2		
	D'	Tundra
28.5		
	C'_2	Microthermal
42.7		
	C'_1	
57.0		
	B'_1	
71.2		
	B'_2	
85.5		
	B'_3	Mesothermal
99.7		
	B'_4	
114.0		
	A'_1	
128.2		
	A'_2	
142.5		
	A'_3	Megathermal
156.7		
	A'_4	
171.0		
	A'_5	
185.2		
	A'_6	
199.5		
	A'_7	

TABLE 2.9

Summer Concentration and Climatic Types

Summer concentration of Thermal Efficiency (%)	Climatic subtype
	d'
88.0	
	c'_1
76.3	
	c'_2
68.0	
	b'_1
61.6	
	b'_2
56.3	
	b'_3
51.9	
	b'_4
48.0	
	a'_1
44.6	
	a'_2
41.1	
	a'_3
38.8	
	a'_4
36.3	
	a'_5
34.0	
	a'_6
31.9	
	a'_7
29.9	
	a'_8

constitute 25% of the annual total. At the poles, the growing season for vegetation is only during the three summer months and the total P.E. for this period will, therefore, be 100% of the annual P.E.. Thus, as one passes from megathermal to frost climates, the concentration of thermal efficiency (P.E.) in the summer quarter of the year rises gradually from 25% to 100%. Based on this thermal efficiency accumulation, the thermal regime of climate is given in Table 2.9.

Sometimes the occasional shifts of the annual water balance of certain stations may be of such magnitude that their very climatic types could be shifted by one or more categories in the drier or the wetter directions. Such temporary shifts of climate are of great interest to applied climatologists, for their frequency and magnitude reflect the conservatism of climate and determine the progressive improvement, stability or deterioration in the climatological potentialities of a region for development. Accordingly, the extreme dryness and wetness of a station can be identified by plotting the moisture index (I_m) values for individual years.

APPLICATIONS OF WATER BALANCE IN DROUGHT CLIMATOLOGY

Drought is short period of water deficiency while aridity is a prolonged and persistent deficiency of water for established use. In India, 99% of the famines that occur are due to droughts (Ray, 1901). Droughts appear as periods of acute water shortage, have been sighted as a major scourge of mankind, since they are a menace to food production, mainly through agriculture (Subrahmanyam, 1967).

Droughts have been defined variously by different researchers (Tannehill, 1947; Hoyt, 1938; Thornthwaite, 1947; Shantz 1927; Thornthwaite & Mather 1955; Palmer 1967; Blair 1943; Henry 1906). But, a completely satisfactory or universal definition of drought has not yet been possible. Depending upon the purpose of study and basic criteria chosen, droughts may be grouped mainly into 4 categories - precipitation droughts, atmospheric droughts, agricultural droughts and hydrological droughts.

Just as there exists various definitions of droughts, approaches to drought studies are also varied. The different methods employed for the study of droughts may be categorized as

a) Statistical techniques (Walker, 1914; James, 1932; Ramdas, 1950; Foley, 1955;

Majumdar, 1958; Naqvi, 1958; Meher, 1966; and Gibbs and Meher, 1967)

b) Non-statistical techniques (Knochenhaver, 1937 and Gaussen, 1954)

c) Dynamic methods (Bond, 1960; Troup, 1965; Namias, 1966; Morris and Ratcliffe, 1976 and Green, 1977) and

d) Water Balance methods (Thornthwaite, 1947; Van Bavel, 1953; Sapozhnikova, 1958; Palmer, 1956, 1957 and Rodda, 1965).

In India, the water balance approach was suggested for the study of aridity and droughts by Subrahmanyam (1958b). Subrahmanyam and his co-workers used the aridity index (I_a) to categorize droughts of various intensities (Subrahmanyam and Subramaniam, 1964, 1965; Subrahmanyam and Sastri, 1967 and 1970; Subrahmaniam and Sarma, 1972; Sastri, 1969; Ramasastri, 1973; Sarma, 1974; Bora, 1976; Ram Mohan, 1978 and Ram Mohan et al., 1984) All these studies project the versatality of the water balance procedure as it enables a realistic quantitative evaluation of water deficiency which is the root cause of all droughts.

In these studies and in the present investigation, the departures of yearly aridity index (I_a) values from the average is used as a measure of the intensity of drought. The yearly departures of aridity index from the median is graphically represented against the respective years. The standard deviation of aridity indices is used as a measure of departure, with the median as the base of reference. Classification of drought years in the order of their intensity are given in Table 2.10.

TABLE 2.10

Classification of Drought Years

Departure of I_a from median	Drought Intensity
Less than $1/2\ \sigma$	Moderate (M)
Between $1/2\sigma$ and σ	Large (L)
Between σ and 2σ	Severe (S)
More than 2σ	Disastrous (D)

The number of drought years of each category in each decade is presented graphically to project the decennial intensity of droughts.

Half-period averages for aridity indices have been calculated and the first value is deducted from the second to understand the prevailing trends in aridity. Aridity is found increasing if the value is positive and decreasing if it is negative.

CHAPTER III

GEOGRAPHICAL FEATURES OF KERALA

The State of Kerala lies between $8^{\circ}18'$ and $12^{\circ}48'N$ and longitudes $74^{\circ}52'$ and $77^{\circ}22'E$. It is bounded by the States of Karnataka on the north, Tamil Nadu on the east and 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. The population of the State (as in 1981) was about 254 lakhs of which 207 lakhs lives in rural areas and 47 lakhs in urban areas (Statistics for Planning, 1983). The birth rate in Kerala is about 24.9 per 1000 persons. Kerala also has the distinction of having the highest percentage of literates (70.4%) among the States of India.

PHYSICAL FEATURES :

Kerals is a narrow strip of land with a width varying from 30 km. in the north and south to about 130 km. in the central region. Though the area of the State is small, variation of physical features is very wide (Fig. 3.1). Topography of the State covers altitudes ranging from below sea level to about 3000 metres above sea level. The Western Ghats form a continuous mountain wall on the eastern border of the State, broken only by the Palghat Gap, and a few other

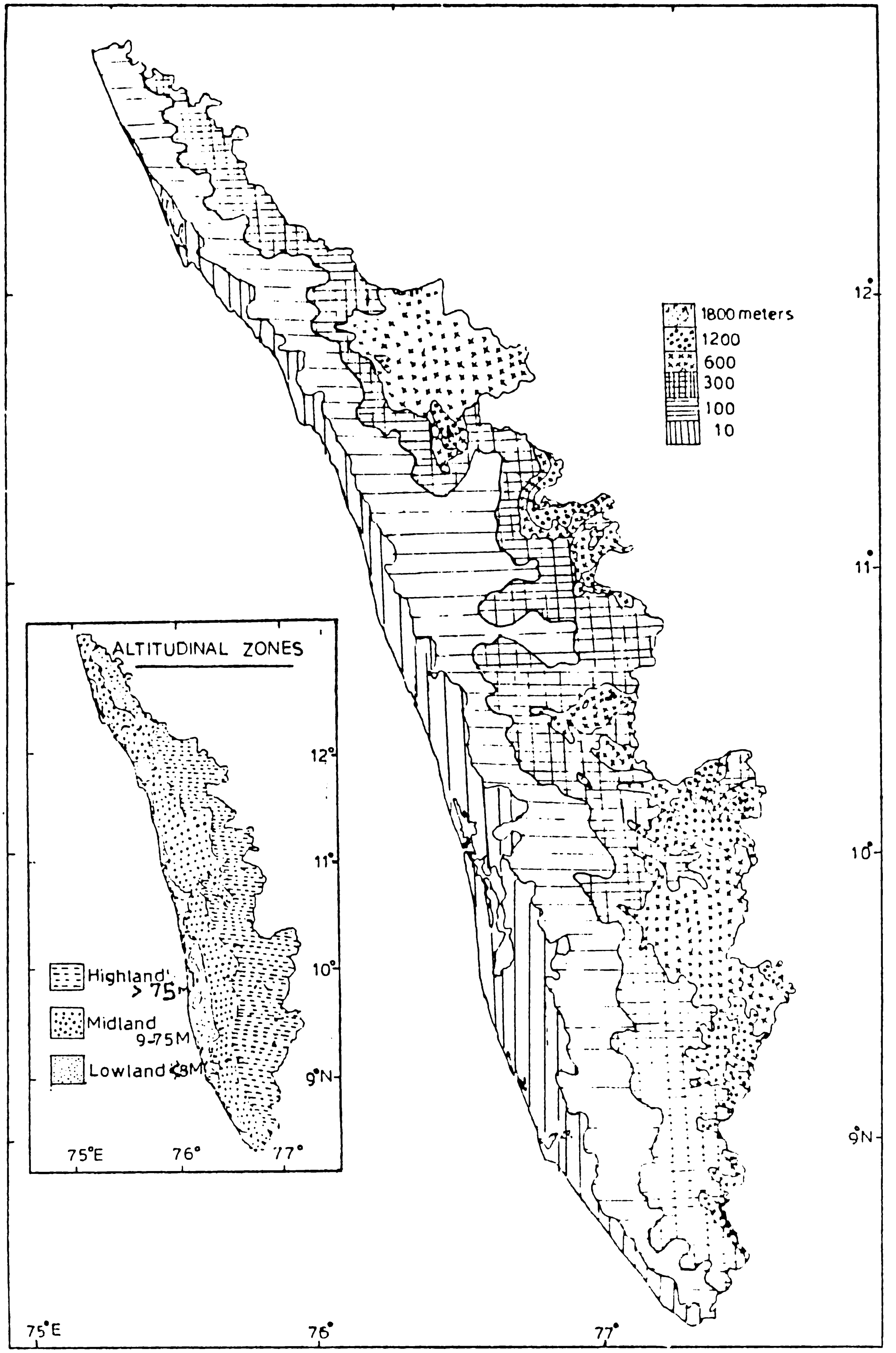

FIG 3·1 PHYSIOGRAPHY OF KERALA

passes. Elevation of the Ghats range from 600 m. to 1500 m.. Wayanad plateau, Kunda hills, Nelliampathy plateau, Periyar plateau and Agasthya malai are parts of this range at different elevations. There are several peaks in this range exceeding 2000 m. in height. Anamalai (2695 m.) is the highest peak in Peninsular India. Palghat Gap is the major break in the Western Ghats within Kerala. It has a width of about 30 km. and elevation below 300 metres. This gap has got a significant role in determining the climate of the State. The northeast monsoon winds which bring the winter monsoon rain enter the State through this gap. The mountain ranges and the high intensity of rainfall during the monsoons give birth to a number of perennial rivers which result in the formation of varied land forms.

The State has a total coast length of 580 kms. The coastal plain has a few scattered hillocks with rock cliffs. There are 34 estuaries in this area. The Vembanad estuary in the central part of the west coast is the largest (205 sq.km.), followed by the Ashtamudi Kayal, south of it. The coastal plain between Cochin and Alleppey contain a series of parallel sand dune ridges. Coastal plain extends more eastward in the central part of the State than in the northern and southern parts.

Based on the topography, the State can be divided into three well-defined natural divisions.

i. The lowlands

This is the coastal belt with its picturesque backwaters. This has extensive paddy fields and scattered areas with coconut, arecanut etc.. It has a depth less than only 8 metres and an area of 3979 sq.km. where 25% of the population lives. Annual rainfall in this region varies from 190 cms. in the south to 350 cms. in the north.

ii. The midlands

This is the central plain intersected by a number of rivers. 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 the 60% of the total. From south to north, variation of the annual rainfall is from 140 cms. to 400 cms. in this region.

iii. The highlands

This is the hilly region on the western side of the Western Ghats covered with dense forests and small streams. Tea, coffee, rubber and cardamom are abundant in this area. Though the area under this division is the largest (18,654 sq.km.), the density of population is very small, only 15% of the total. Variation of the annual rainfall from south to north in this region is from 250 cms. to 500 cms.

CLIMATE

Diversity of physical features results in the diversity of climate of the State. On the whole, the State has a pleasant climate with cool winter and warm summer. Cool climates exist in the highland region throughout the year while the rest of the State enjoys a temperate climate. Atmospheric humidity in the State is generally high, varying from 70% to 90%. Orography of the Ghats provides copious rainfall with the State which is about 300 cms. in an year; of which 75% occurs during the southwest monsoon season. Detailed discussion of rainfall distribution is presented in Chapter V.

i. Seasons

Rainfall and temperature to a certain extent can be employed as indicators to define various seasons of Kerala. In the broad background of the Indian patterns suggested by India Meteorological Department, the seasons in Kerala have been demarkated in the present study as follows:

a) Hot weather period or the pre-monsoon season - March to May.

b) Southwest monsoon season - June to September

c) Retreating southwest monsoon or the northeast monsoon season - October and November.

d) Winter or cool weather season - December to February.

Winter months experience minimum cloudiness and rainfall. Thunderstorm activity is the peculiarity of the hot weather season. The southwest monsoon season constitutes the principal rainy season while the north-east monsoon months constitute secondary rainfall period.

ii. Variations of pressure and temperature

The mean sea level pressure in the State is about 1009 mb. during summer and about 1012 mb. during winter. 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:).

Kerala, being a coastal State, does not experience large extremes of temperature either in summer or in winter. March to May are the hottest months when temperature exceeds 32^{o} C. In June, it comes down after the onset of monsoon and increases during October and November and then falls below 27^{o}C. Along the coast, the diurnal variations range from

5 to 7°C, which increase to more than 15° C in the high ranges. The midland region of the State has the highest mean temperature, more than 27.5° C while it is moderate in the coast and low in eastern highlands (Fig. 3.2.).

LAND USE

The land-use types are distinctly governed by physiography and climate of the State. There are mainly five broad categories of land-use distributed unevenly (Fig.3.3). The arable land forms a continuous stretch along the entire State spanning from the coast to the inland upto 100 m. above m.s.l. and further east only along the river valleys. The next important group is the forest land, the western limit of which can be roughly marked by the 300 m. contour. The entire eastern part of the State, except near the Palghat Gap is forest land. Several plantations have been developed within the forests. The high altitude plantations in Periyar and Wayanad plateaus are mainly tea, coffee and cardamom and the plantations along the western fringe of the forest are mostly rubber. Grasslands are observed in isolated patches throughout the State. Extensive waste lands, formed of hard crust laterite, which are unsuitable for cultivation are found mostly in the northern part of the State.

Because of the high density of population,

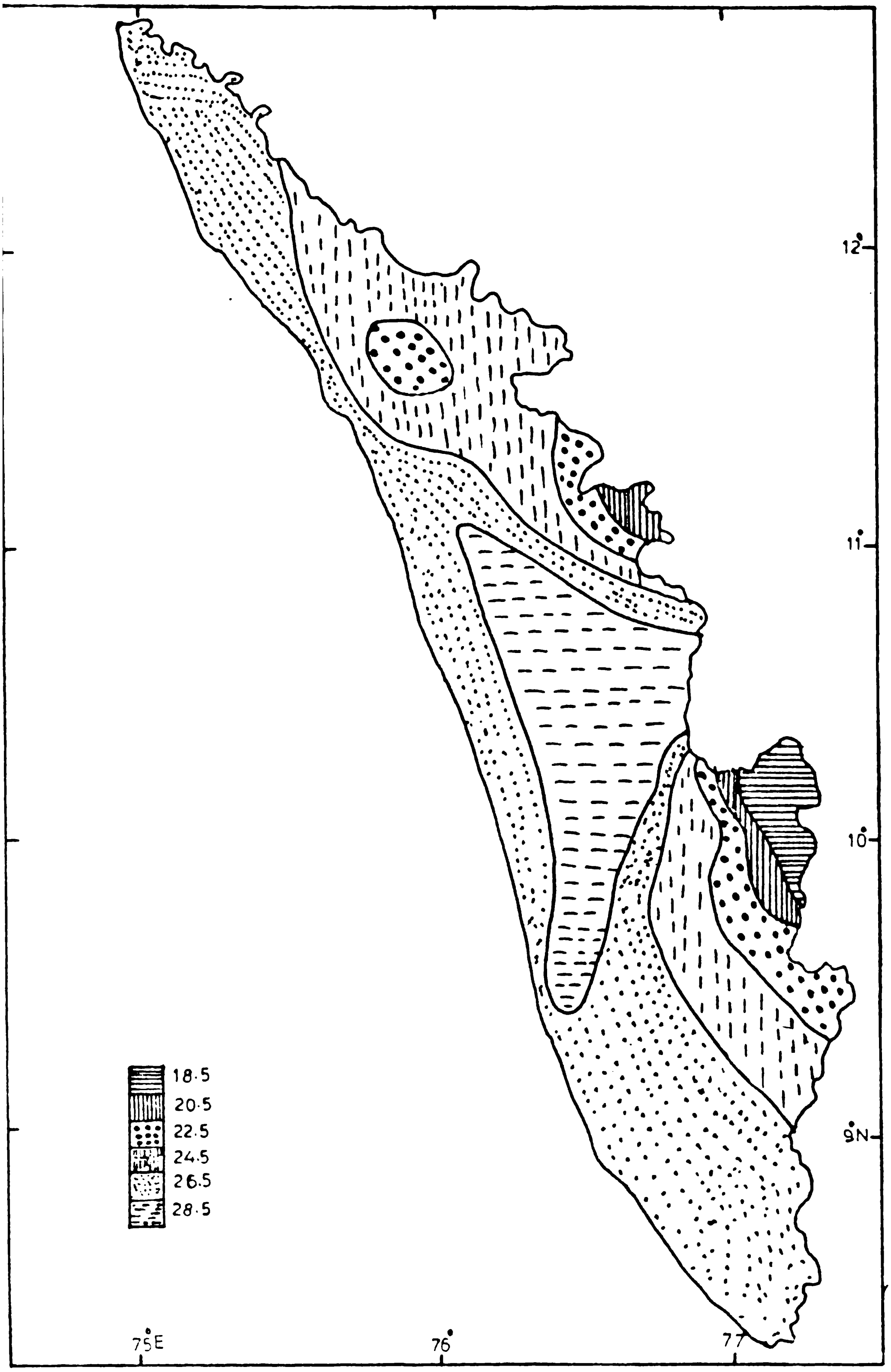

FIG 3·2 MEAN ANNUAL TEMPERATURE (°C)

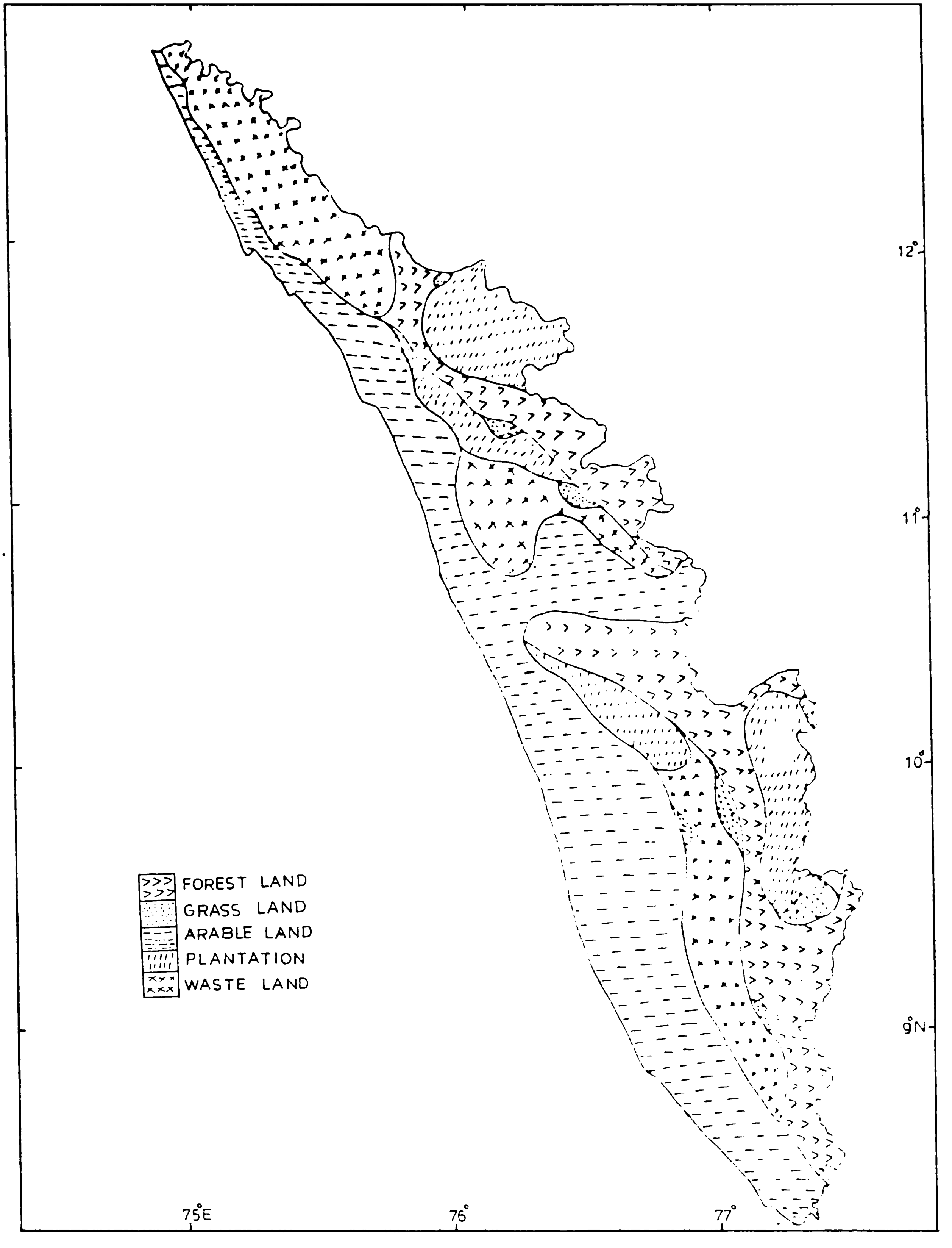

FIG 3·3 LAND USE PATTERNS

Kerala has the lowest land-to-man ratio in India and the available arable land is also diminishing fast.

SOIL TYPES

Laterite and forest loams cover the major part of the State (Fig. 3.4). Based on the physio-chemical properties and morphological features, they are classified into ten broad groups. (Soils of Kerala, Department of Agriculture, Kerala State, 1985).

i. Coastal Alluvium

This soil observed in the coastal area is formed by the deposition of marine and fluvial sediments. The soil has high sand content and low water holding capacity with pH value less than 6.5.

ii. River Alluvium

This type of soil, developed along river valleys is very deep with surface texture ranging from sandy loam to clay. It is very fertile and has high water holding capacity.

iii. Red Loam

This occurs as colluvial deposits in isolated patches in foothills and hillocks and associated with laterites. Red colour shows the presence of iron oxides. The soil is highly porous and friable and not fertile.

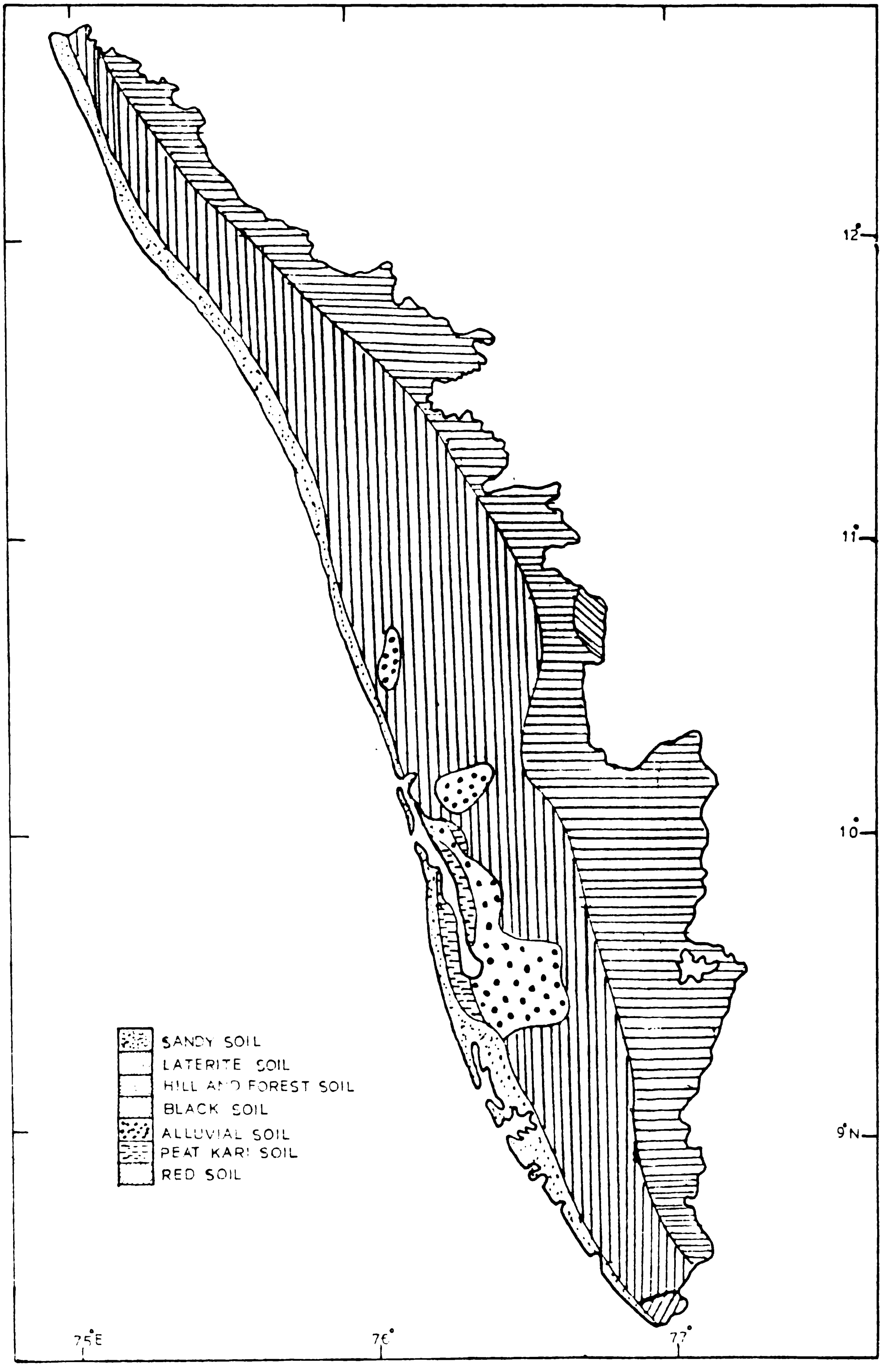

FIG 3.4 SOIL TYPES

iv. Laterite Soil

This covers most part of the State. Though the soil is acidic and poorly contain nitrogen, phosphorous, potash and organic matter, it is well drained, widely cultivated and responds to management practices.

v. Greyish Onattukara

This type of soil occurs in the districts of Alleppey and Quilon. It is highly porous with low holding capacity for water and fertilisers. The soil is acidic in nature and extremely deficient in major plant nutrients.

vi. Acidic Saline

This is found mainly in the Kuttanad region. This type of soil include 'Kari' soil (black soil with high organic content developed in low lying water logged areas), 'Kayal' soil (found in reclaimed area and has high clay content) and 'Karappadam' soil (found along river cources and with high silt content). Salinity and waterlogging is a problem where this type of soil is found. But, paddy is successfully grown here.

vii. Brown Hydromorphic Soil

This type of soil, found in wetland areas is having moderately rich contents of organic matter, nitrogen and potash. It has deficiency in lime and phosphate.

viii. Hydromorphic Saline Soil

This is observed along the coastal strip where inundation by sea causes salinity. The problem of acidity occurs in some areas.

ix. Black Soil

Black soil is found in the north-eastern part of Palghat district. The soil is dark and has low contents of organic matter. It is moderately alkaline and high in clay content. It is sticky and plastic in nature and is found suitable for a limited variety of crops.

x. Forest Loam

This is found in the eastern part of the State within the forest area on the weathered crystalline rocks. It has high organic content and nitrogen content, but poor in bases. It is very fertile and promotes prolific undergrowth.

VEGETATION

There are five main types of vegetation in the State - Tropical wet evergreen forests, Tropical semi-evergreen forests, Tropical moist deciduous forests, Subtropical broad leaved hill forests and Montane wet temperate forests (Fig. 3.5).

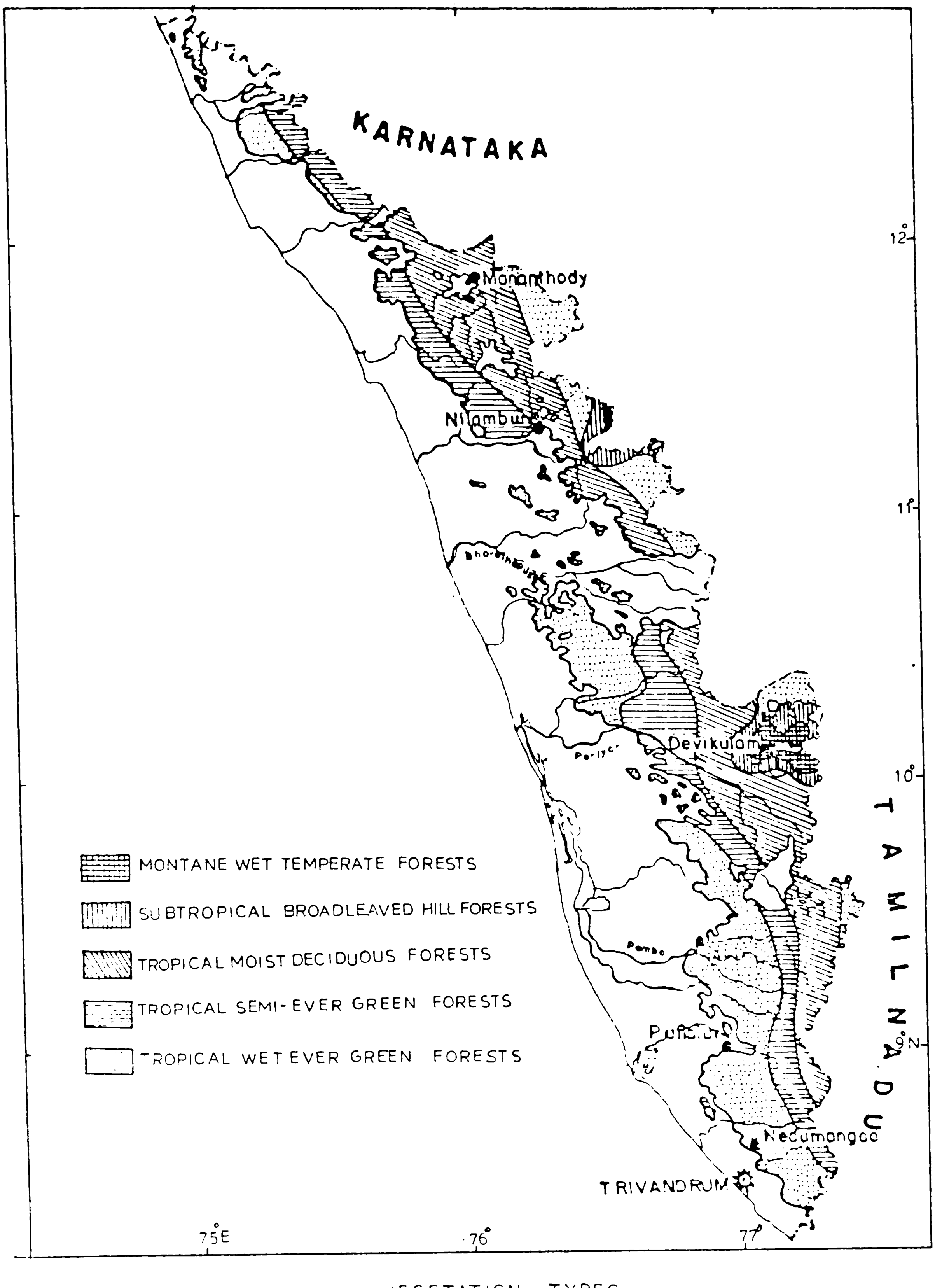

FIG 3.5 VEGETATION TYPES

Wet-evergreen, semi-evergreen and moist deciduous forests are located in the rainfall zone of 200-300 cms. with temperature more than 20^{o} C and elevation above 300 metres.

Isolated areas of tropical wet evergreen forests in 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. Wet-evergreen and semi-evergreen forests are major source of raw material for plywood and match industries.

Trees in the moist deciduous type of forests remain leafless during the period December to June. Several commercially valuable trees are included in this group.

Subtropical broad leaved hill forests are confined to small areas in the eastern border of Idukki, Palghat and Wayanad Districts.

The Montane wet temperate forests known as temperate shola, occur in the valleys of the high ranges.

AGRICULTURE

Agriculture is the chief source of livelihood of the people and the most important sector in the economy of the State. The abundance of rainfall and natural fertility of the soil have made the State an essentially agricultural region. Agriculture accounts for about 50% of the State income and it absorbs about 50% of the workforce. About 56% of the total area of the State is under cultivation. There is a diversity of crops which give good yields and characterised by the high intensity of cropping. Coconut, paddy, arecanut, sugarcane and banana are the important crops grown in the coastal region. Main crops in the midland region are tapioca, pepper, cashew, coconut, ginger, pulses, oilseeds, coffee and rubber and those in the hills are rubber, coffee, tea and cardamom. Many of these products help the State to earn foreign exchange too.

Important seasonal crops are paddy, pulses, ragi, sesamum, sugar-cane, tapioca, groundnut, ginger, turmeric and cotton. About 10% of the cropped area is irrigated, mainly for the cultivation of paddy and sugar-cane.

The most important seasonal crop is paddy which has three important crop seasons:

i. Autumn (Virippu) crop corresponding to the southwest monsoon.

ii. Winter (Mundakan) crop corresponding to the Northeast monsoon.

iii. Summer (Punja) crop.

The present level of production can however meet only 50% of the State's requirements.

SLOPE

Corresponding to the physiographic zones, mainly six units of slopes are observed in the State (Fig.3.6).

i. Steep to very steep hill ranges

This is observed in the Sahyadris and adjoining midland, having an altitude of more than 300 m. and in the high level plateaus of the Western Ghats except in the Palghat Gap. Slope ranges from 70 to 100 percent.

ii. Moderate to steep sloping ridges

The upland zone having an altitude of 50 m. to 300 m. exhibit this slope range (55 to 60%). Steep and narrow valleys and ridges are features of these ranges.

iii. Gentle to moderate sloping spurs

This range with slope 10 to 20 per cent lie between the uplands and coastal plains. Isolated hillocks surrounded with slopes of steep gradient are observed here.

iv. Gentle to moderate sloping inter-hilly basins

This represents the Wayanad plateau which is

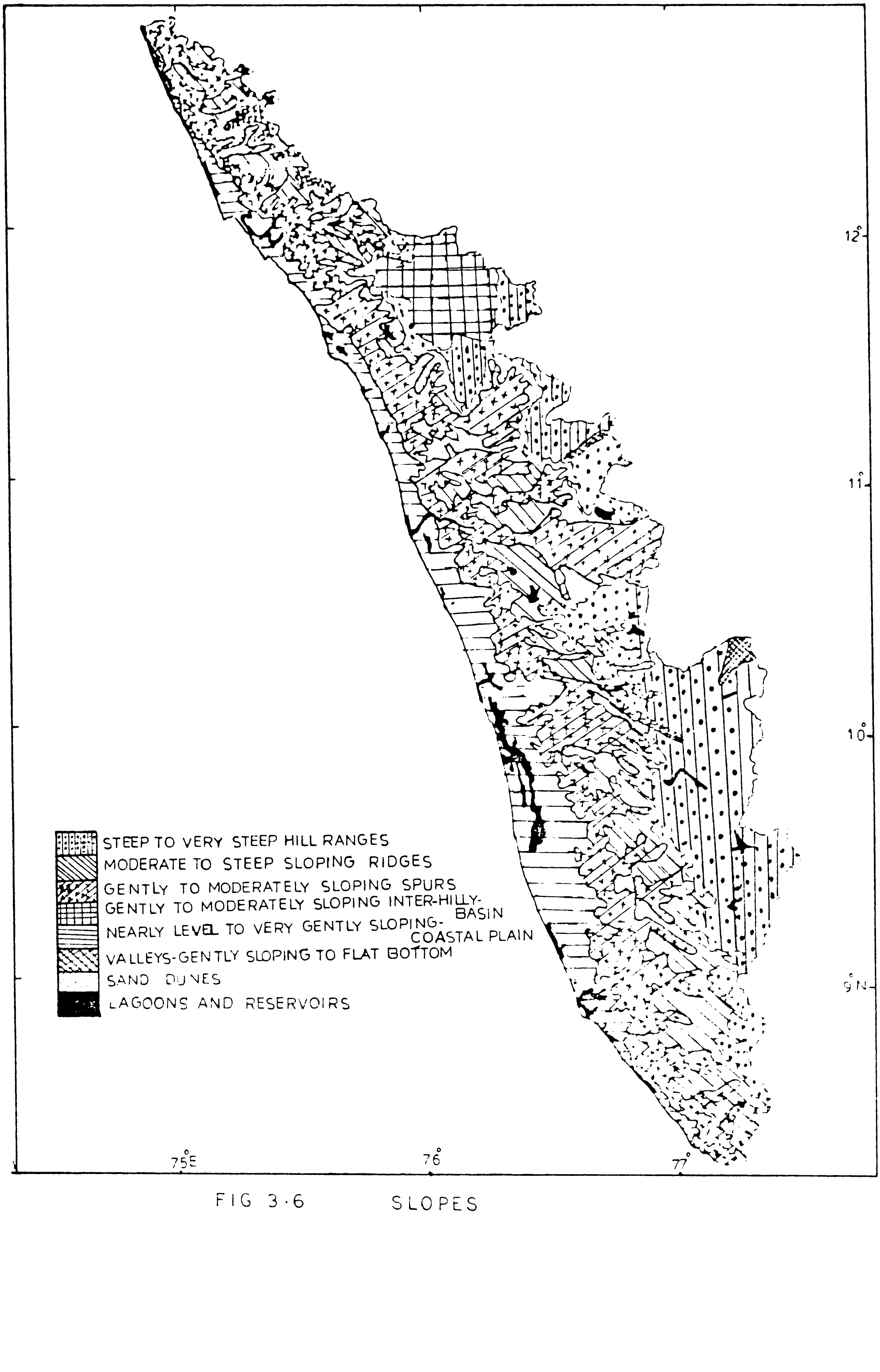

FIG 3·6 SLOPES

characterised by gentle to moderate slopes ranging from 10 to 20 per cent.

v. Nearly level to very gently sloping coastal plains

This range lie between the coastline and the 10 m.contour and is characterised by features like alluvial plains, lagoons, coastal dunes and mudflats.

vi. Valleys - gently sloping to flat bottom

This type of sloping pattern is observed along the river courses where the bed level is less than 50 m. Valley sections are broad and mostly U - shaped. Valleys have gentle slopes of 3 to 5 percent and gradually merge with the coastal plain.

NATURAL REGIONS

Considering the physiography, climate, soil and vegetation, the State can be divided into seven natural regions (Fig. 3.7). These regions are distinct and influence land use pattern and other human activities. (Resources Atlas of Kerala - Centre for Earth Sciences Studies, Trivandrum, 1985).

i. Eastern Highlands

This zone occurs in two patches, separated by Palghat Gap, and covers about 40% of the total area

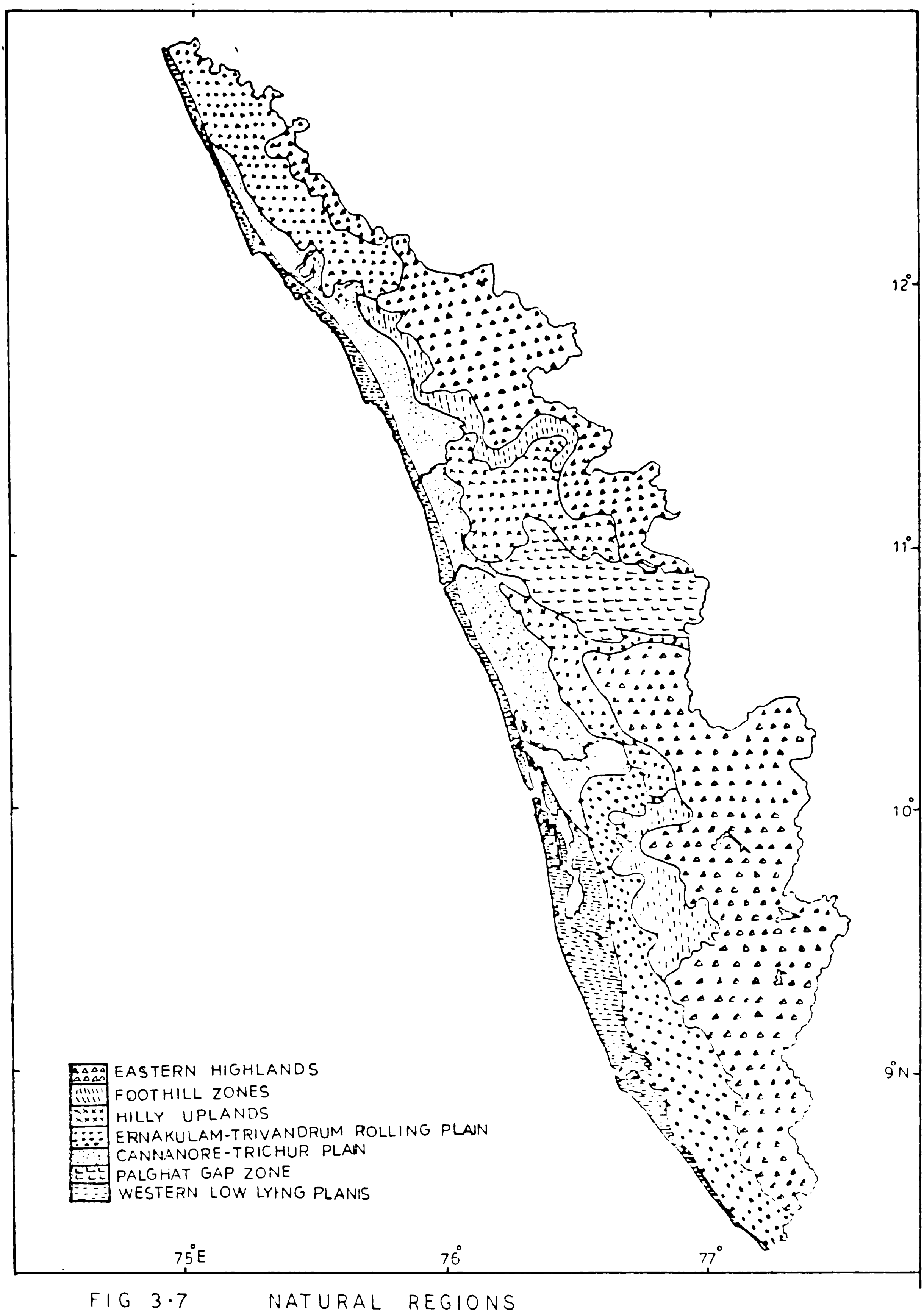

FIG 3·7 NATURAL REGIONS

of the State. Wayanad Plateau, Nelliampathy plateau and Periyar plateau which are bounded by steep scarp slopes occur in this zone. Rainfall varies from 200 cms. to 300 cms. in the western fringe and decreases towards the east. Local elevation differences within this zone produces pronounced temperature variations. Vegetation type varies from tropical rainforest to dry deciduous. The soil is forest loam with higher proportion of humus. Land use is dominated by plantations of tea, coffee and cardamom. A number of hydro-electric and irrigation projects are in this zone, especially in the southern parts.

ii. Flat Foothill Zone

This zone is marked in two narrow strips flanking the highland zone. Northern part surrounding the Wayanad plateau is characterised by near vertical scarp slopes of more than 600 m. height. The zone closely resembles the hilly upland zone, except that the rainfall here is very high and slopes are mostly concave. Tropical rainforest is the major natural vegetation. Soil is mainly laterite with patches of brown hydromorphic type in the enclosed valleys. Land use is dominated by tree crop culture.

iii. Hilly Uplands

This zone is located in three separate

patches within the midland region and receives comparatively lesser rainfall. Semi-evergreen and moist deciduous types of vegetation occur here. The northernmost segment is almost devoid of vegetation due to hard crust laterites. Plantations of rubber, tree-crops, tapioca, arecanut and pepper dominate.

iv. Palghat Gap Zone

This zone has a wide ranging influence on physical and cultural landscapes of the State. Flood plains, alluvial fans, residual hills and gently undulating plains define the topography of the zone. The region is dominated by laterite outwash, alluvium and black soils. Maximum crop diversification in the State is found in this area.

v. Ernakulam - Trivandrum Rolling Plain

Topography of this region in undulating with an average height of 40 m. The alluvial valleys cutting across the laterite soil support paddy cultivation. The entire area is devoid of natural vegetation.

vi. Cannanore - Trichur Plain

This is the northern counterpart of the Ernakulam - Trivandrum plain. But, it is less undulating and includes lowlying Kole lands of Trichur. Rainfall is comparatively less in the northern part of this zone.

vii. Western Lowlying Plain

This region extends along the coast and has an elevation of about 10 m. with hillocks and rock cliffs reaching a height of 50 m. at some places. Central part of the region surrounding Vembanad Lake, is a lowlying alluvial and suitable for paddy cultivation. The land use is dominated by coconut and paddy.

RIVER SYSTEMS

The copious rainfall from the two monsoons give rise to a number of rivers and streams which traverse the State. There are 44 rivers with numerous tributaries, all originating in the Western Ghats (Fig. 3.8), of these 41 flow westward to meet the Arabian Sea and 3 flow eastward to join the Bay of Bengal, crossing the State of Tamilnadu. Of the west-flowing rivers, some traverse a few kilometeres in the States of Tamilnadu and Karnataka, before entering Kerala State. The length of the rivers vary from 8 kms. to 250 kms. with an average length of 64 kms. (Table 3). The general direction of flow of the rivers are from north-west to south-east and from north-east to south-west. Many of the rivers are exploitable for irrigation and hydro-electric power generation.

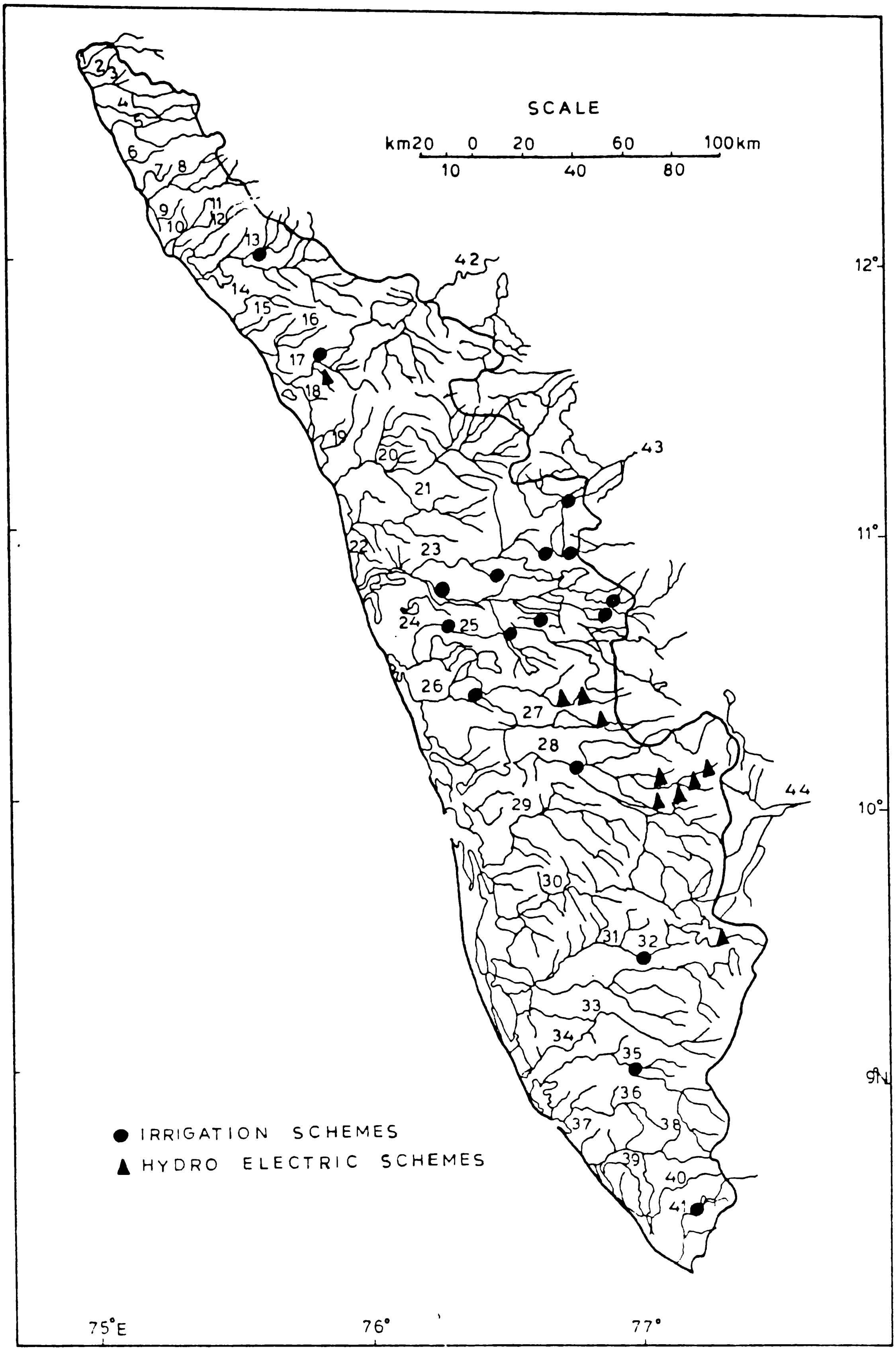

FIG 3·8 DRAINAGE PATTERN

TABLE 3.1

River Systems of Kerala

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	2	3	4	5	6	7
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	Nileshwar	46	190	1356	937	329
8	Karingode	64	429			
9	Kavvayi	31	143	1143	603	-
10	Peruvamba	51	300			
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	7135	2616	3541
19	Kallayi	22	96			
20	Chaliyar	169	1535			
21	Kadalundi	130	1122			

Contd......

22	Tirur	48	117	1165	60	221
23	Bharathapuzha	209	4400	6540	3349	4684
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
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	1324	889	755
38	Vamanapuram	88	687			
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)

The four major rivers - Periyar, Bharathapuzha, Pamba and Chaliyar - drain about 35% of the State. Total runoff of all these rivers is estimated to be about 78,041 million cubic meters (Mm^3). Of this, 70,323 Mm^3 is from the catchments within Kerala and the remaining from Karnataka and Tamilnadu. Out of this, 42,772 Mm^3 is utilizable quantity which can be fully exploited by careful planning.

LAKES AND BACKWATERS

There exists a continuous chain of lagoons and backwaters along the coastal line of Kerala. The Vembanad backwater is the most important estuarine system on the west coast of India itself. The other important backwaters in Kerala are : Kambla, Kalnad, Bekkal, Chittur, Valapattanam, Karapuzha, Kavvayi, Veliyangode, Cranganore, Perur, Kayamkulam, Ashtamudi, Anjengo, Katinamkulam and Veli. The backwaters are all interconnected by natural and man-made canals which form important navigation systems in the State. These backwaters and lagoons are connected to the sea through small openings. These openings are called ' 'Azhis' if they are permanent and 'Pozhis' if they are temporary. Some shallow portions of these backwaters are reclaimed for cultivation. A few fresh water lakes also exist in the State.

One major problem related to the existence of the backwaters is the intrusion of saline water into the rivers and canal beds. During the pre-monsoon months, flow from rivers practically ceases and saline water from the lakes and backwaters flows into the lower reaches of rivers. This adversely affects the cultivation and the supply of drinking water in the coastal areas.

CHAPTER IV

HYDROCLIMATOLOGY OF THE WESTERN GHATS REGION

The eastern boundary of Kerala is almost fully flanked by the Western Ghats and any hydrometeorological study of the State will be incomplete without a detailed reference to the Western Ghats.

The Western Ghats form an unbroken range of hills of length 1500 km. and lie on the Western Coast of Peninsular India (Fig. 4.1). With an average height of 900 metres and an orientation which is near north-south, it extends from 9°N in Kerala to 21°N in Maharashtra. The orography of the Ghats is one of the prominent factors that determines the climate of South India. The mountain ranges receive rain from both southwest and northeast monsoons though the rainfall received during northeast monsoon season is very low. The western side of the Ghats is directly exposed to the southwest monsoon winds and the forced ascent of the moist-laden air causes heavy rain on the windward side of the Ghats; the eastern (leeward) side, however receives scanty rainfall resulting in the dry climates of interior peninsula.

The stretch of Western Ghats that separate Kerala from the neighbouring states, has an elevation

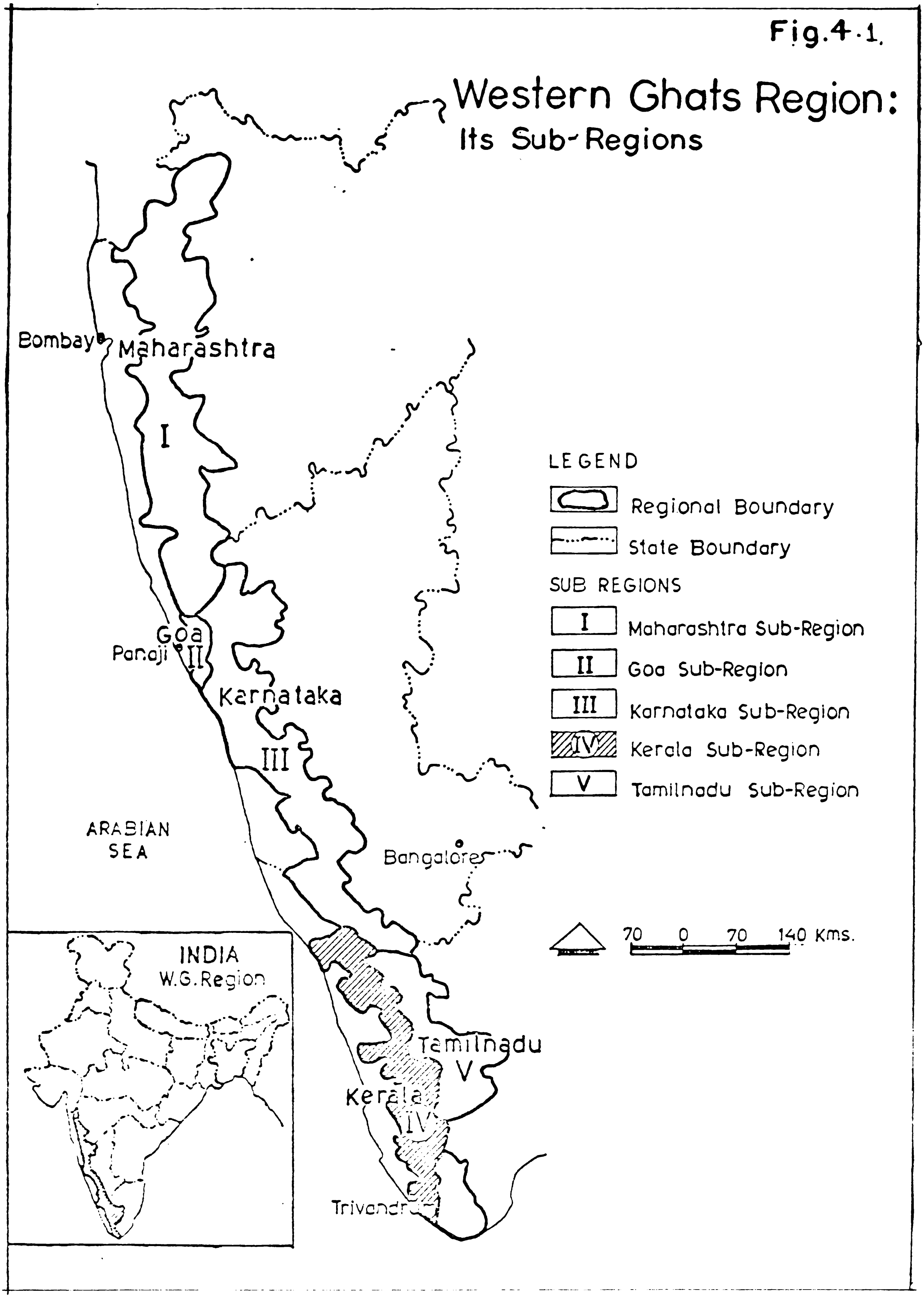

Fig.4.1.
Western Ghats Region:
Its Sub-Regions
Bombay
Maharashtra
I
Goa
Panaji
II
Karnataka
III
ARABIAN
SEA
Bangalore
Tamilnadu
V
Kerala
IV
Trivandrum
INDIA
W.G. Region
LEGEND
Regional Boundary
State Boundary
SUB REGIONS
I Maharashtra Sub-Region
II Goa Sub-Region
III Karnataka Sub-Region
IV Kerala Sub-Region
V Tamilnadu Sub-Region
70 0 70 140 Kms.

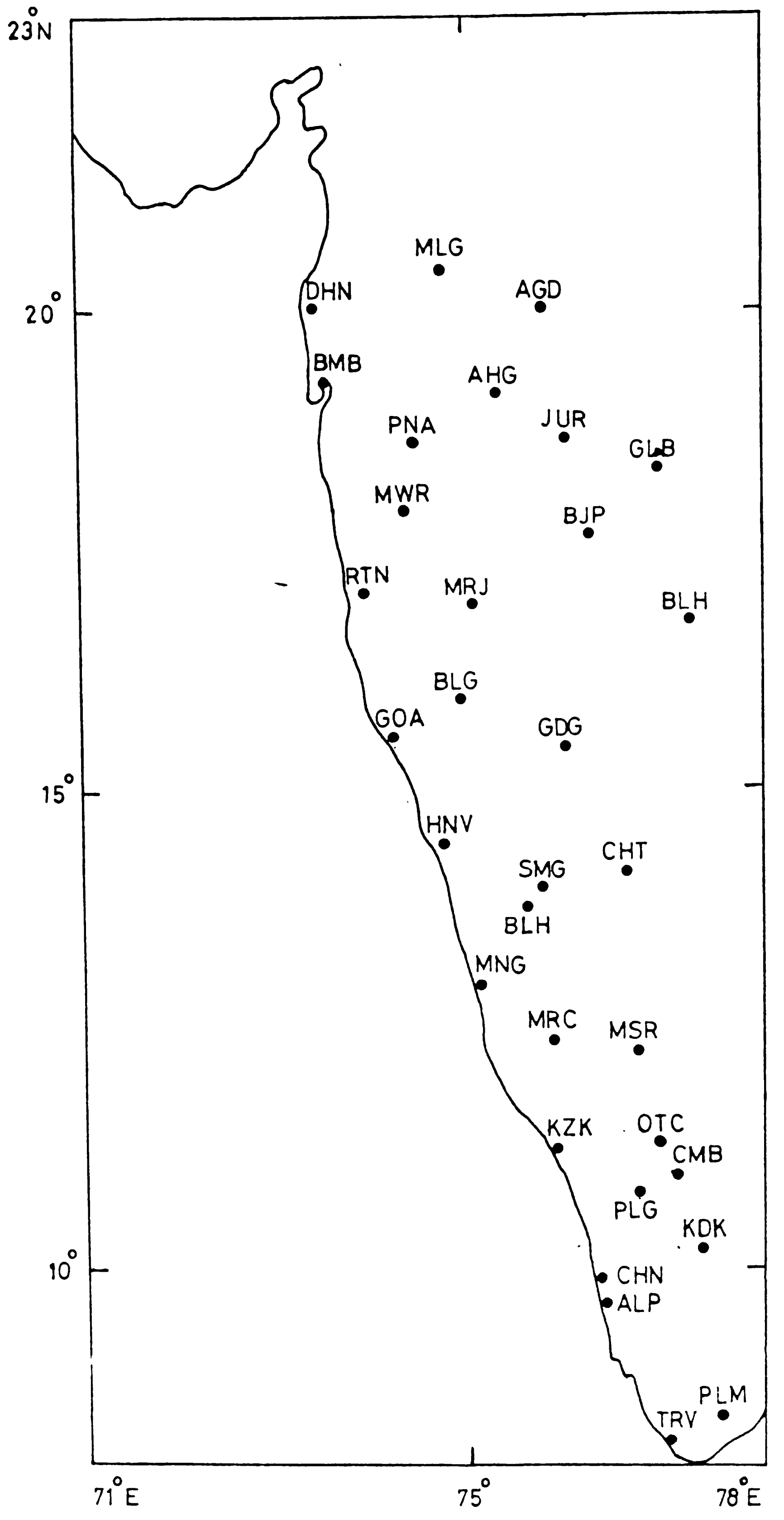

FIG 4.2. WESTERN GHATS REGION
LOCATION OF REPRESENTATIVE STATIONS

ranging from 760 m. to 1220 m. and peaks rising to over 2000 m. The highest peak in the Ghats, the Anamudi (2695 m.) is situated at the crest of Anamalai in the Idukki district of Kerala. East of Anamalai run the Palani hills on which the hill-station of Kodaikanal (2506 m.) is situated. South of Anamalai lie the Cardamom hills and to the north, the Nilgiris where the peak Doda Betta (2640 m.) is situated. To the north of Nilgiris lie the Coorg mountains that divide the northern part of Kerala from Karnataka.

In this chapter, rainfall and temperature data for 32 representative stations in the Western Ghats region (Fig. 4.2) have been analysed, in an attempt to study the hydroclimatology of the region.

STUDY OF HYDROCLIMATIC PARAMETERS

i. Rainfall distribution

The distribution of rainfall in the Western Ghats region is influenced by the latitude and height of the station and exposure to the monsoon winds. There is a variation in the rainfall from north to south and also west to east. On the windward side, the rainfall is very high, ranging between 150 cms. and 300 cms. due to the orographic effect of the Ghats (Fig. 4.3). On the leeward (eastern) side, rainfall decreases to 50 cms. In general, higher

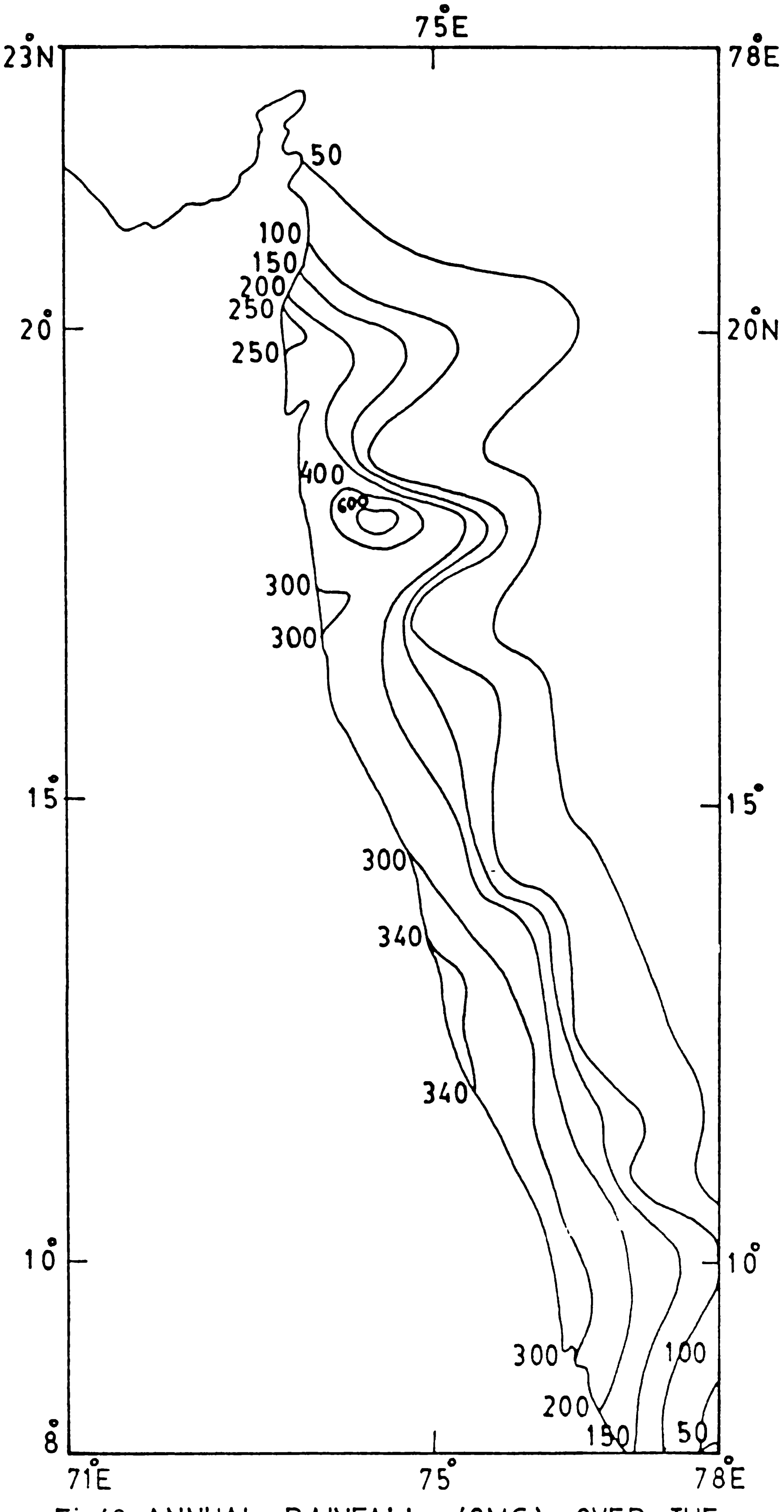

Fig4.3. ANNUAL RAINFALL (CMS) OVER THE WESTERN GHATS REGION

amounts of rainfall are noticeable in the coastal areas which decreases inland. But, pockets of very high rainfall are observed in the higher altitudes. Amboli (650 m.ASL) which receives 748 cms. of rainfall annually is the station with highest amount of rainfall in this region, followed by Gaganbavada (690 m.ASL) which receives 621 cms. and Mahabaleshwar (1382 m.ASL) which receives 618 cms. of rainfall in an year. In order to smoothen the isolines, some of such values are not plotted in the figures. From the studies using rainfall data for the period 1900 to 1980, it is found that there are a number of stations in the high altitudes of the Ghats which receive more than 400 cms. of rainfall (Table 4.1).

Along the coast, rainfall increases towards the central region, both from south and north. A considerable decrease in rainfall is observed in the northernmost and southernmost parts where the Ghats end. Exposure to the moist-laden winds is an important factor in determining the rainfall of the Ghats region which is clearly shown in the amount of rainfall received in Ootacamund. Vythiri and Devala in the Nilgiris receive 400 cms. of rainfall whereas Ootacamund east of it and on a slightly lower latitude receives only 138 cms. of rainfall. This is because Ootacamund lies about 25 km. inland from the

TABLE 4.1

Annual Rainfall in the Western Ghats

Station	Latitude	Number of Rainy Days	Rainfall (Annual)
1. Pirmed	9^{o} 34'	167	517 cms.
2. Kanjirappally	9^{o} 34'	153	416 cms.
3. Anamalai	10^{o} 35'	151	424 cms.
4. Vythiri	11^{o} 33'	135	444 cms.
5. Kuttiyadi	11^{o} 40'	135	450 cms.
6. Makut	12^{o} 05'	143	505 cms.
7. Bhagmandala	12^{o} 23'	151	603 cms.
8. Karike	12^{o} 28'	148	486 cms.
9. Amboli	16^{o} 00'	125	748 cms.
10. Gaganbavada	16^{o} 33'	129	621 cms.
11. Mahabaleshwar	17^{o} 56'	119	618 cms.
12. Lonavala	18^{o} 45'	107	430 cms.

western edge of Nilgiri plateau and therefore the air loses most of the moisture before reaching there (Dikshit, 1979). Increase in the height of the Ghats north of 16^{O}N produces areas of very high rainfall between 16^{O}N and 18^{O}N. Amboli (748 cms.), Gaganbavada (621 cms.) and Mahabaleshwar (618 cms.) lie in this region. North of 18^{O}N, rainfall decreases because of the decreasing height and changing alignment of the Ghats and also the depletion of the force of the monsoon winds. Stations lying on the leeward side of the Ghats, especially those in Tamil Nadu are exposed to the northeast monsoon winds and receive some rainfall in October and November.

Coming to the seasonal distribution, the rainfall increases towards the south during the pre-monsoon season (Fig. 4.4). Also, an increase is noticeable towards the coast except in the northern parts of the Ghats region. Stations in the northern parts receive less than 10 cms. of rainfall while it increases to more than 60 cms. in the coastal area of southern parts. The isohyets do not follow the orientation of the Ghats. This is because rainfall occurrence during this season is due to local systems which are not comparable with large systems such as monsoons.

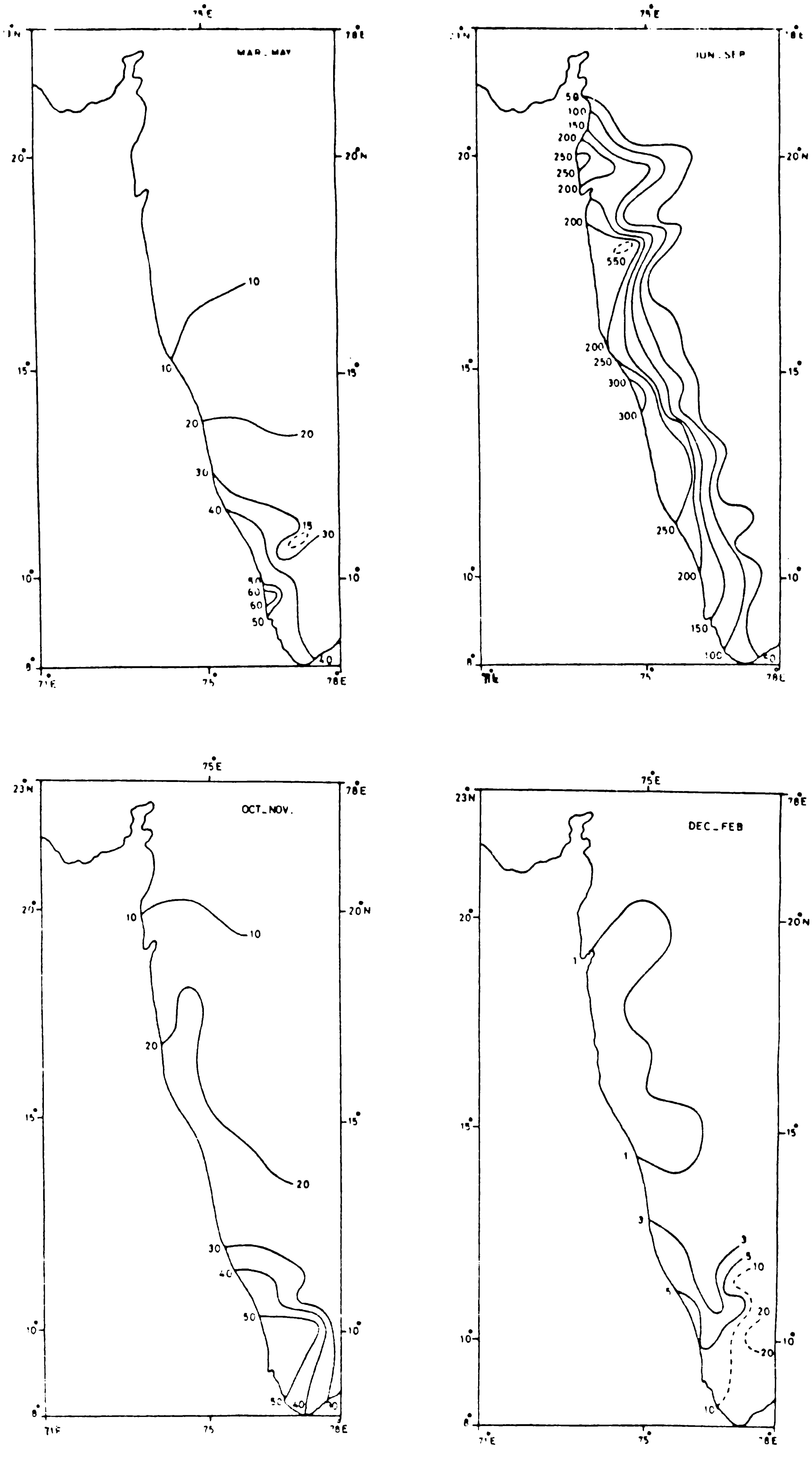

FIG. 4.4. SEASONAL RAINFALL (CMS)

During the southwest monsoon season, most of the stations in the Ghats region receive more than 75% of their annual rainfall. Rainfall increases from less than 50 cms. on the eastern side of the Ghats to more than 250 cms. on the coastal zone. An increase is clearly observed towards the central sector of coastal region from south and north where the rainfall is more than 300 cms., Pockets of very high rainfall mentioned earlier receive more than 80% of their rainfall during this season. As in the case of annual rainfall, the isohyets follow the orientation of the Western Ghats.

Rainfall pattern during the northeast monsoon season is somewhat similar to that of the pre-monsoon season. Rainfall varies from around 10 cms. in the northern parts to more than 60 cms. in the southern coastal area. Rainfall generally decreases from west to east. Rainfall during this season is important as the moderate climate of the region, the rich vegetation cover, the double-cropping of paddy crop and generation of hydro-electric power depend on it. It helps the recharge of soil moisture before it is completely exhausted.

Winter is a period of scarce rainfall in the Ghats region. Though some stations in the southernmost part get around 10 to 20 cms. of rainfall, the amount decreases considerably towards the north: about 3 to 5 cms. of rainfall in some areas and in others around 1 cm. or negligible rainfall during this period.

ii. Distribution of the number of rainy days

Number of rainy days roughly follows the amount of rainfall, though some exceptional cases are there. It varies from 30 in the extreme north of the Ghats region to more than 120 days in the coastal area of the southern part (Fig. 4.5). The number decreases to 45 in the eastern side of the Ghats and to the extreme south of the Ghats region. Values of around 120 are observed south of 15°N and exceptionally high values are noted in some high altitude regions of the Ghats where amount of rainfall received is also very high. The decreasing pattern of the number of rainy days from south to north does not follow the annual rainfall pattern which shows an increase towards the centre and thereafter, a decrease. This shows that the intensity of rainfall is highly variable in the Ghats region. Detailed study of such parameters are made for the State of Kerala which will be described in the next Chapter.

The higher values in the southern part is due to the early onset of monsoon in this region compared to the north and also due to the rainfall received during the northeast monsoon season. Kerala, especially

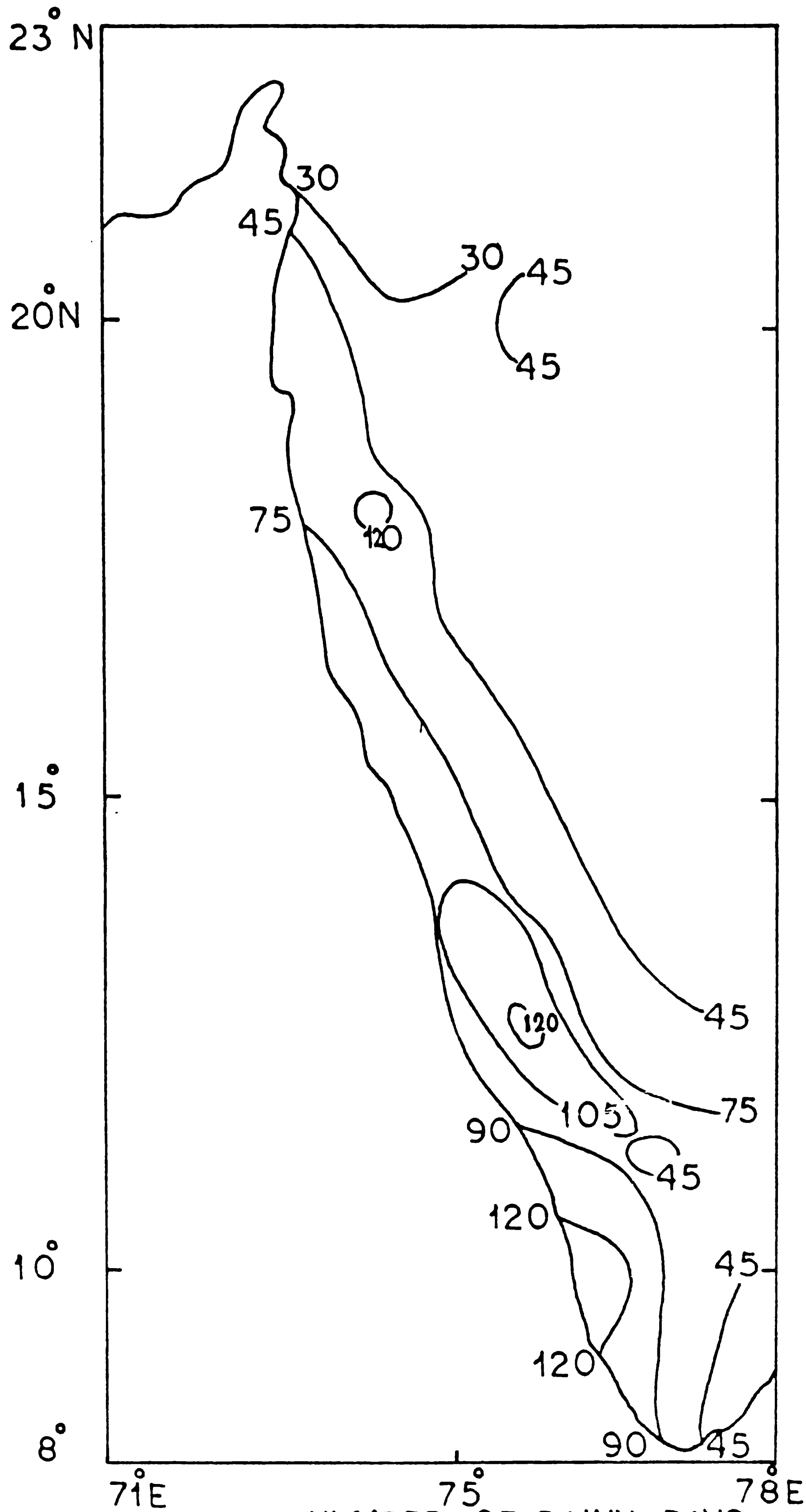

Fig. 4.5. NUMBER OF RAINY DAYS
ANNUAL

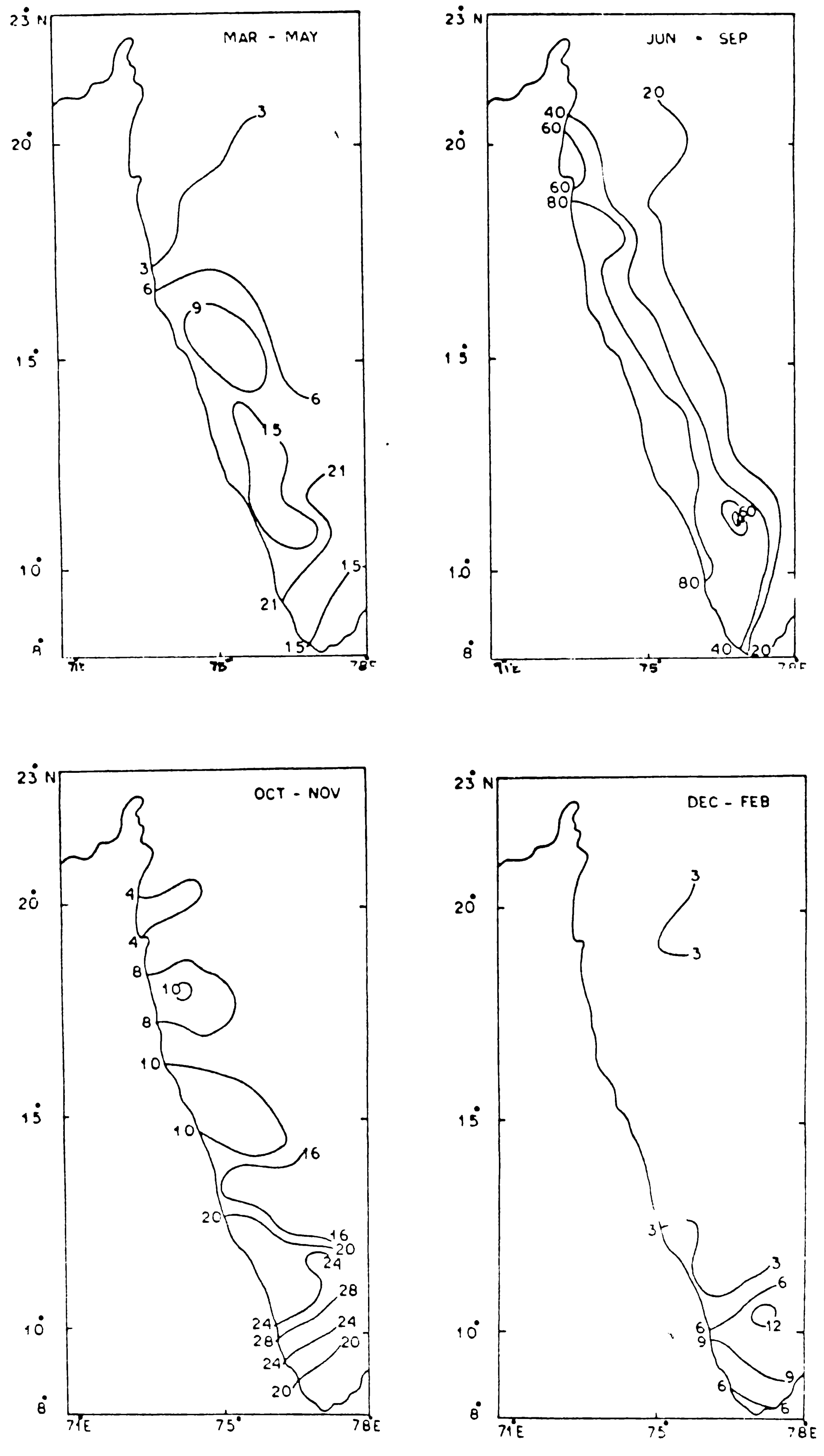

FIG.4.6. NUMBER OF RAINY DAYS – SEASONAL

the southern part of it, receives rainfall in all months of the year, though the intensity is low. In the northern end of Kerala and further north upto the Maharashtra coast, though the rainfall is much higher than the southern sector, the number of rainy days does not show a similar increase. From this, it can be inferred that, the intensity of the southwest monsoon rainfall is more over north Kerala and beyond compared to southern districts of Kerala.

On a seasonal basis, patterns of the number of rainy days are similar to that of annual, except for a small variation during the southwest monsoon season (Fig. 4.6). During pre-monsoon season, the number of rainy days is only 3 in the northern parts which increases to 6 and 9 in the central parts and to 21 in the southernmost region. Further south, it decreases to 15.

During the southwest monsoon season, the isolines of the number of rainy days follow the orientation of the Ghats and the isohyets of annual rainfall. The values range from 20 in the eastern side of the Ghats to 80 in the coastal area. Along the coast, values decrease to 40 in the extreme north and south.

During the northeast monsoon season, the pattern of the number of rainy days is somewhat similar to that during the pre-monsoon season, but with higher values. On an average, rainfall is received on 4 days in the northern region, and on 8 days over southern Kerala. It is received on 10 days in the central region and the number again increases further south which is upto 28 in the southern coastal region. Thereafter it decreases to 20.

The number of rainy days is practically zero in the Ghats region except in the southern parts during winter. In the northernmost part, however, some stations get rain upto 3 days, in the eastern side of the Ghats. Rainfall is recorded upto 12 days in the southern region.

iii. Seasonality of rainfall

The Ghats region has an abundant water potential which can be exploited for various purposes such as agriculture, irrigation, hydel power generation, industries and municipal use. However, variability of rainfall in space and time significantly affects the availability of water in the required amounts over different regions in different seasons. Therefore, an assessment of the seasonality of rainfall assumes great importance in planning any project related to agriculture or hydrology. As mentioned earlier, western side of the Ghats experiences heavy rainfall while dry climates dominate the eastern side of it. The temporal distribution of precipitation is uneven, with most of the rainfall occuring in the southwest monsoon season. The seasonality of rainfall over the Western Ghats region is studied using a simple index defined by Walsh and Lawler (1981).

Seasonality Indices for the Western Ghats region (Fig. 4.7) have a wide range from "low equable" to "highly seasonal" categories. Among the 32 stations selected for this study, the lowest value is observed at Kodaikanal (o.40) and the highest at Mahabaleshwar (1.23). Isolines run parallel to the Ghats with values increasing towards the north and towards the coast. The values range from 0.6 to 1 in the southern coastal areas and 1 to 1.2 further north with values exceeding 1.2 in certain regions in the central and northern coasts. The degree of seasonality of rainfall seems to be associated with latitude, as evidenced by the generally increasing values towards the north. Also, altitude alone is not a factor that determines the seasonality because the high altitude stations in the south do not exhibit higher values. The lower values in the south are mainly because of the rainfall

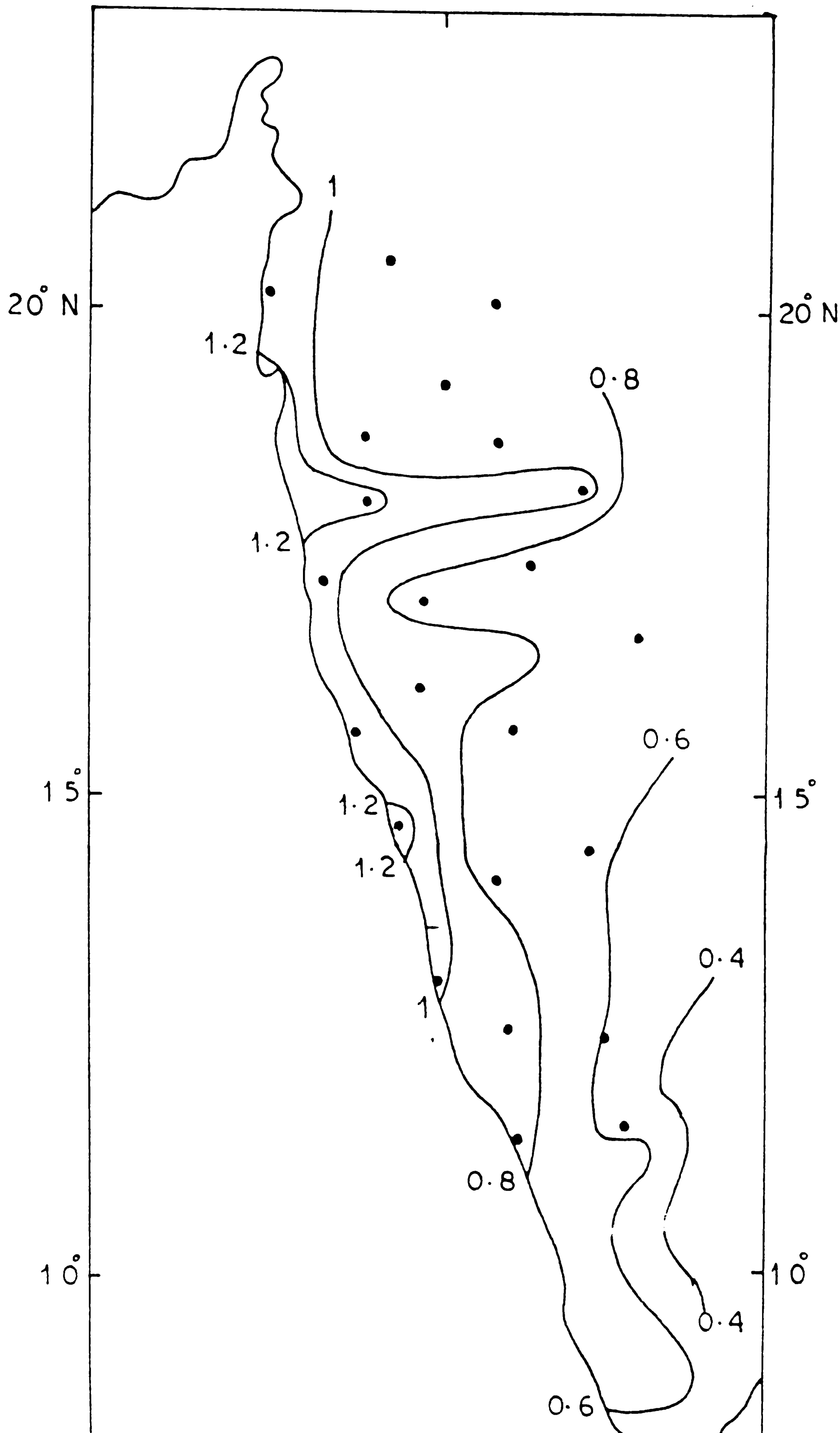

FIG. 4.7. VALUES OF SEASONALITY INDICES IN THE WESTERN GHATS REGION.

received during the northeast monsoon season. Also no stations in the southern region is free from rainfall in any month.

The ratios ($\overline{SI}/\overline{SI_i}$) at three stations - Kodaikanal, Shimoga and Mahabaleshwar - representing the low equable, moderately seasonal and highly seasonal categories respectively are presented below:

TABLE 4.2

Mean Seasonality Indices Derives from

(a) Mean Monthly Data ($\overline{SI}$) and

(b) Averaging Individual Year Data ($\overline{SI_i}$)

Station	Mean annual rainfall (cms.)	$\overline{SI}$	$\overline{SI_i}$	$\overline{SI}/\overline{SI_i}$
Kodaikanal	167	0.40	0.64	0.63
Shimoga	105	0.78	0.92	0.85
Mahabaleshwar	618	1.23	1.25	0.98

Seasonality values based on individual year data ($\overline{SI_i}$) are all higher than those based on climatic data ($\overline{SI}$), showing wide fluctuations in the annual rainfall regimes. The ratio is higher for stations exhibiting higher seasonality of rainfall (larger $\overline{SI}$ values) indicating greater conservatism of annual rainfall patterns.

The lowest value of ($\overline{SI}$ / $\overline{SI}_i$) ratio for Kodaikanal (0.63) indicates the least reliability of annual rainfall and that the peak rainfall does not occur with any particular timing or degree of concentration. Maximum rainfall has occured at Kodaikanal in all the months of the year except February, May and June. Percentage frequency of occurrence of maximum rainfall is 14% in August, 30% in October and 34% in November.

Distribution of rainfall is more reliable in Shimoga where the ratio is 0.85 though annual rainfall (105 cms.) is lower than in Kodaikanal (167 cms.). Most of the rain occurs from May to October and the peak may occur in any of the six months from June to November. The percentage frequency of occurrence of maximum rainfall is 63% in July.

The value of 0.98 for Mahabaleshwar indicates the high reliability and conservation of annual rainfall. Rainfall mostly occurs in the months of June to September and the peak occurs in a spread of three months only - June to August. About 78% of the peak rainfall occurs in July and 20% in August.

Amboli, the station which records the highest amount of rainfall in the Western Ghats region, also has a highly reliable rainfall pattern. Rainfall occurrence is mostly in the months of June to September and 75% of the peak rainfall occurs in July.

The study reveals that rainfall is more uniformly distributed throughout the year in the elevated regions of the Ghats than in the lower altitudes. Similarly, the southern portion of the Ghats experiences more uniformly distributed precipitation than the northern regions. But, the higher values of seasonality based on individual year data and climatic data indicate that annual rainfal pattern has wide fluctuations in the entire Ghats region.

iv. Index of water availability

The index of water availability is the percentage ratio of actual evapotranspiration to precipitation. It explains how much of the precipitation is actually returned to the atmosphere and how much is actually utilizable. This parameter is important for agricultural and hydrological planning.

The index values show that the rainfall that is received in the eastern side of the Ghats is fully returned to the atmosphere (Fig. 4.8). In the coastal area, only 40% of the water is lost by evapotranspiration and the rest is available for exploitation. But, the loss of water is more along the southern coastal area, where 60% to 80% of the available water is lost to the atmosphere. Loss of water increases

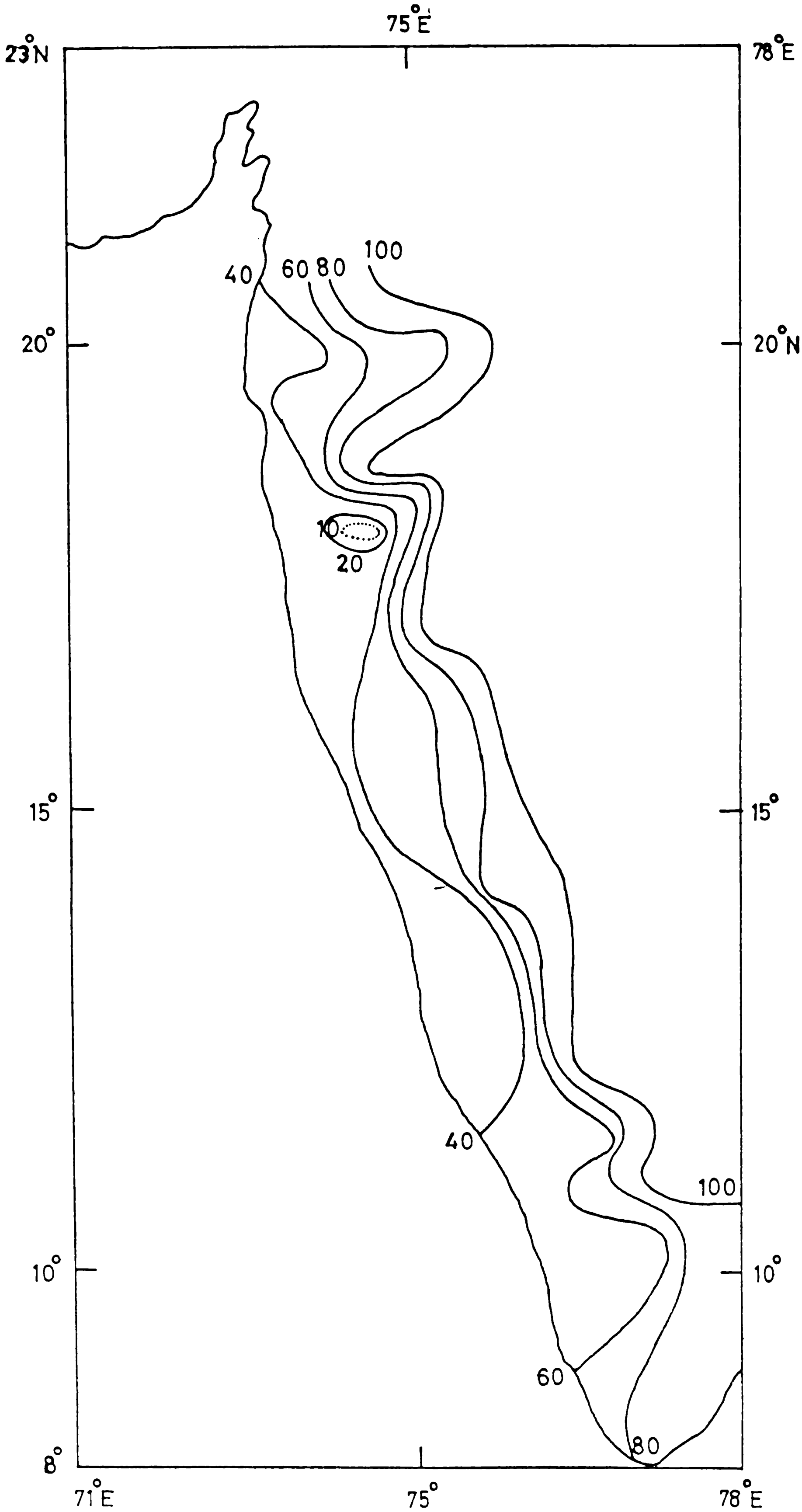

FIG 4.8. INDEX OF WATER AVAILABILITY

from the coastline towards the east. In the stations selected for this study, only Mahabaleshwar is an exception where only 10% of the water is returned to the atmosphere in an year. The isolines follow the isohyets and the orientation of the Ghats.

WATER BALANCE OF THE WESTERN GHATS REGION

The Western Ghats region, which is the second rainiest region in the country has an abundant water potential that is exploitable. As rainfall occurs in this region mainly during one season (southwest monsoon) only, a comprehensive quantitative study of the availability of the water resources is necessitated for meeting the water requirement in other seasons. Water balances of thirtytwo stations in the Western Ghats region have been studied on an annual and seasonal basis.

i. Potential Evapotranspiration

Distribution of the annual potential evapotranspiration (P.E.) follows the orientation of the Ghats (Fig. 4.9). Water need (P.E.) is more in the western side of the Ghats than in the eastern side. Along the coast, it is more than 170 cms. south of 12° N and also in the north around Bombay. The P.E. values decrease to less than 145 cms. in the eastern side of the Ghats. Stations in the high elevations

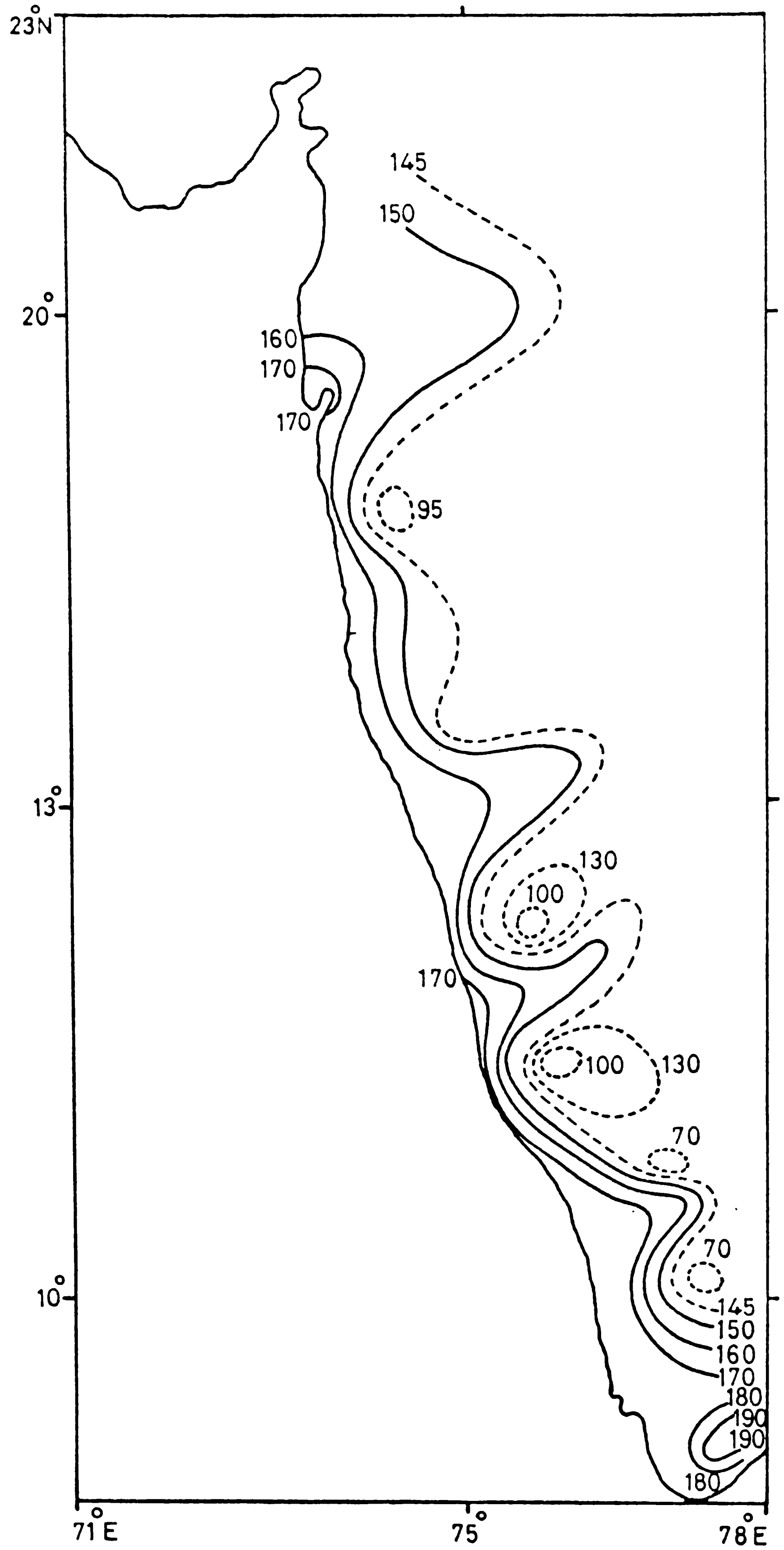

FIG. 4.9. POTENTIAL EVAPOTRANSPIRATION - ANNUAL (CMS)

of the Ghats such as Mahabaleshwar (95 cms.), Balehonnur (100 cms.), Mercara (100 cms.), Ootacamund (70 cms.) and Kodaikanal (70 cms.) exhibit comparatively low water need. In the extreme south, very high values of P.E. are found around Palayamkottai (190 cms.).

ii. Actual Evapotranspiration

As in the case of P.E., the Actual Evapotranspiration (A.E.) is more on the western side of the Ghats than in the eastern (Fig. 4.10). On the western side, A.E. values range from 90 cms. to 110 cms. in the northern half (north of 15°N) and from 110 cms. to 150 cms. in the southern half (south of 15°N). A.E. values more than 150 cms. are found in the coastal region around Alleppey and Cochin. In the eastern side of the Ghats, A.E. decreases to 70 cms.

iii. Water Deficit

The amount of water deficit depends more on the temporal distribution of rainfall than the total amount. Figure 4.11 which shows the annual water deficit in the Western Ghats region does not exhibit a pattern that follows the orientation of the Ghats. In general, the deficit values decrease from 70 cms. in the north to 30 cms. in the south, because of the influence of the northeast monsoon in the south. As discussed earlier, the northern regions exhibit greater seasonality of rainfall (Fig. 4.7). The

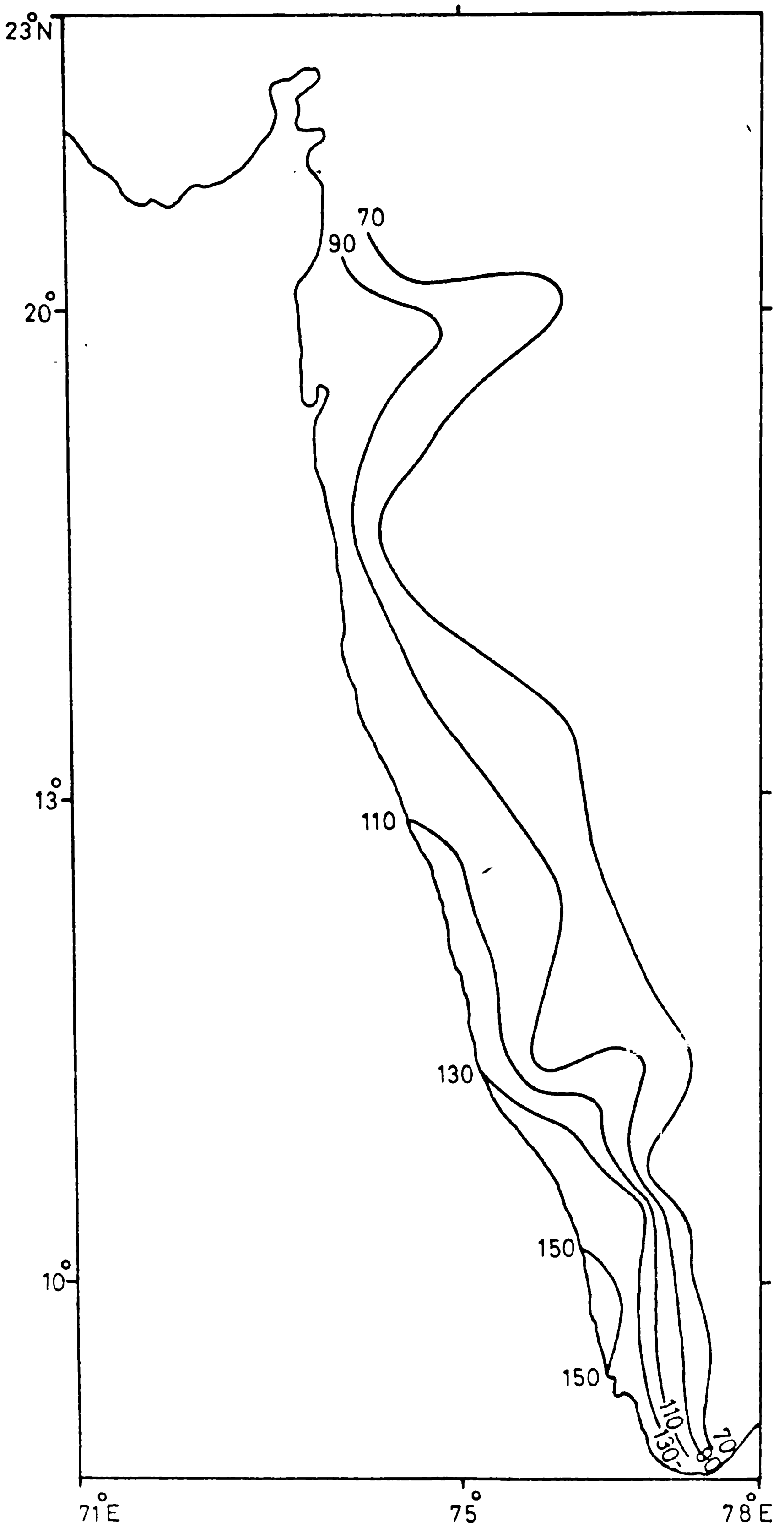

FIG.4.10. ACTUAL EVAPOTRANSPIRATION – ANNUAL (CMS)

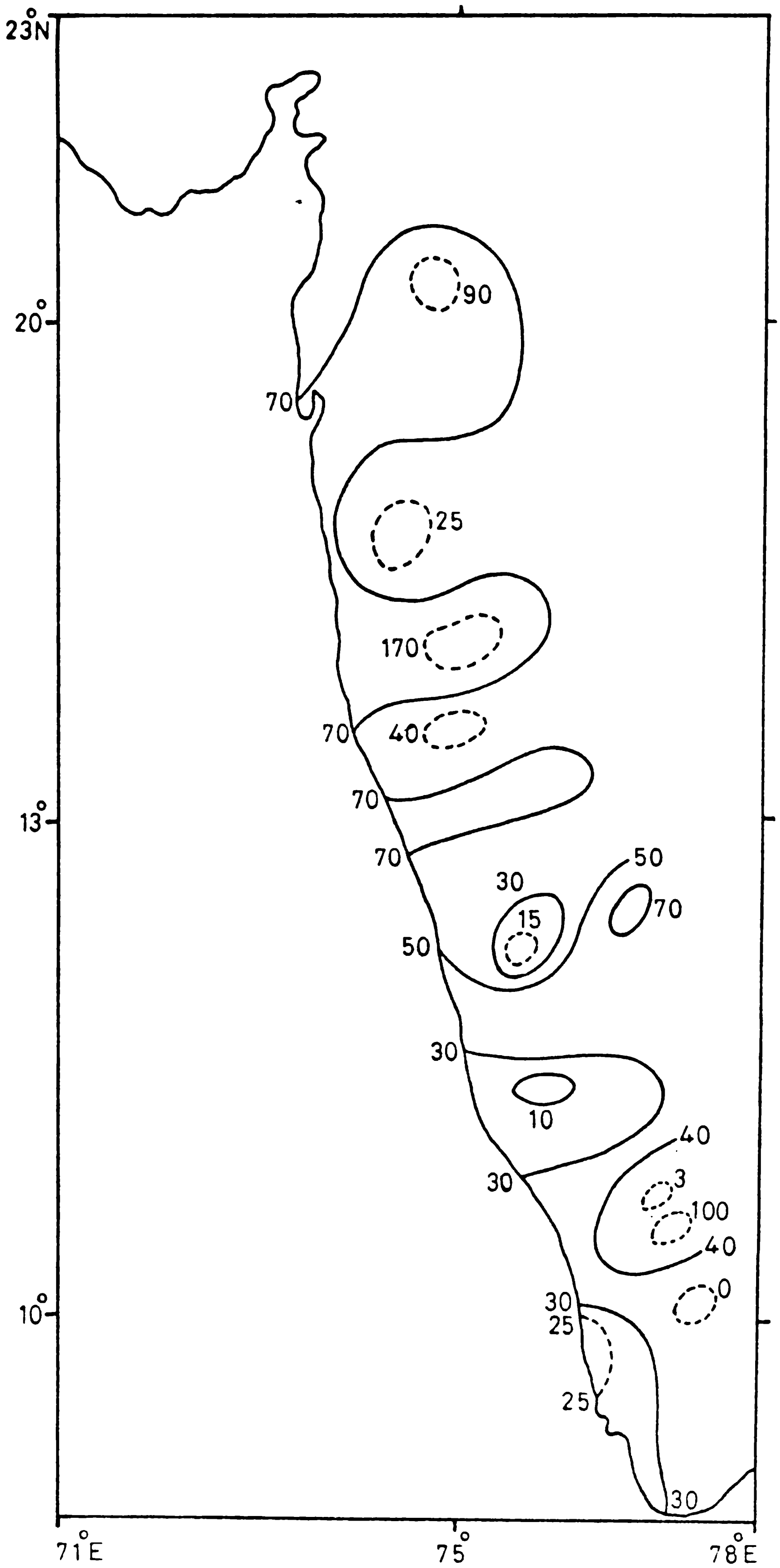

FIG. 4.11. ANNUAL WATER DEFICIT (CMS)

deficit decreases to 25 cms. in the coastal region around Alleppey and Cochin. Kodaikanal is the only station which experiences no water deficiency in an year and Miraj (170 cms.) is the station which exhibits maximum water deficiency in the Ghats region, followed by Coimbatore (100 cms.). However, water deficiency in the elevated areas of the Ghats are less compared to other areas, as exemplified by Kodaikanal (0), Ootacamund (3 cms.), Mercara (10 cms.), Balehonnur (15 cms.) and Mahabaleshwar (25 cms.). Here too, the decrease in water deficit from north to south is noticeable.

iv. Annual and Seasonal Runoff

On a climatic basis, the surplus water that occurs at any station appears an runoff which is distributed through months. On the western side of the Ghats, annual runoff values are very high (Fig. 4.12) while runoff is non-existent on the eastern side. Runoff upto 240 cms. are observed around Honaver and Mercara and upto 400 cms. around Mahabaleshwar. With values increasing towards the coast and towards the centre from south and north along the coast, the isolines of runoff closely follow the isohyets. But, the amount of rainfall that appears as runoff is more in the high altitude regions.

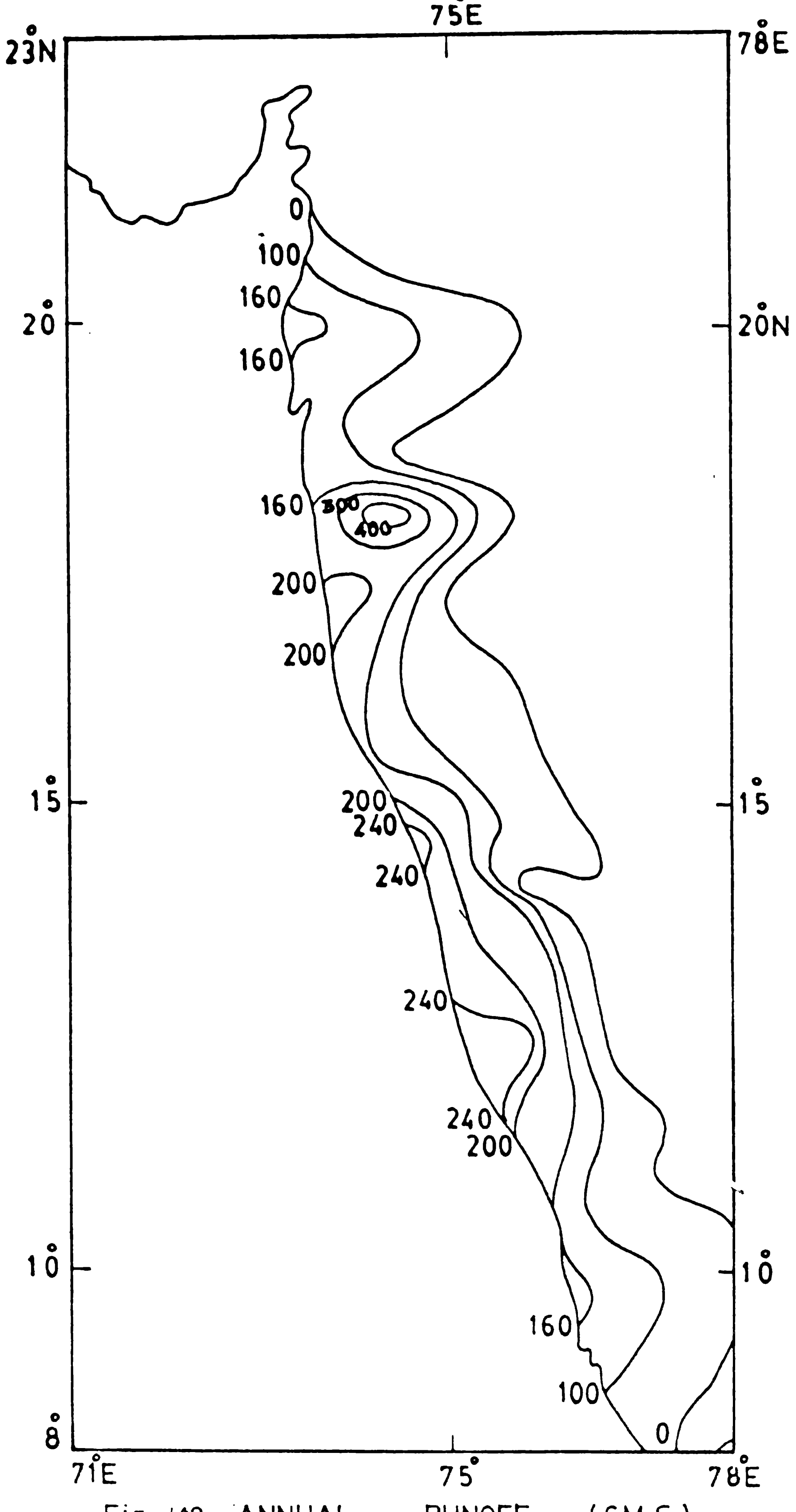

Fig. 4.12 ANNUAL RUNOFF (CMS)

Runoff values during the pre-monsoon season (Fig. 4.13) vary from 1 cm. in the north and central coastal areas to 5 cms. in the southern coast. Except for Kodaikanal, there is no runoff in the high altitude regions.

During the southwest monsoon season, runoff increases and values range from 50 cms. to 150 cms.. Maximum values are around Mahabaleshwar (500 cms.) and Mercara (200 cms.). Runoff pattern resembles the rainfall pattern in this period.

During the northeast monsoon season, considering rainfall-runoff relation, more water appears as runoff in the entire Ghats region. This may be due to the fact that soil moisture conditions have been satisfied and groundwater acquifers and surface water storages have been filled from the abundant southwest monsoon rainfall. Runoff values range from 10 cms. to 40 cms. and the increase is towards the coast and towards the south.

During the winter season, runoff is observed only in the southern half of the Ghats region, in the low altitudes. Runoff is more compared to the rainfall which may be due to the northeast monsoon rainfall in this region and the release of groundwater.

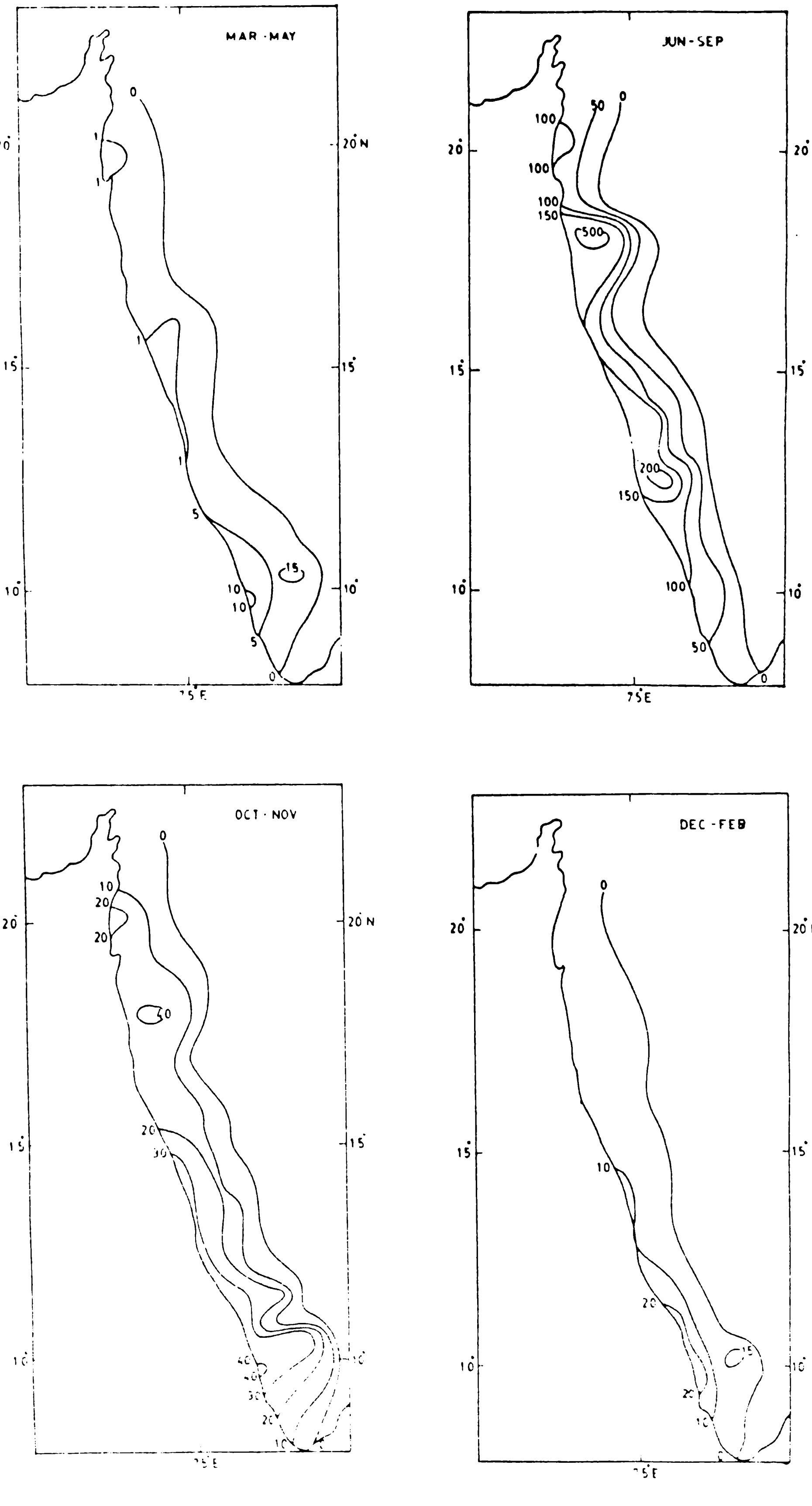

Fig. 4.13. SEASONAL RUNOFF (cms)

v. Water Detention

Detention values upto 5 cms. are noted in the southern region in the pre-monsoon period (Fig. 4.14), but for most other parts of the Ghats region there is no detention at all except for some small areas in the northern and central coasts where a detention of 1 cm. is observed. Detention values upto 200 cms. are found in the coastal regions during southwest monsoon season. Values decrease to between 15 cms. and 60 cms. during the northeast monsoon season. Values increase towards the southern coastal area. No detention is found in the northern half of the Ghats region during the winter season. In the southern half, values range from 10cms. to 30 cms. In all these seasons, detention of water is observed mainly in the low altitude regions.

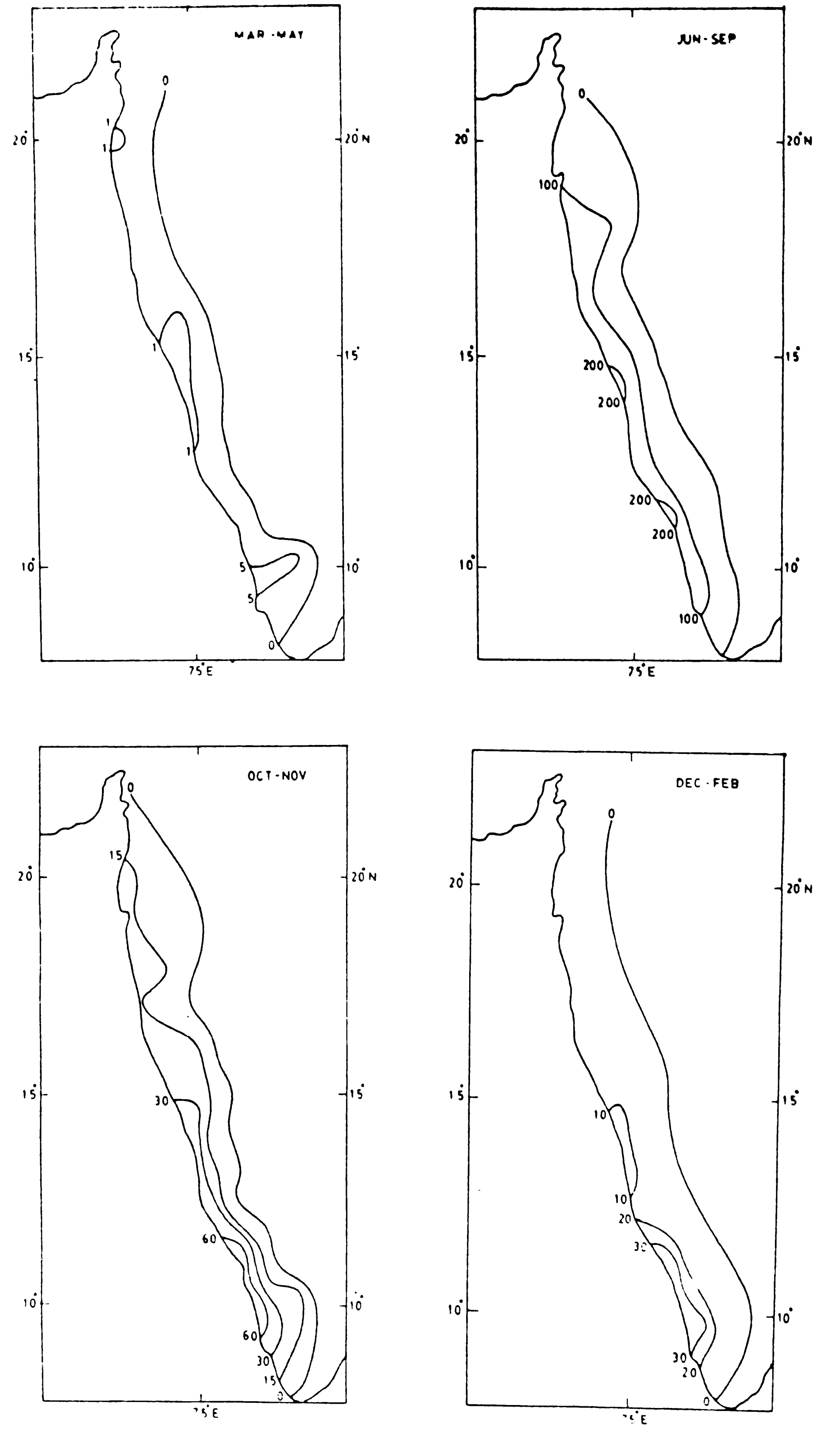

Fig. 4.14. SEASONAL DETENTION (cms)

CHAPTER V

HYDROMETEOROLOGICAL STUDIES OF KERALA STATE

It is now abundantly clear that the Western Ghats have an overpowering influence on Kerala as the prosperity or otherwise of the agriculture-based economy is inextricably linked to the water resources provided by the Ghats to the State. The water resources, in turn, are dependent on the temporal and spatial distribution of rainfall, the water balance and its variations, the consequent climatic shifts and the variability of the water surpluses and runoffs that occur over the Ghats.

The Kerala sub-region of the Western Ghats covers 21,856 sq. km. which is 56.25% of the total area of the State, but with only 32.25% of the population. More than 90% of the population in this region lives in rural areas.

An attempt is made here to understand the hydrometeorology of Kerala State in relation to the hydroclimatic features of the Western Ghats already discussed in Chapter IV. Data from 50 representative stations have been studied for this purpose (Fig. 5.1).

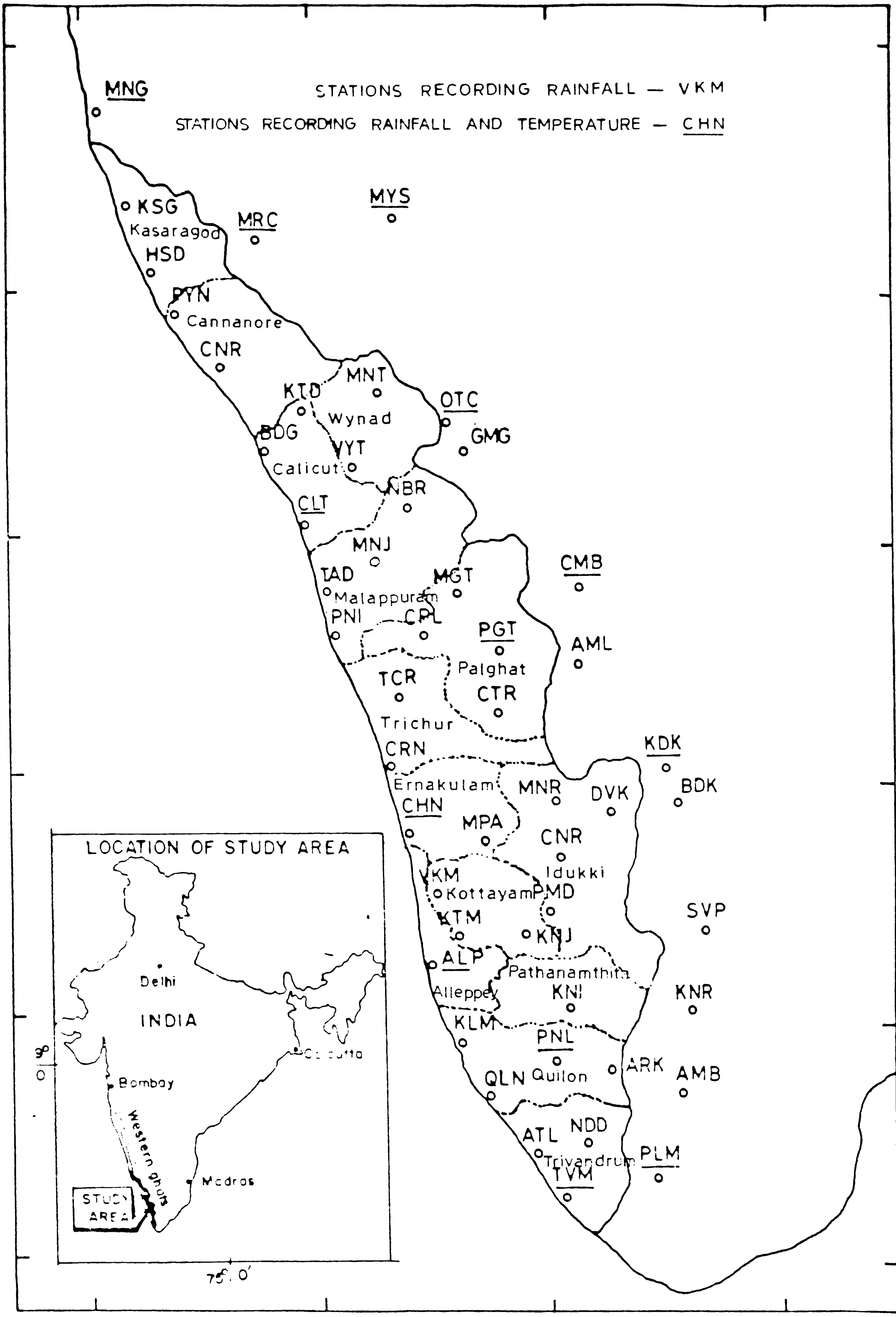

FIG. 5·1 KERALA — LOCATION OF REPRESENTATIVE STATIONS

SECTION I. ANALYSIS OF RAINFALL

i. Distribution of rainfall

Kerala receives the highest annual rainfall among the States of India - about 300 cms. in an year which is three times the average rainfall of India. The State receives rainfall for almost ten months in an year from both monsoons and local systems though most of the rainfall occurs during the southwest monsoon period.

Annual rainfall increases along the west coast from 150 cms. in the south to more than 350 cms. in the north (Fig. 5.2). Rainfall decreases sharply across the eastern side of the Ghats and the isohyets follow a predominant north-south orientation in their vicinity. There exist two pockets of heavy rainfall, around Pirmed (491 cms.) and Kanjirappally (410 cms.) in the south and around Vythiri (437 cms.) and Kuttiyadi (435 cms.) in the north. The highest rainfall in Kerala (683 cms.) was recorded at Pirmed in 1911. Also, Kuttiyadi reported 615 cms. of rainfall in 1924. It is interesting to note that the station Chinnar which records the lowest amount of rainfall (61 cms.) in the State lies close to Pirmed. Chinnar recorded its lowest rainfall of 11 cms. in 1926 and its highest rainfall (172 cms.) in 1922.

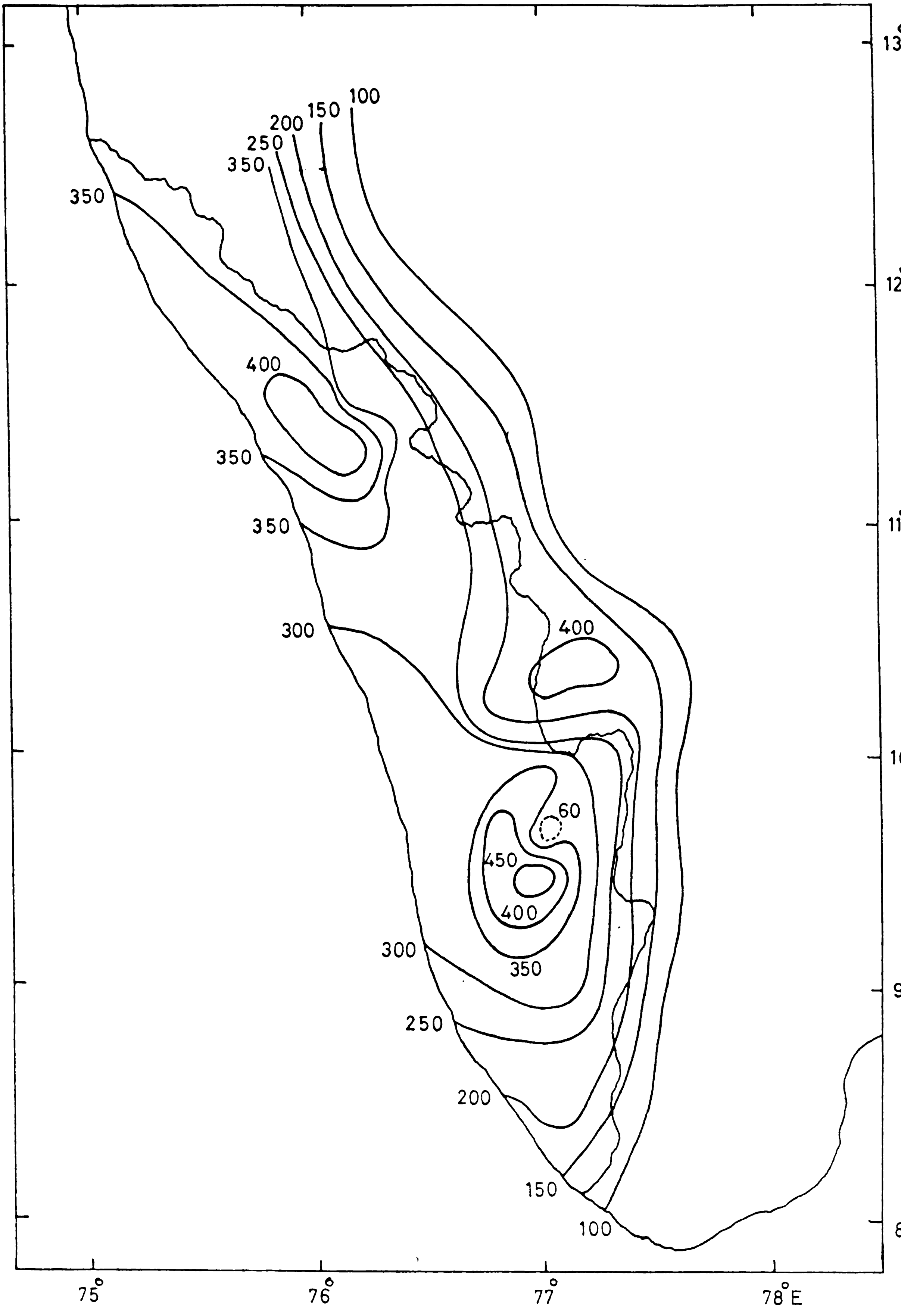

FIG 5.2. ANNUAL RAINFALL OVER KERALA (CMS)

The maximum rainfall during the pre-monsoon season (Fig. 5.3) is received at Kanjirappally (100 cms.), accounting for 24% of its annual rainfall (Fig. 5.4). From this pocket, the rainfall decreases towards south and north. Trivandrum and Kasaragod districts get about 30 cms. of rainfall, the seasonal rainfall being about 20% and 10% of the annual respectively. However, Chinnar in Idukki district receives only 9 cms. of rainfall in this season, which is 10% of the annual.

The rainfall distribution during the southwest monsoon season is similar to that of the annual pattern. Rainfall increases from 85 cms. in the south (50% of annual) to 290 cms. in the north (80% of annual). Pockets of heavy rainfall are observed around Pirmed (328 cms.), Munnar (288 cms.), Vythiri (355 cms.) and Kuttiyadi (325 cms.). A low rainfall region is observed around Chinnar (15 cms.). At Chinnar, only 28% of the annual rainfall is received in this season, while at the nearby Munnar, it is 78%. On the lee side (eastern side) of the Ghats, rainfall sharply decreases to about 10 cms. (20% of annual).

Northeast monsoon is the period during which the eastern slopes of the Ghats also receive fairly

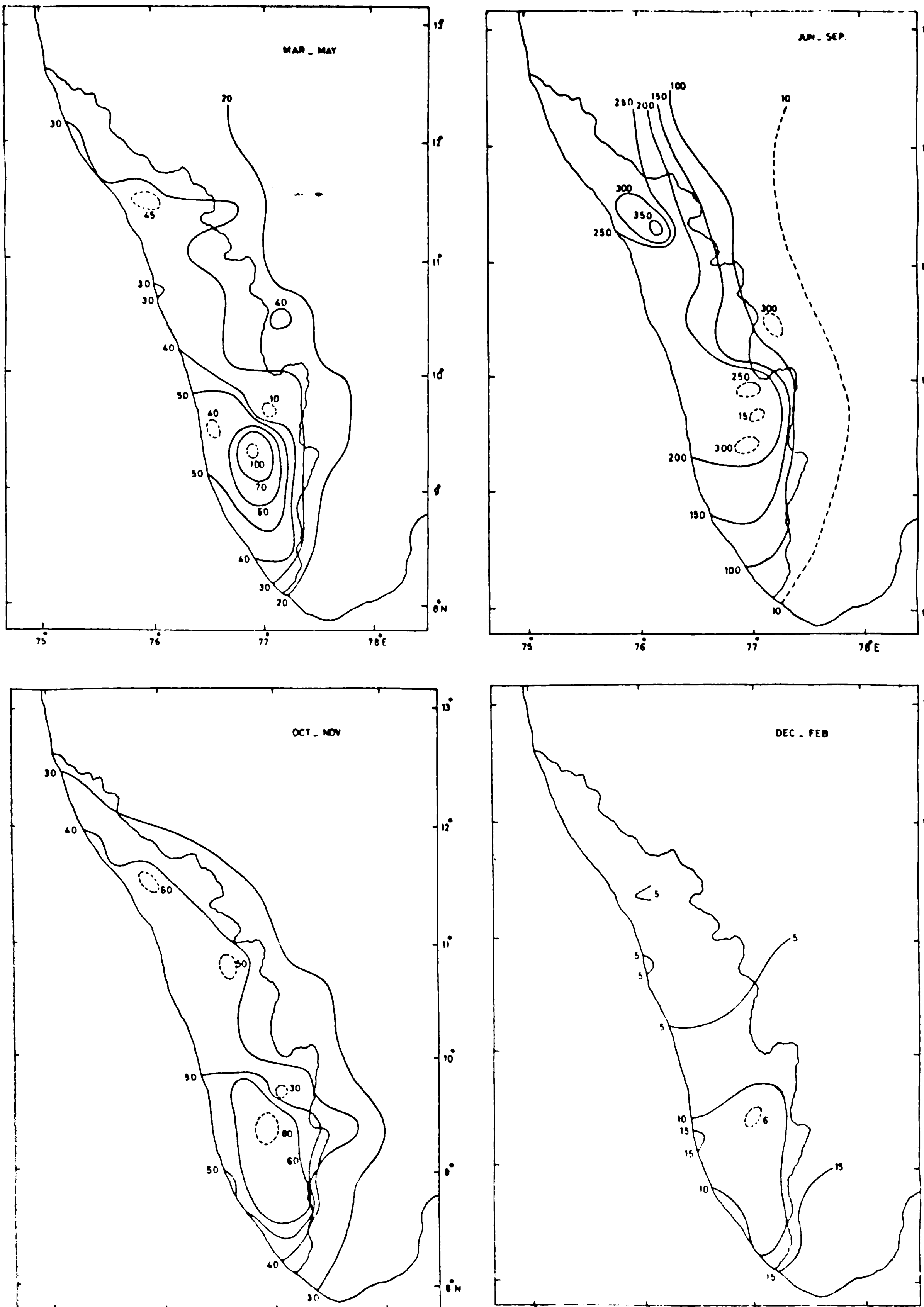

FIG 5.3. SEASONAL RAINFALL (CMS)

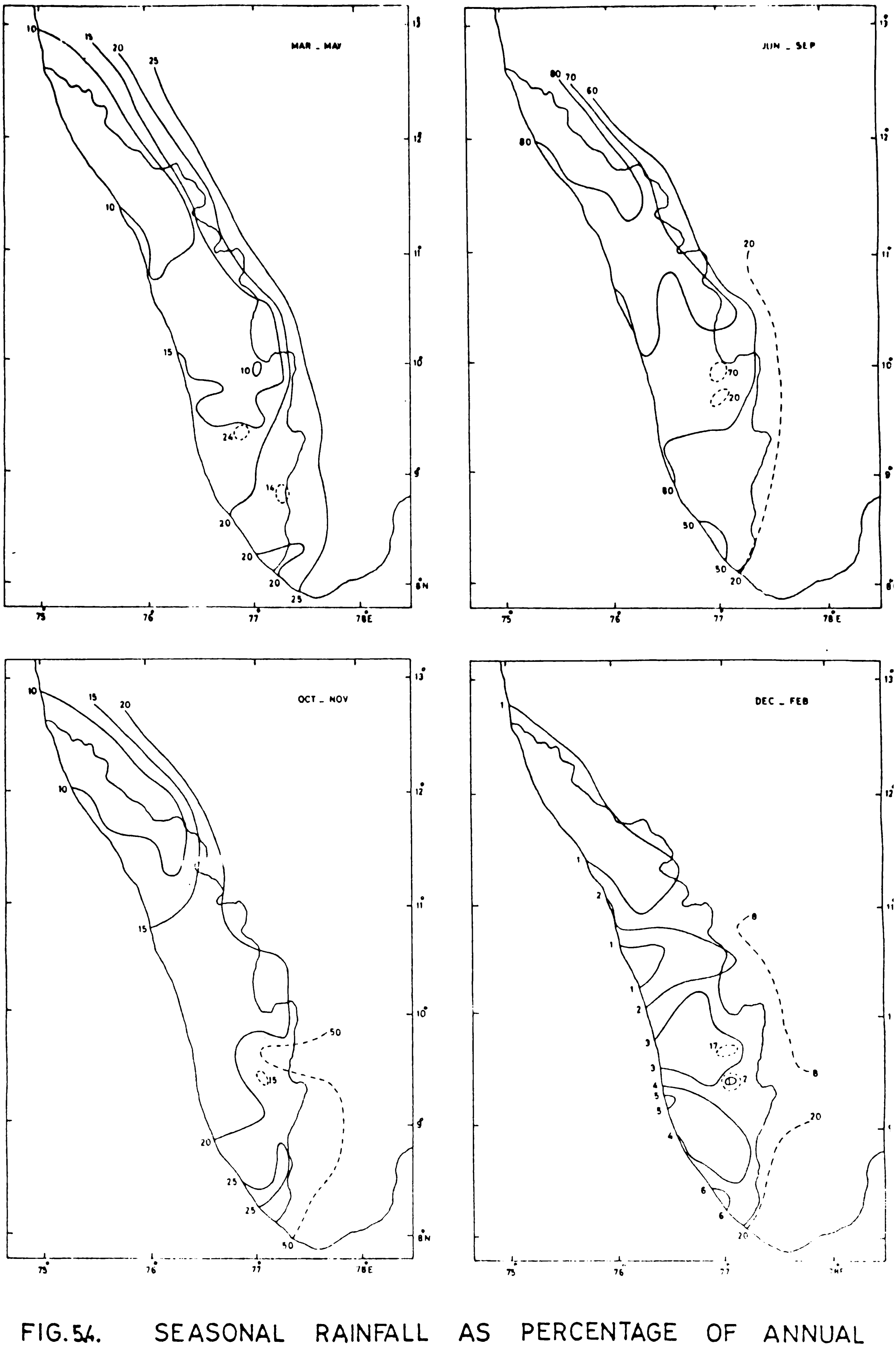

FIG. 54. SEASONAL RAINFALL AS PERCENTAGE OF ANNUAL

good amounts of rainfall, comparable to the western sides. The Ghats region receives about 30 cms. to 40 cms. of rainfall in this season, accounting for 20% of the annual rainfall. Once again, a pocket of comparatively heavy rainfall is observed around Kanjirappally (87 cms.) and Pirmed (81 cms.), with values decreasing towards north and south, with Chinnar (31 cms.) receiving the lowest amount. Northern districts get less than 10% of their annual rainfall in this period while the southern districts get 25% and adjoining Tamil Nadu, about 50%.

Winter is a period of very low rainfall for the whole State. Rainfall decreases from less than 15 cms. (6% of annual) over Trivandrum district to less than 5 cms. (1% of annual) in the northern districts. Alleppey receives the highest amount (15 cms.) which is 5% of the annual while Chinnar receives 6 cms. accounting for 17% of its annual rainfall. The adjoining Tamil Nadu areas receive 20% of the annual rainfall during this season.

ii. Number of rainy days

Analysing the distribution of the number of rainy days on an annual basis, it is found that it is more around Pirmed (167 days) and Kanjirappally (153 days) (Fig. 5.5). However Chinnar, which is not

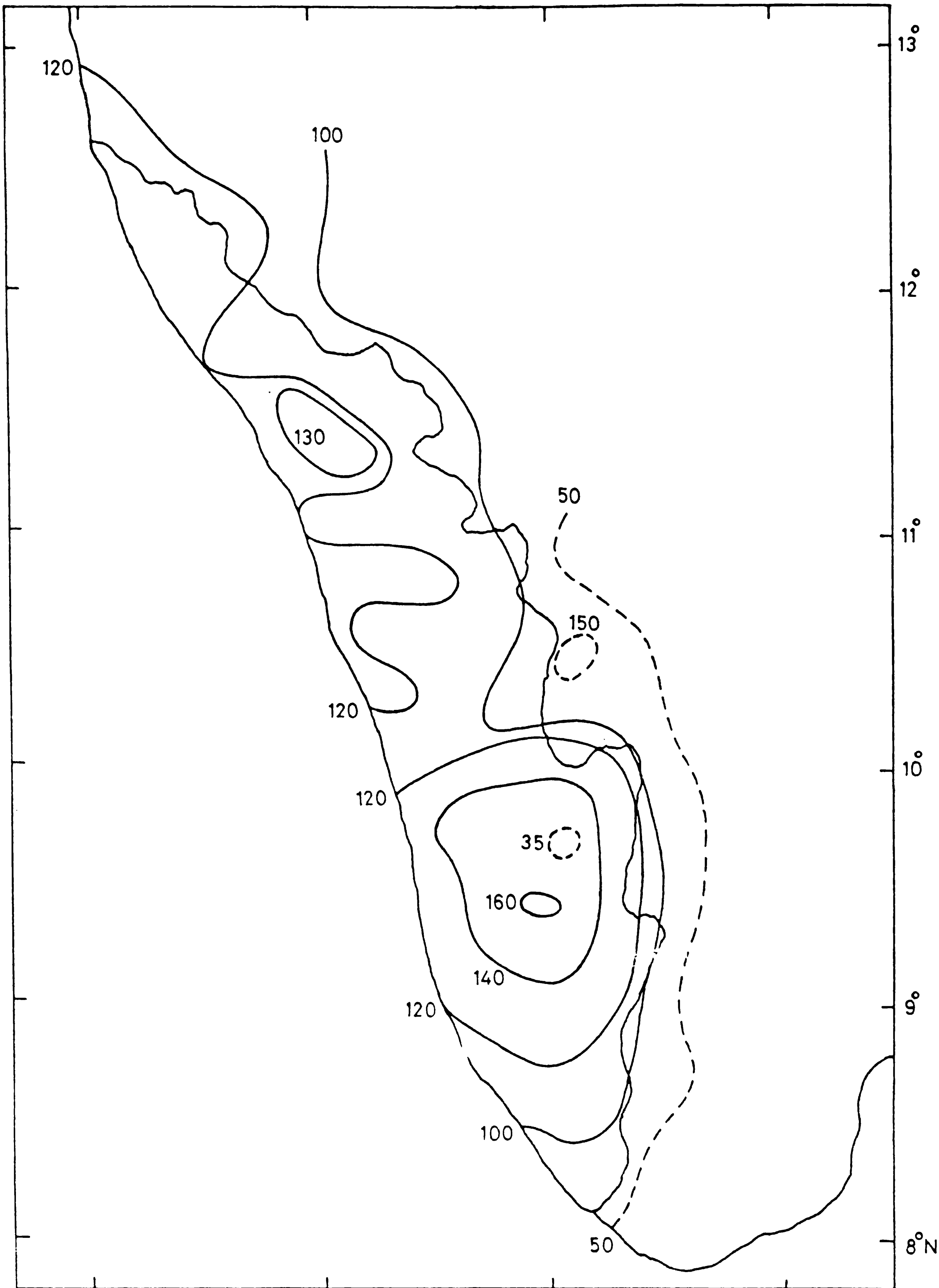

FIG5.5. NUMBER OF RAINY DAYS — ANNUAL

far away from these stations, but with different topography, receives rainfall only on 36 days in an year. The southern districts have only 100 to 120 rainy days whereas the northern districts experience rain on more than 120 days in an year.

During the pre-monsoon season, the number of rainy days in the State varies from 15 to 25 (Fig. 5.6) which is about 10 to 20% of the annual number (Fig. 5.7). Again, a pocket around Pirmed experiences a larger number of rainy days (30) than the neighbouring regions. In fact, at Chinnar, rainfall occurs on only 6 days in this season.

The number of rainy days during southwest monsoon increases from 45 (50% of annual) at Trivandrum to 90 at Kasaragod (75% of annual). Pirmed receives rainfall on 100 days (60% of annual) while Chinnar on only 10 (36% of annual). Over the Eastern side of the Ghats in adjoining Tamil Nadu, the number of rainy days decreases to 10 which is 25% of the annual.

During northeast monsoon period, the number of rainy days varies from 15 in the northern districts (15% of annual) to more than 20 in the southern districts (20% of annual). Chinnar, with 12 rainy days accounting for 33% of the annual number is however,

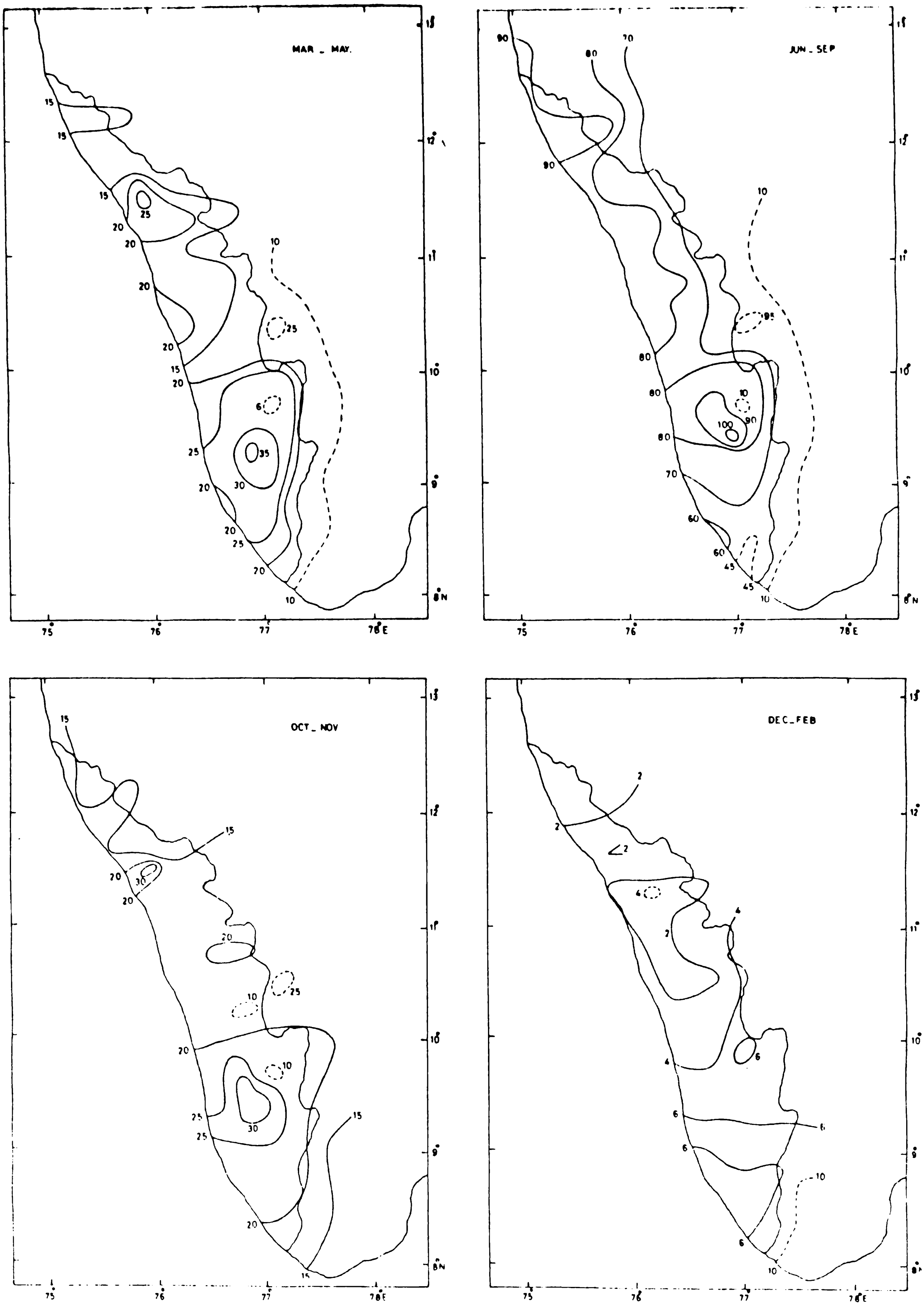

FIG. 5.6. NUMBER OF RAINY DAYS — SEASONAL

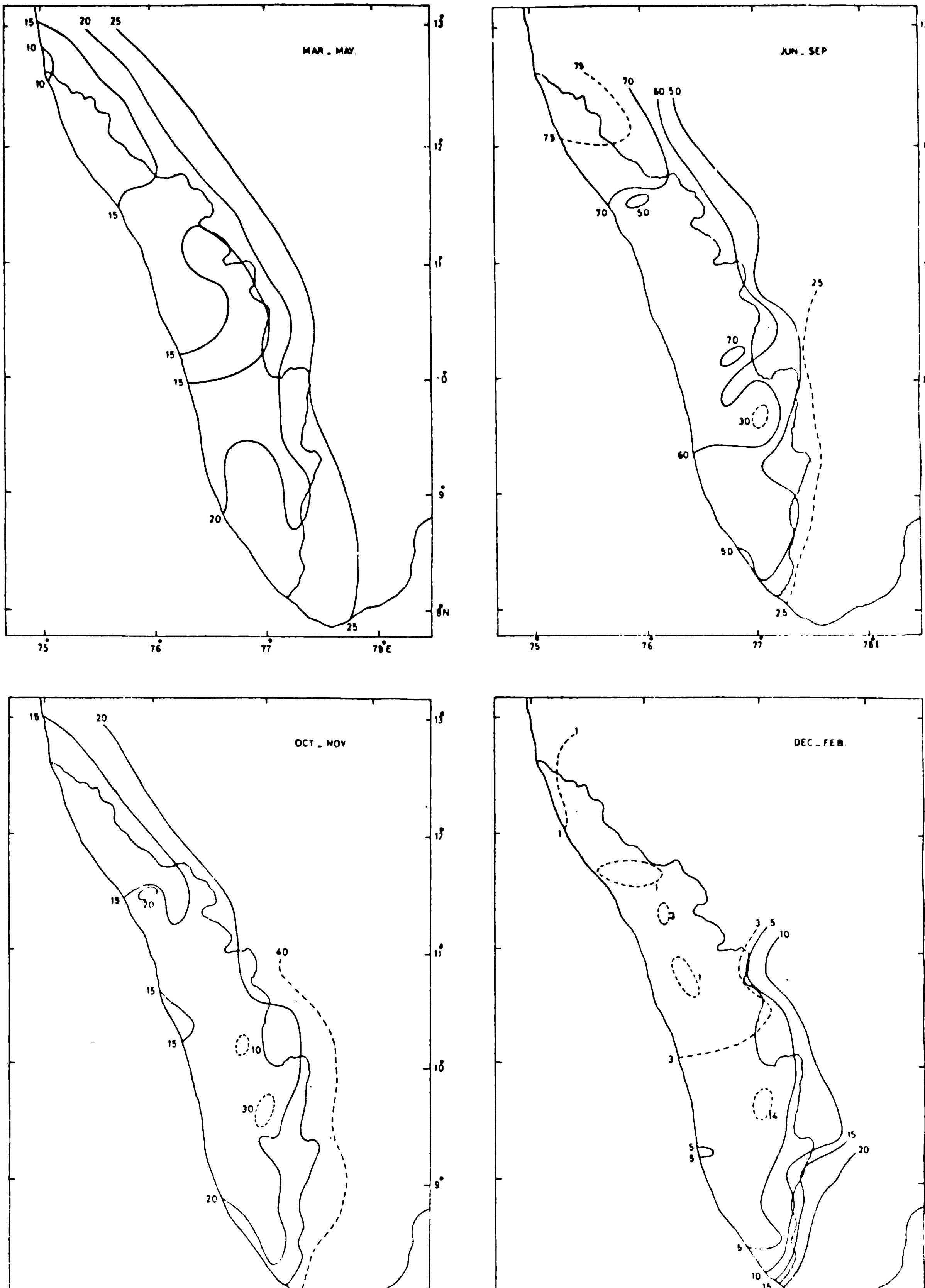

FIG. 5.7. NUMBER OF RAINY DAYS AS PERCENTAGE OF ANNUAL

an exception. In the neighbouring Tamil Nadu, the number of rainy days is around 15 which is 40% of the annual.

The number of rainy days during the winter months is very small, ranging from 1 (1% of annual) in the northern districts to 6 in the southern parts of Trivandrum district (15% of annual). Adjoining Tamil Nadu receives rainfall on about 10 days in this season, which is 20% of its annual number of rainy days.

iii. Rainfall Intensity

Rainfall intensity, which is the ratio of total rainfall to the number of rainy days, does not show any regular or identifiable pattern over the State, either on an annual (Fig. 5.8) or a seasonal (Fig. 5.9) basis. With an average of 2.5 cms./rainy day for the State as a whole, the rainfall intensity values range from around 2 cms./rainy day in the southern districts to about 3 cms./rainy day in the northern districts : Chinnar has the lowest value of 1.7 cms./rainy day and Vythiri, the highest value of 3.2 cms./rainy day. Considering the seasons, it is observed that the intensity values increase from South Kerala towards North Kerala in all the seasons of the year except in the October-November months

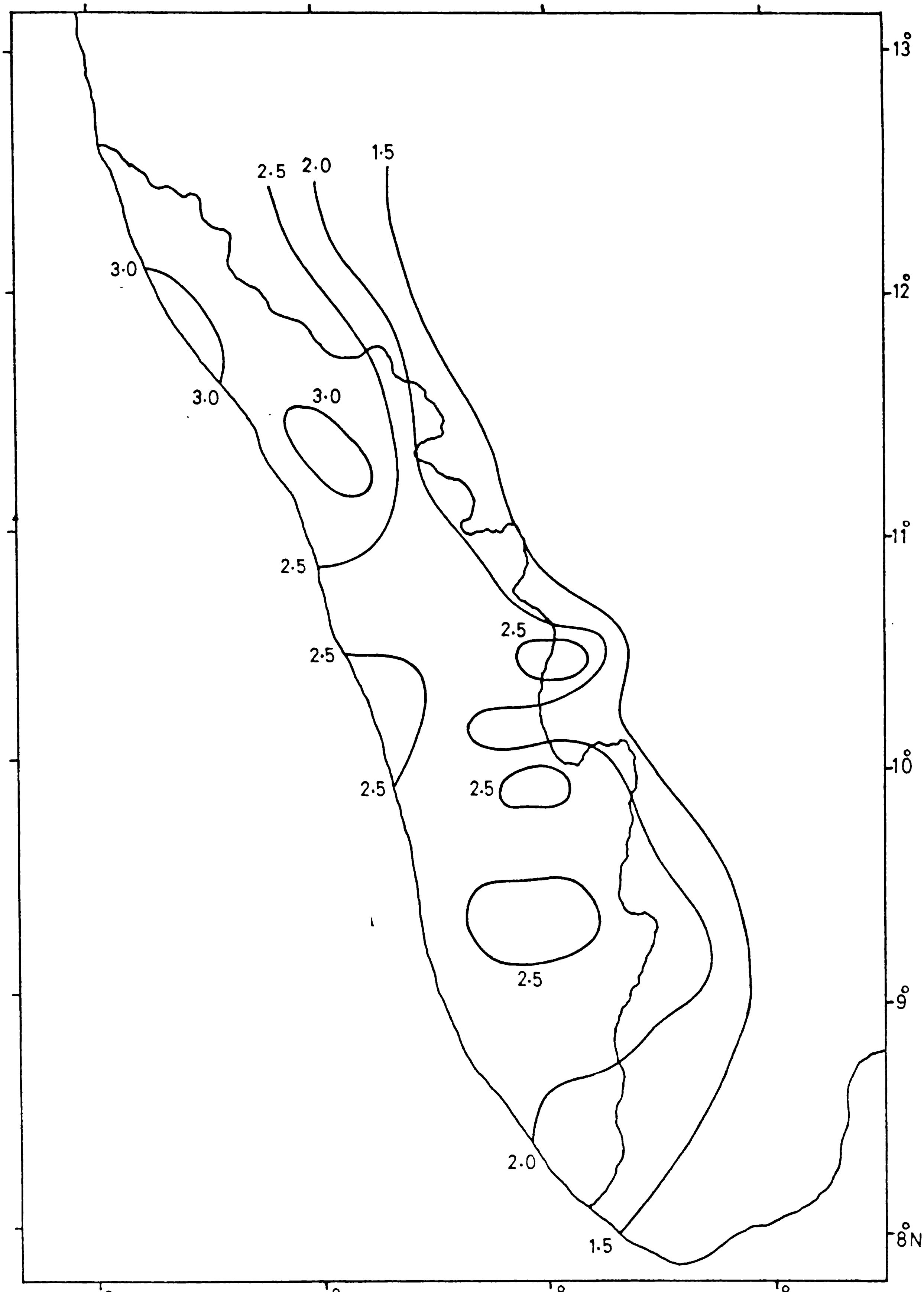

FIG.5.8. INTENSITY OF RAINFALL – ANNUAL (CMS/RAINY DAY)

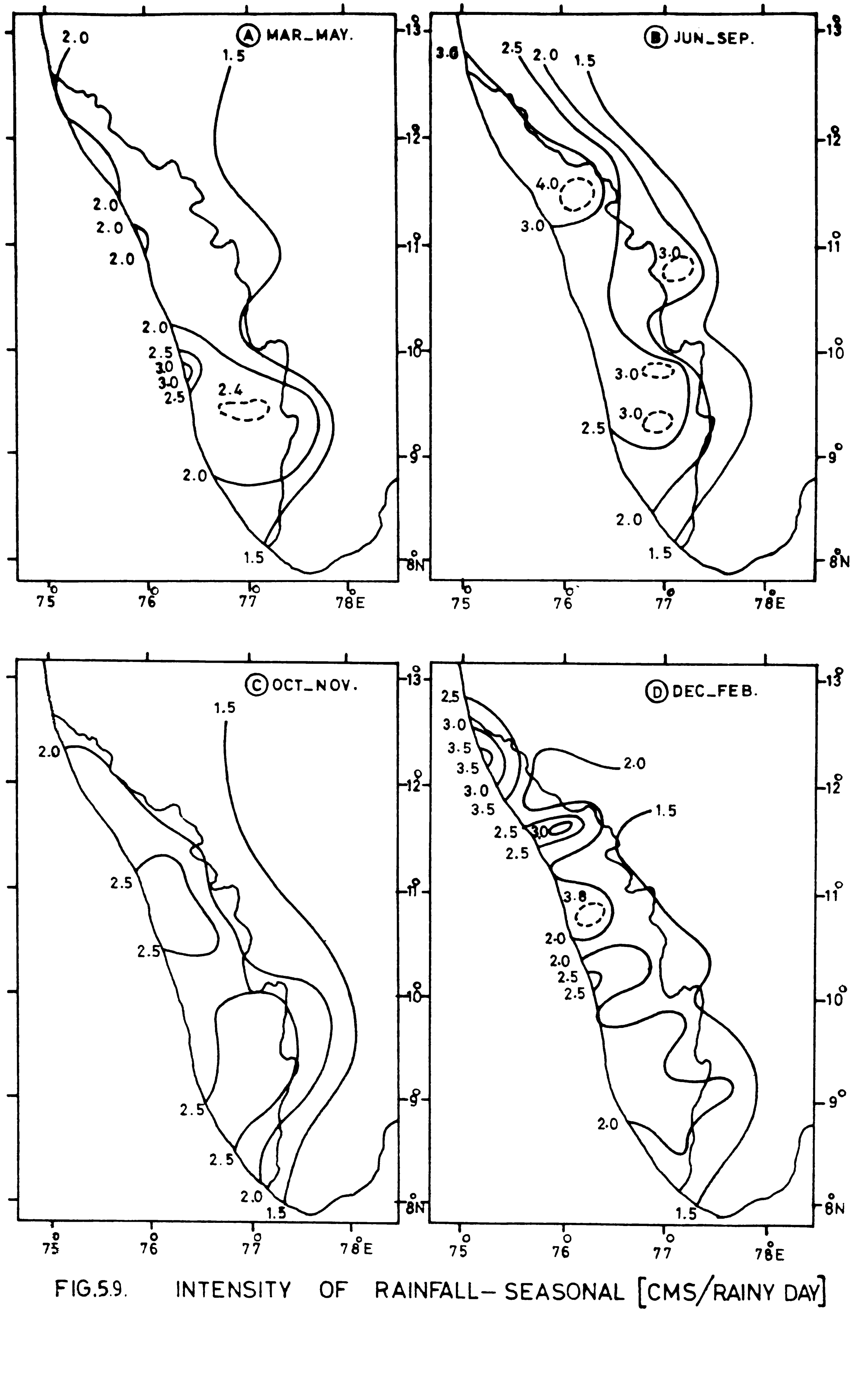

FIG.5.9. INTENSITY OF RAINFALL– SEASONAL [CMS/RAINY DAY]

when the gradient is from north to south. Interestingly, both the highest and the lowest intensities in the four seasons are observed at Vythiri - 4 cms/rainy day during the southwest monsoon season and 1.2 cms./rainy day during the winter season respectively.

iv. Precipitation ratio

Precipitation ratio, which is the percentage ratio of the difference in rainfall between the maximum and minimum rainfall over a series of years to the mean annual rainfall is a measure of the stability of the rainfall. Lower values of the ratio denote greater stability of rainfall and higher values, smaller stability. Also, if the value is around 100, variation of annual rainfall is equal to mean annual rainfall.

The distribution of precipitation ratio on an annual and seasonal basis does not show any particular recognizable pattern over Kerala and hence is not presented here. The values show that annual rainfall is more stable compared to the seasonal rainfall. In general, stations experiencing high rainfall show more stability of rainfall than low rainfall stations. However, the stations experiencing higher stability of annual rainfall need not necessarily show such a stability seasonally.

Payyannur (55%), Kasaragod (56%) and Trichur (57%) exhibit greater stability in the rainfall distribution while Chinnar (267%) exhibits largest instability. Rainfall is most stable during southwest monsoon season and most unstable during winter months. On comparing seasonal values, it is observed that the largest instability is at Kuttiyadi (951%) in the winter season and largest stability at Manjeri (65%) in the southwest monsoon months.

v. Variability of Rainfall

A coefficient is computed to study the variability of rainfall, which is the ratio of standard deviation of rainfall to mean rainfall and expressed as percentage. Annual rainfall variability is always smaller than the seasonal variability. For most parts of the State, the annual variability of rainfall is between 15% and 20% (Fig. 5.10). Chinnar with 73% variability is an exception.

Pre-monsoon is a period of high rainfall variability (Fig. 5.11). The coefficient ranges from 30% in Idukki-Pathanamthitta districts to 70% over the northern parts of the State. The variability increases from the coastal area towards the Ghats. For Chinnar, the coefficient is 165% while Konni has the lowest value of 23%.

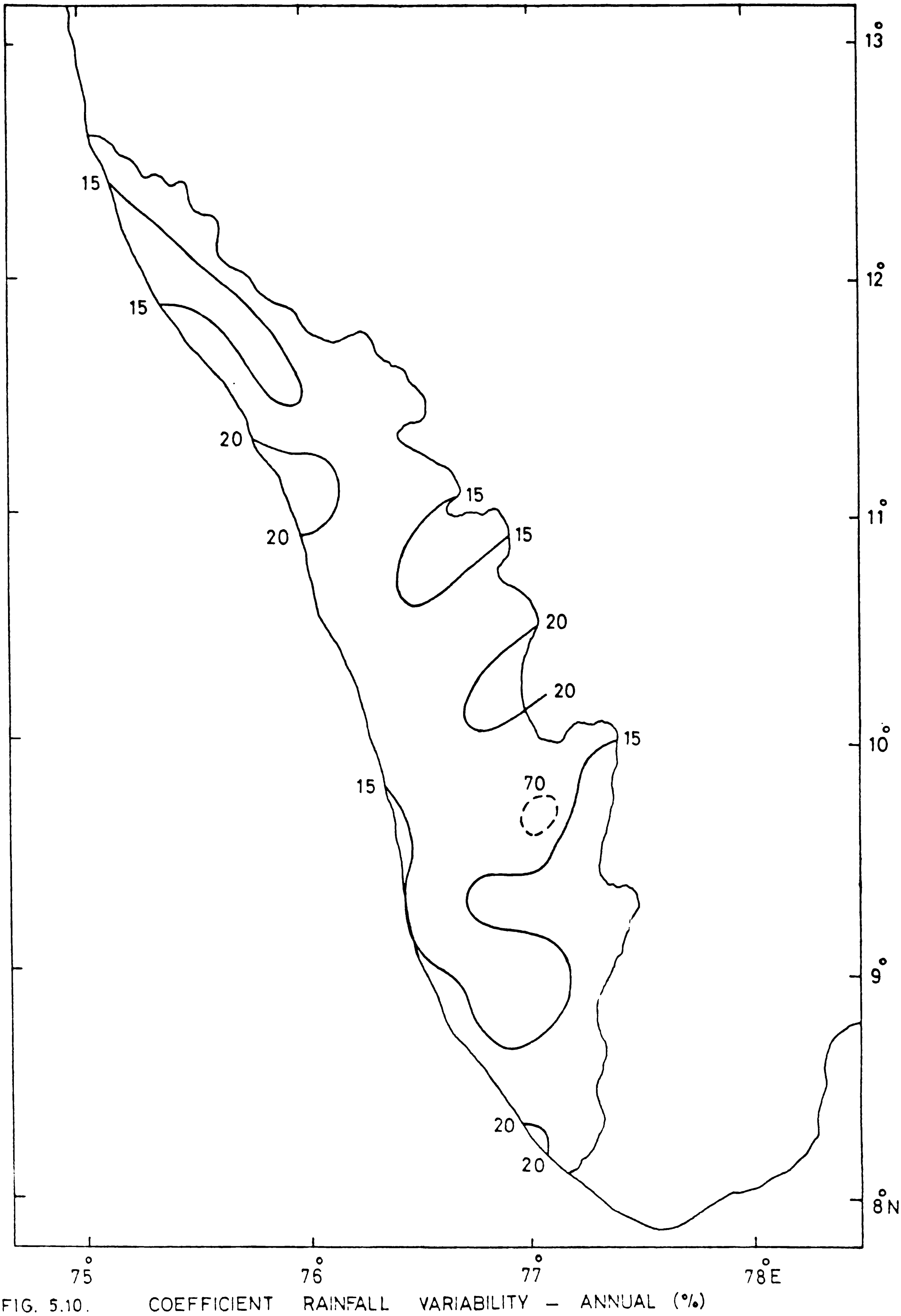

FIG. 5.10. COEFFICIENT RAINFALL VARIABILITY – ANNUAL (%)

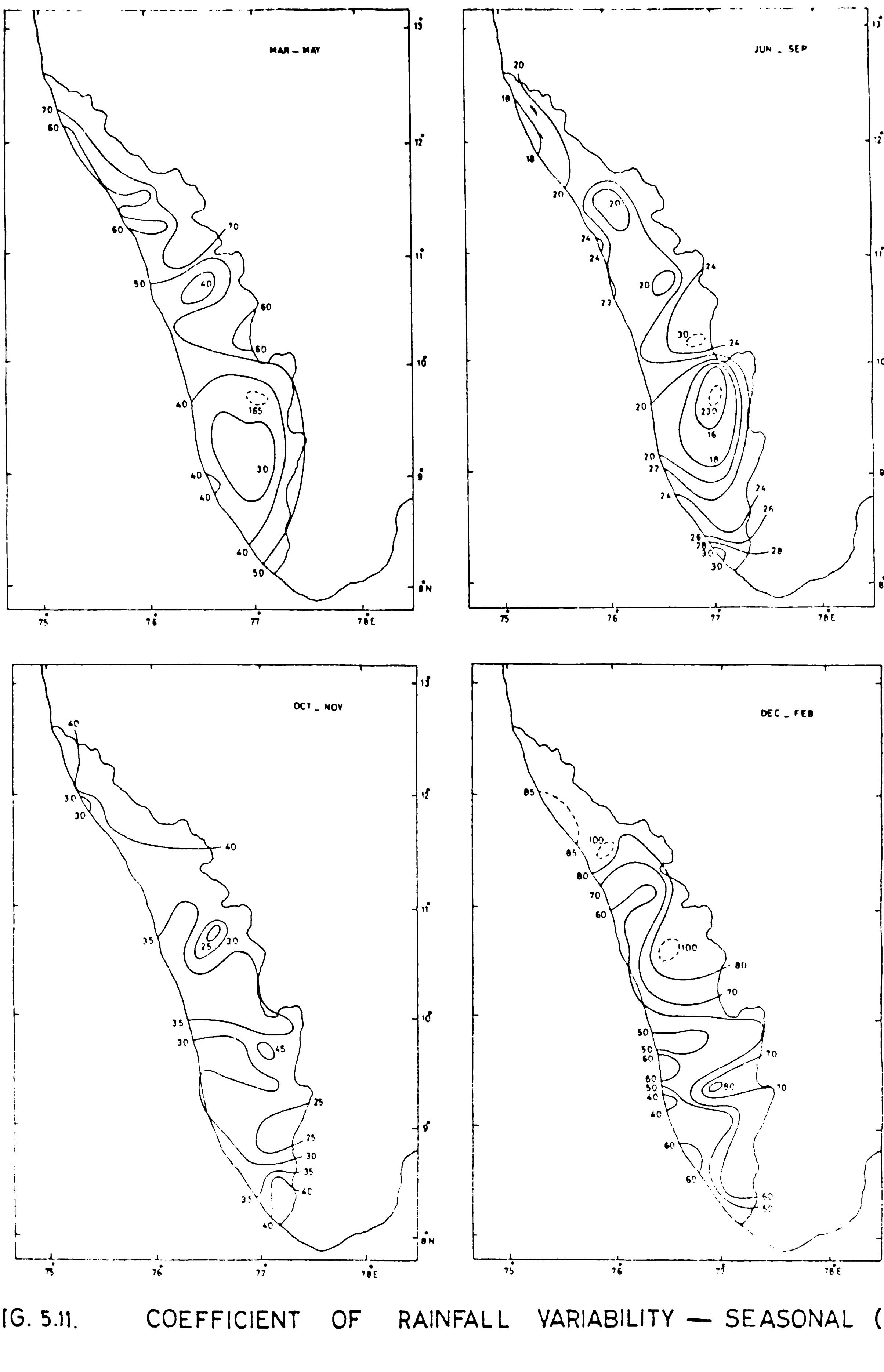

FIG. 5.11. COEFFICIENT OF RAINFALL VARIABILITY — SEASONAL (%)

Seasonally, southwest monsoon is the period of minimum rainfall variability. Range of variability is from 18% to 30% for the whole State. Coefficients in the southern regions are higher compared to the northern regions. The lowest coefficient is for Munnar (15%) and the highest is for Chittur (30%), save for exceptionally high value for Chinnar (230%).

Variability of rainfall ranges from 25% to 40% during northeast monsoon period, though for most of the stations, it is around 35%. The minimum variability is at Mannarghat (22%) and the maximum at Mannanthody (52%).

Winter is the period of the highest variability of rainfall for all stations. The values decrease from north to south, from 80% to 50%. The lowest coefficient is exhibited by Nedumangad (40%) and the highest by Kuttiyadi (118%).

The probability of occurrence of maximum and minimum rainfall is an important factor in water resources management. According to Sanderson (1972), the maximum rainfall at any location would not exceed an amount equal to the mean rainfall (P) plus 2 times standard deviation ($P + 2\sigma$) and the minimum rainfall would not go below an amount equal to ($P - 2\sigma$) in 97.5% of the time. The figure 5.12.a shows the

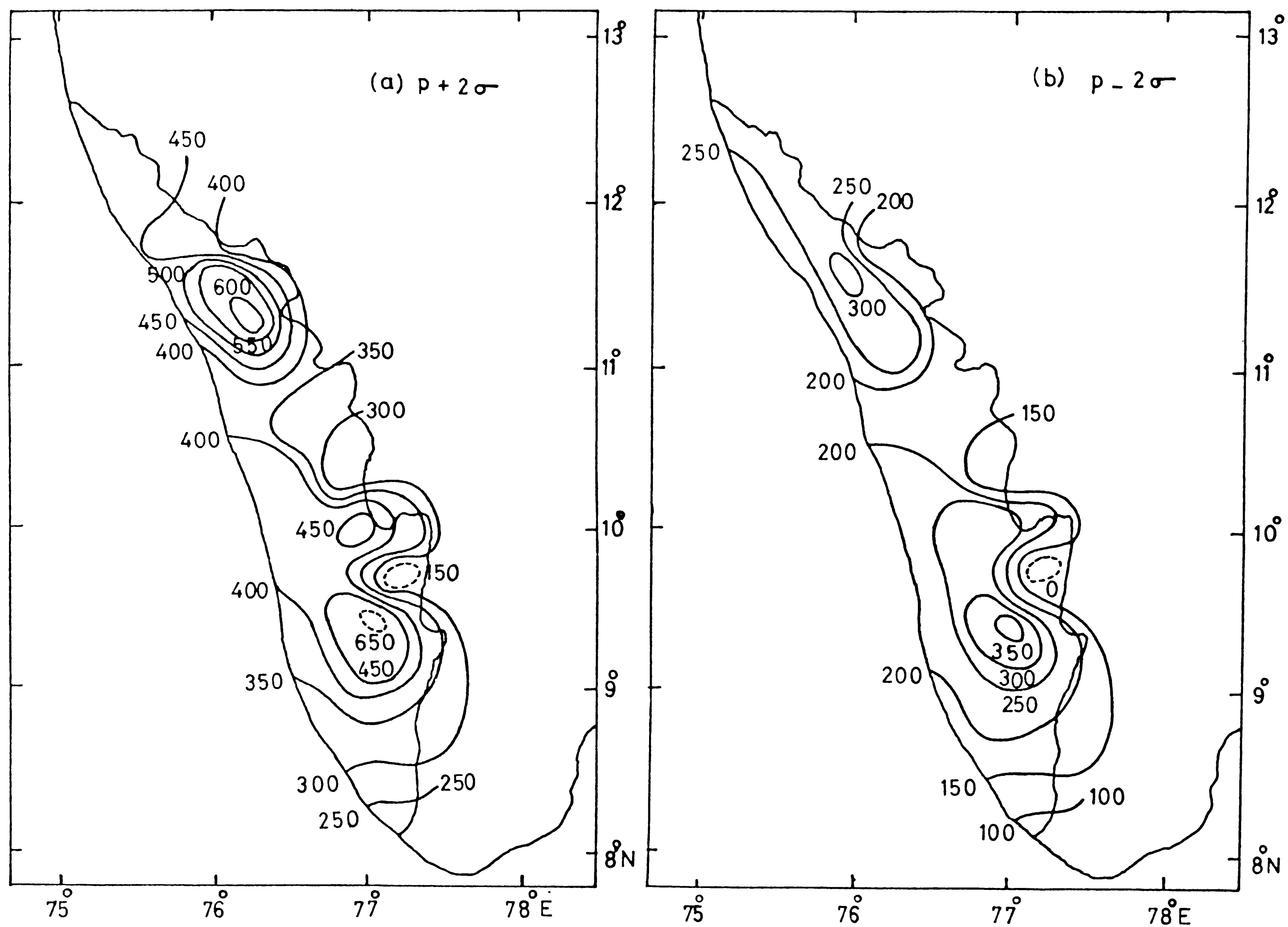

FIG 5.12. MEAN ANNUAL RAINFALL OVER KERALA ± 2 STANDARD DEVIATION (CMS)

distribution of ($P + 2\sigma$) values. Rainfall can exceed these values only in 2.5 years out of 100. The values generally vary from 250 cms. in South Kerala to 450 cms. in northern districts as also in parts of Idukki district. Theoretically, Pirmed and Vythiri can experience more than 650 cms. and 600 cms. of rainfall respectively in 2.5 out of 100 years. The minimum limits ($P - 2\sigma$) vary from 100 cms. in the south to 250 cms. in the north (Fig. 5.12.b). Around Vythiri in the north and Pirmed in the south, these limits are around 300 cms. and 350 cms. respectively. At Chinnar, rainfall can be as low as zero in 2.5 years out of 100.

vi. Departures of Annual Rainfall

A study of the departures of annual rainfall for the period 1901 to 1986 using Nicholson's (1983) method reveals that more positive rainfall departures occurred in the State (46 years) than negative departures (40 years) (Fig. 5.13). The year 1924 was the wettest year with a deviation of 250% as compared to the standard deviation (σ), while 1976 was the driest year when the deviation was -156% followed by 1986 with a deviation -133%. The occasions of large positive departures were 1924 (250%), 1933 (230%), 1946 (176%) and 1961 (201%) and of large negative departures, 1928 (-96%), 1934 (-102%), 1935(-99%),

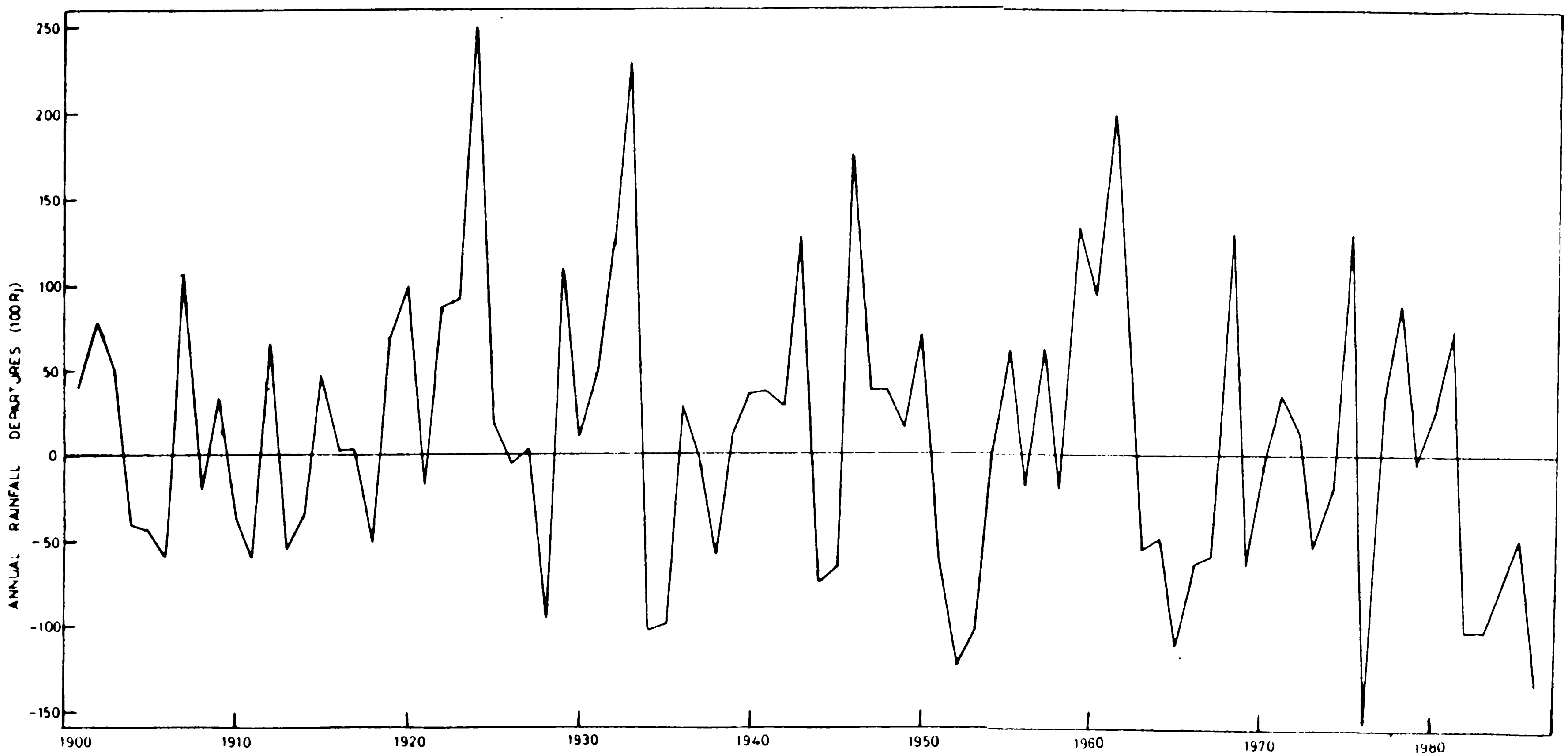

FIG. 5.13. KERALA — STANDARDISED ANNUAL RAINFALL DEPARTURES

1952 (-124%), 1953 (-104%), 1965 (-110%) 1976 (-156%), 1982 (-102%), 1983 (-102%) and 1986 (-136%). The year 1954 may be considered as a "normal" year as the rainfall departure was only -1% of the standard deviation. The other years with small departures of rainfall were 1916 (2%), 1917 (4%), 1926 (-4%), 1927 (4%), 1937 (5%), 1970 (-7%) and 1979 (-5%). No wet or dry spells continued for a period more than 5 consecutive years. In 1919, the departures were positive in the southern part of the State, but the northern part experienced negative departures. The maximum positive departure (580%) among the stations selected for this study was observed at Punalur in 1919 and the maximum negative departure (-260%) at Perumbavur in 1953. There does not seem to be any periodicity in the occurrences of rainfall departures in the drier or wetter directions.

SECTION II. WATER BALANCE OF KERALA

The hydrological potentialities of a region cannot be assessed by the study of precipitation alone, even though it is the only source of water supply to any region. The transport of water from the earth back to the atmosphere, variously known as water loss, consumptive use, evapotranspiration etc., has also to be considered simultaneously. Evapotranspiration, thus, represents an important mass transfer from ground to atmosphere, the reverse of precipitation in the hydrologic cycle. A comparative study of precipitation and potential evapotranspiration - measured or computed - gives a good idea of the water balance of the region.

In this Section, detailed water balance studies of 13 representative stations have been made, of which 6 stations are inside Kerala and the rest, in its vicinity.

i. Potential Evapotranspiration (P.E.)

Potential Evapotranspiration or the water need is the amount of water that would evaporate from the soil and transpire from the vegetation when there is no water deficiency. As observed in chapter IV, it is more than 170 cms. over the entire Ghats in an year (Fig. 4.9). Seasonally (Fig. 5.14), during

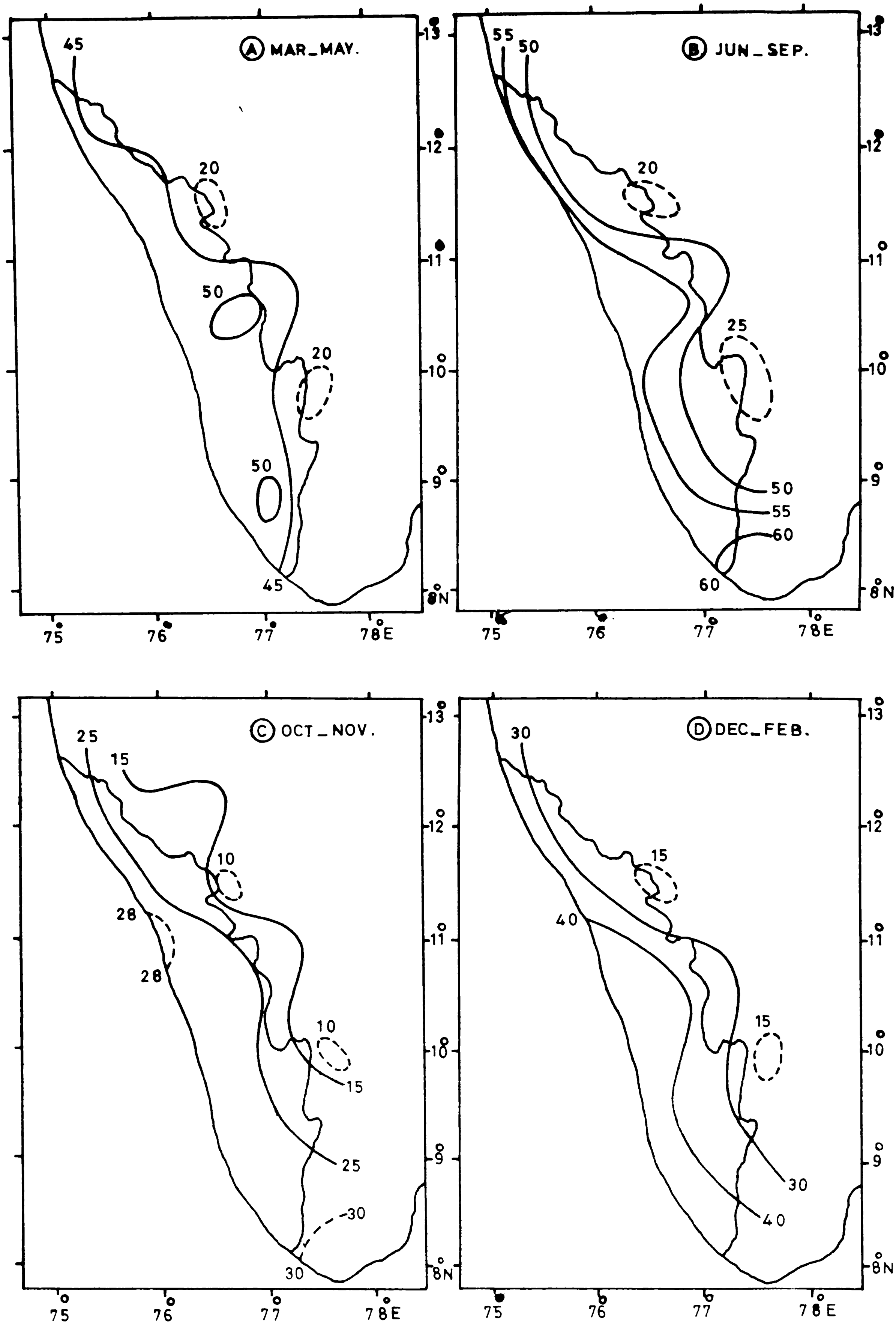

FIG. 5.14 POTENTIAL EVAPOTRANSPIRATION – SEASONAL (CMS)

March-May, P.E. values range from 45 cms. to 50 cms. in the State, increasing to more than 50 cms. during the southwest monsoon season. Water need of about 25 cms. to 28 cms. is experienced during October-November. However, during December-February, P.E. values are higher - more than 40 cms. at all stations inside the State. During all the seasons, the elevated regions over the Ghats (some beyond the boundaries of the State) experience much lower water needs compared to the plains inside Kerala State.

ii. Actual Evapotranspiration (A.E.)

For the development and management of water resources, the actual amount of water that evaporates and transpires (A.E.) is more important than the P.E.. Actual Evapotranspiration is an approximate index of water used by plants and hence of plant growth (Muller, 1972).

In Kerala, the annual values of A.E. vary from 150 cms. around Alleppey and Cochin to 130 cms. towards the Ghats region (Fig. 4.10). Seasonally (Fig. 5.15), the A.E. values during March-May increase from 25 cms. in the north to more than 45 cms. in the south. During the southwest monsoon season, the values decrease from more than 55 cms. along the west coast to 50 cms. around the eastern boundary of the

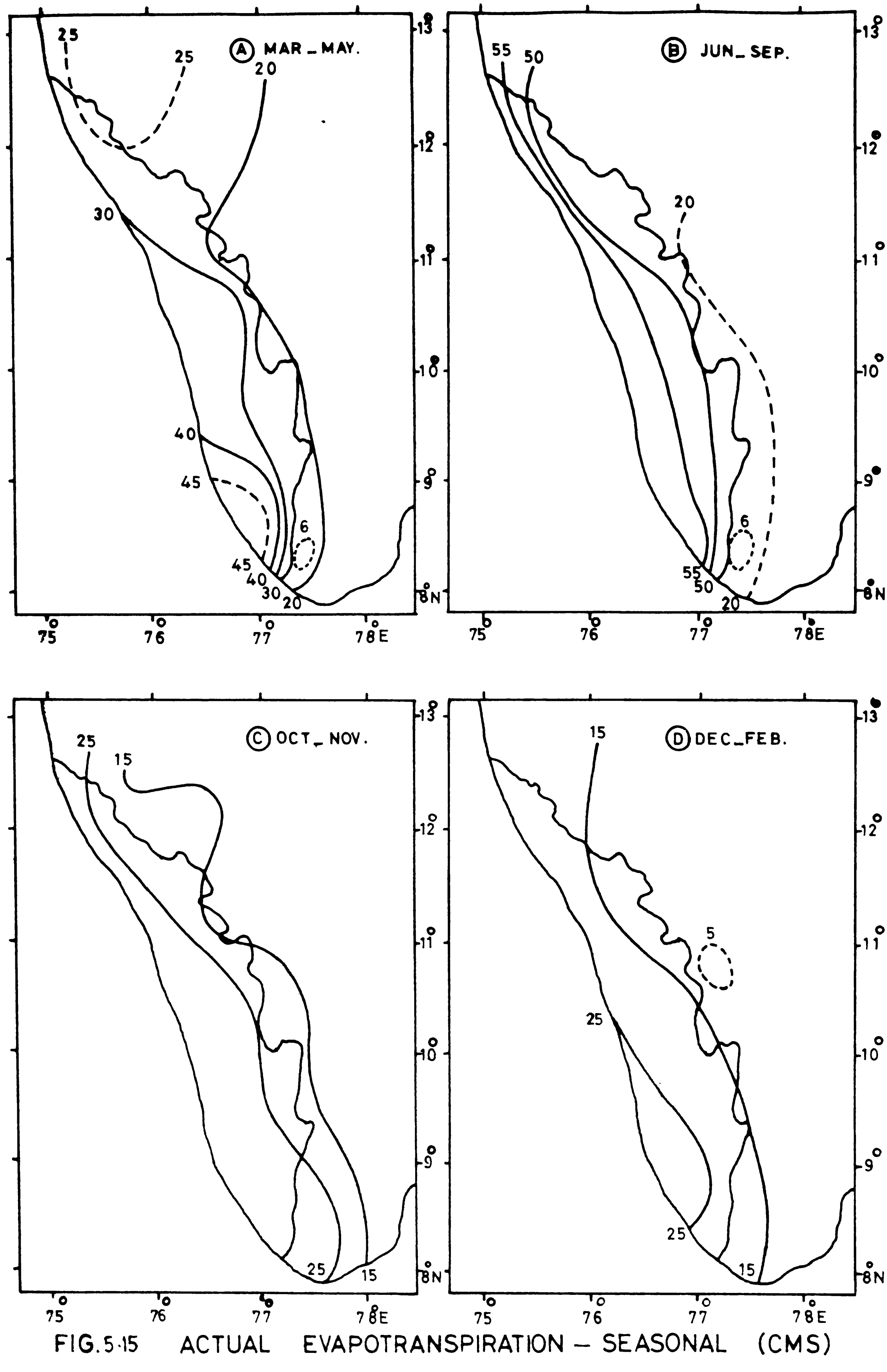

FIG. 5.15 ACTUAL EVAPOTRANSPIRATION – SEASONAL (CMS)

State. The A.E. values vary from 25 cms. to 30 cms. over the entire State in the other two seasons. Decrease in A.E. is noticeable on the leeward side of the Ghats.

iii. Water Deficit (W.D.)

Water deficit is a measure of the additional water required for any region to meet the full demands and hence, is a basic criteria for the development of water resources. It provides information on the total volume of water needed at any time and gives a definite measure of droughts. When compared with water surplus of other seasons, it indicates whether there is sufficient water accumulating during the wet seasons to permit the exploitation of water resources during the lean months.

As stated earlier, annual water deficit of 25 cms. to 35 cms. occurs over the State (Fig. 4.11). Seasonally, there exists water deficiency only during the pre-monsoon and winter months and distribution for these periods alone are presented (Fig. 5.16). During the pre-monsoon period, northern parts of Kerala exhibit a water deficiency (W.D.) of around 15 cms.. Southwards, the values decrease to less than 10 cms., especially over the coastal areas. Over the extreme south, deficit again increases to 20 cms.. Around

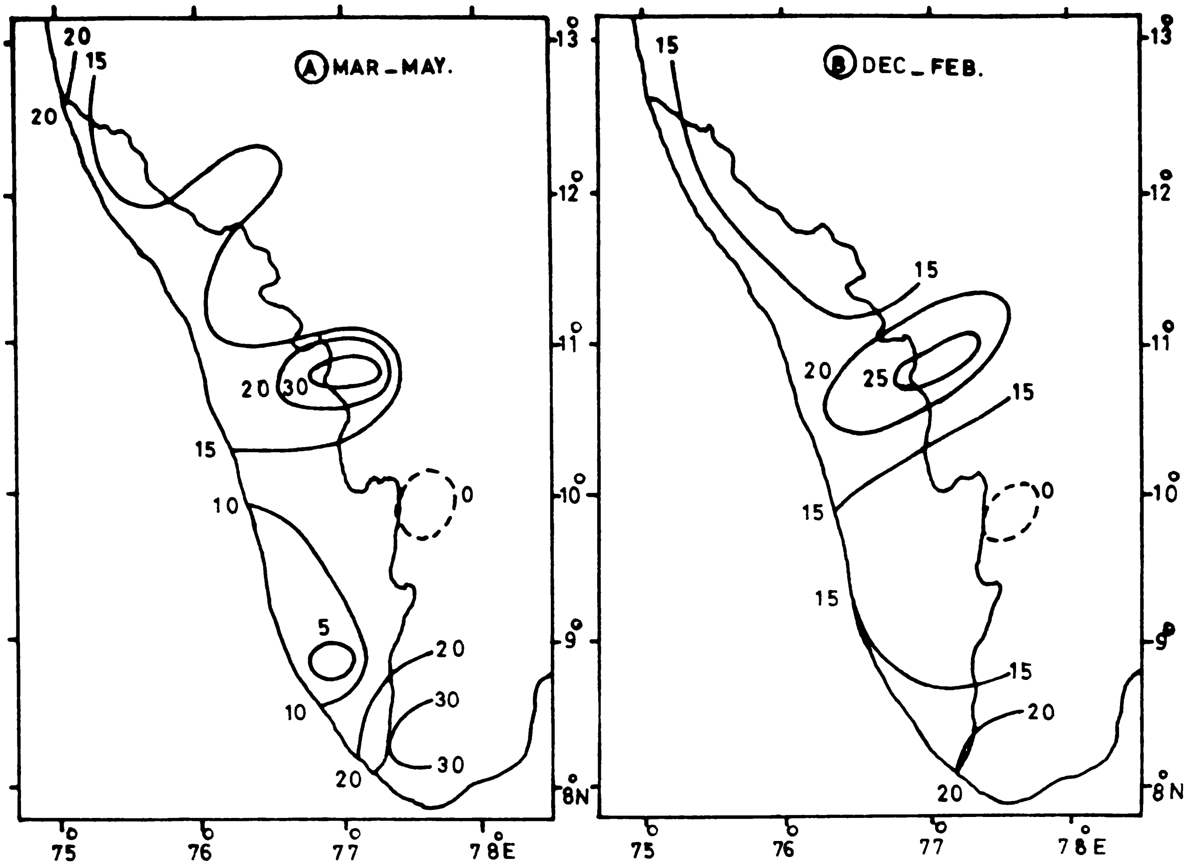

FIG. 5.16. WATER DEFICIT – SEASONAL (CMS)

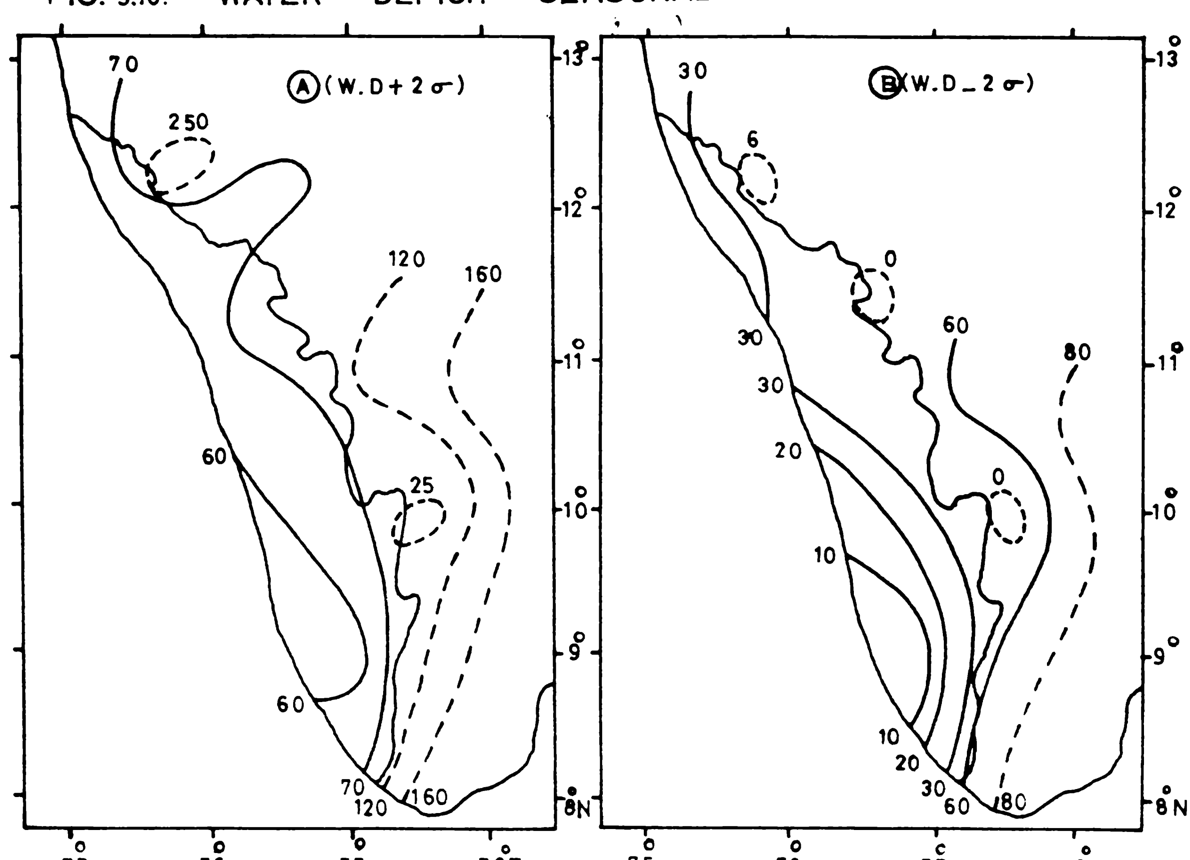

FIG. 5.17. WATER DEFICIT ± 2 STANDARD DEVIATION (CMS)

15 cms. of water deficit is observed over the whole State in the pre-monsoon months. Eastern side of the Ghats have more water deficiency during these seasons.

Value of (W.D. + 2σ) and (W.D. - 2σ) are plotted in Fig. 5.17. The pattern thus obtained suggests that in 97.5% of the times, water deficiency of 60 cms. in the coastal area around Alleppey and Cochin and 70 cms. in the rest of the State cannot be exceeded. Similarly, a minimum of 10 cms. to 30 cms. water deficiency can be expected in the State in 97.5% of the years. In both the cases, higher values are noted in the eastern side of the Ghats.

iv. Water Surplus (W.S.)

Water surplus represents the excess of rainfall after the demands of water need (P.E.) and that needed to field capacity have been met. This is the water available for runoff and streamflow. By definition, water surplus is the amount of water which does not remain in the surface soil layers but which is available either for overland or surface flow or for deep percolation to the water table contributing to groundwater and subsurface flow.

As already discussed in the previous Chapter, annual water surplus vary from 50 cms. around Trivandrum, 150 cms. around Punalur to more than 200 cms. in the northern portion of the State. An exception is

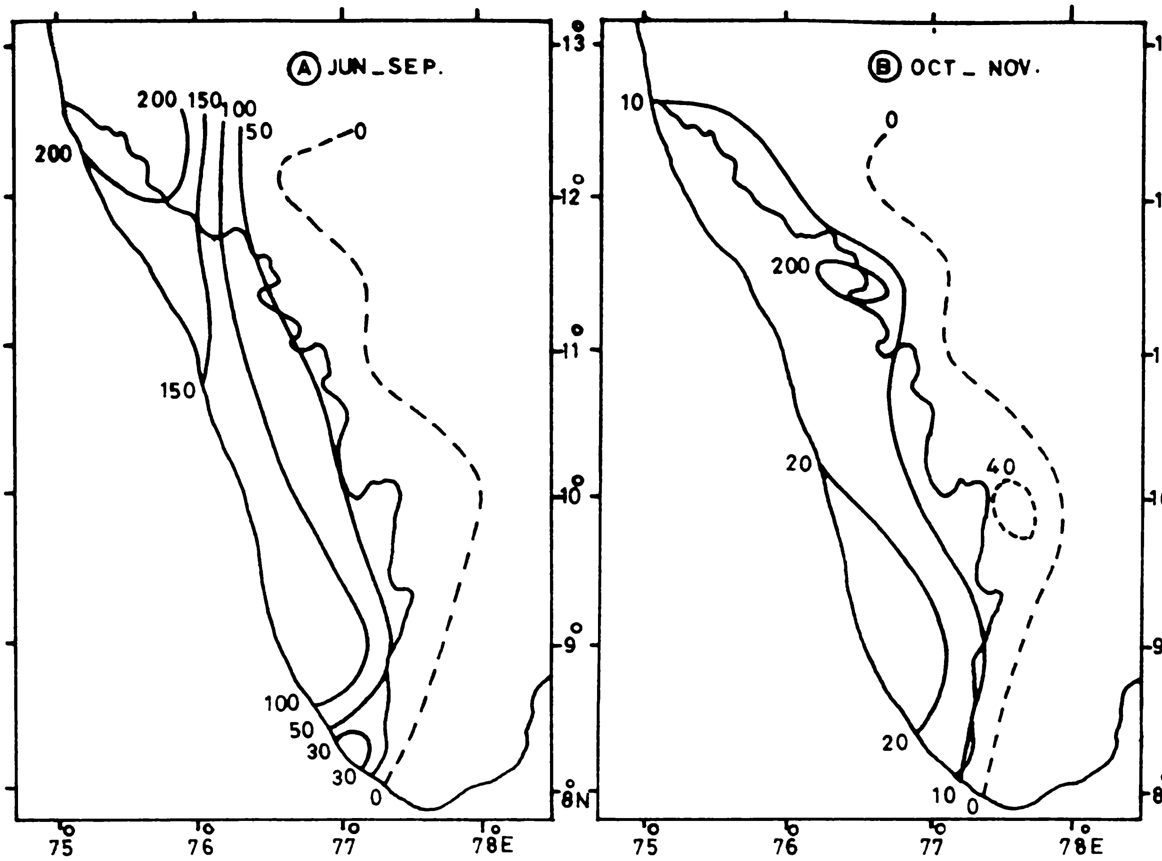

FIG.5.18. WATER SURPLUS – SEASONAL (CMS)

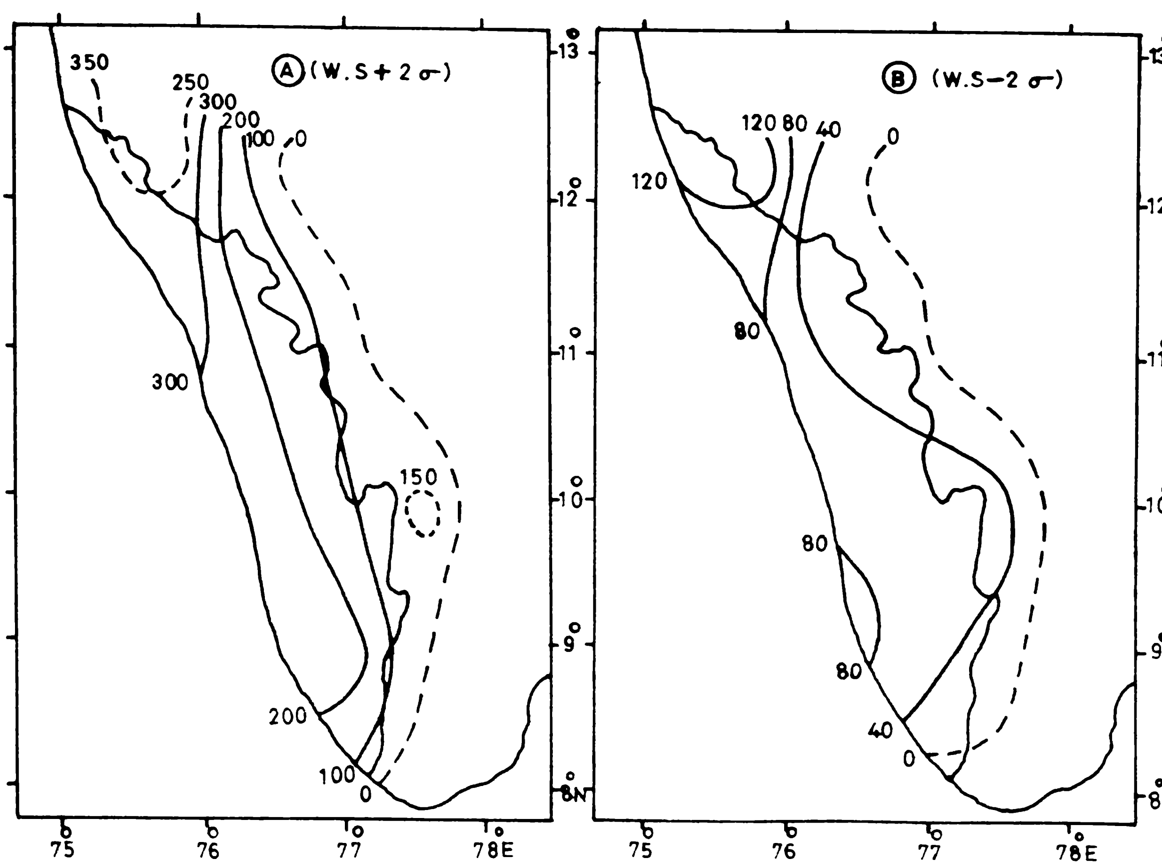

FIG.5.19. WATER SURPLUS ± 2 STANDARD DEVIATION (CMS)

the Palghat region which exhibits only 70 cms. of water surplus (Fig. 4.12). Figures showing seasonal distribution of water surplus (Fig. 5.18) are presented only for the periods June - September and October - November as no water surplus is observed in the State during other two seasons, except at Alleppey, where a surplus of 8 cms. occur in the pre-monsoon season. More than 75% of the annual water surplus occurs in the southwest monsoon season. The surplus values vary from 35 cms. around Trivandrum and 100 cms. in Quilon District to nearly 200 cms. in the extreme north of the State. During October - November months, more surplus occurs in the southern coastal portion of the State (20 cms.) than in the north (10 cms.). However, Alleppey exhibits a water surplus of around 30 cms..

Distribution of (W.S. + 2σ) and (W.S. - 2σ) values (Fig. 5.19) suggest that the surplus can be a maximum of 100 cms. in the extreme south and between 300 cms. and 350 cms. in the extreme north. Surplus can be as low as zero around Trivandrum and less than 120 cms. in the extreme north of the State in 2.5 years out of 100.

v. Runoff

Runoff represents the return of precipitation to the sea or inland water bodies by both surface and underground routes. Runoff is influenced by both climatic and physiographic factors. Climatic factors include precipitation, interception and evapotranspiration while physiographic factors include slope, soil type and vegetation. Climatic factors show seasonal variations in accordance with the climatic environment which are reflected in the seasonal runoff.

On a climatic basis, values of annual water surplus and annual runoff are identical (Fig. 4.12). But, seasonal runoff patterns differ from seasonal water surplus pattern (Fig. 5.20). In the pre-monsoon months, the runoff decreases from 10 cms. around Alleppey to 4 cms. in the northern and eastern boundaries of the State and to less than 1 cm. in the extreme south. During southwest monsoon period, large areas of the State exhibit a water surplus of around 100 cms. though the range is from 30 cms. (in the extreme south) to 200 cms. (in the extreme north). Around Palghat, the runoff is only 55 cms. During northeast monsoon period, the runoff increases from 30 cms. in the Ghats region to 35 cms. in the coastal area. Alleppey exhibits 40 cms. of runoff during this period while for

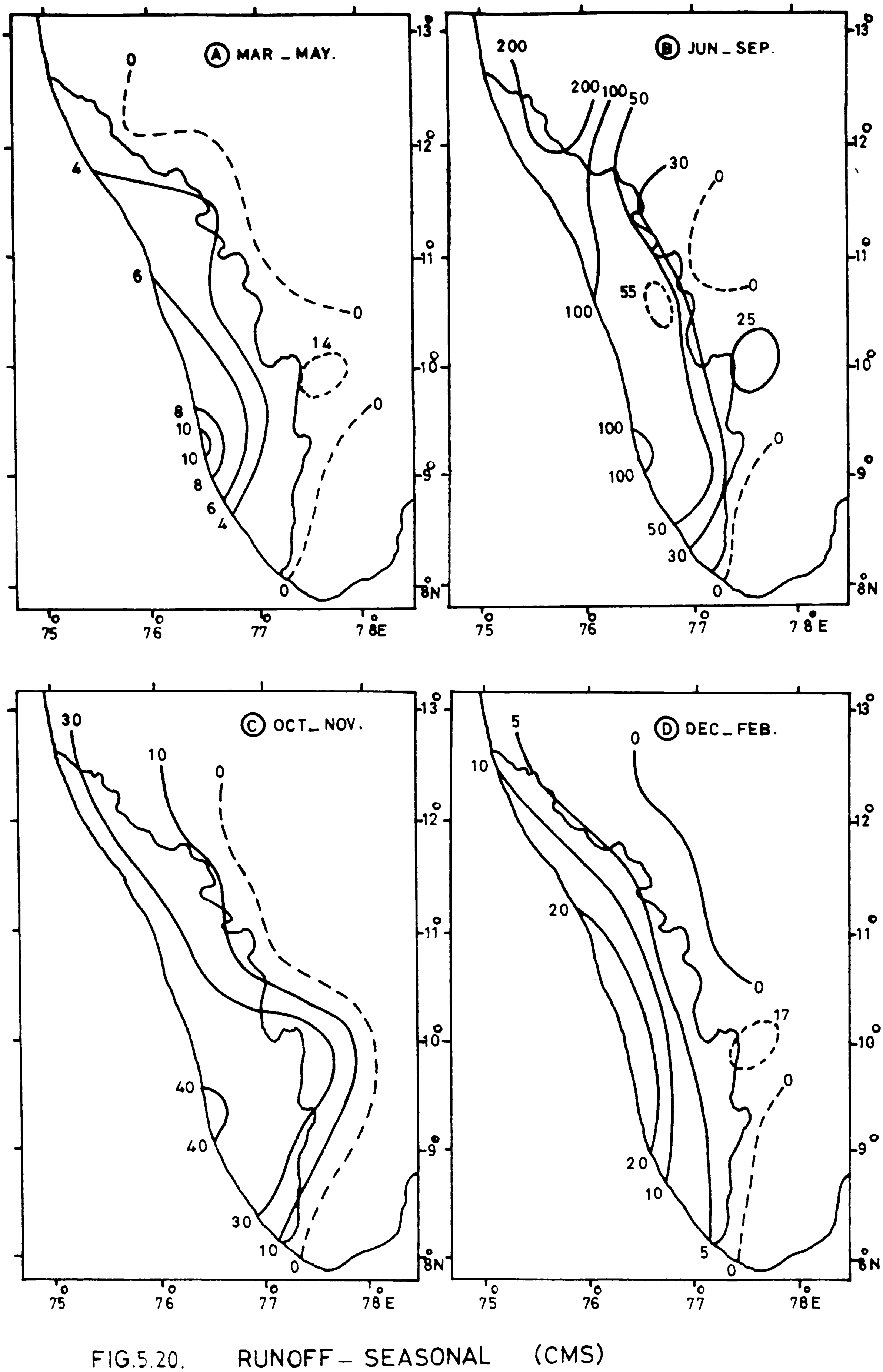

FIG.5.20. RUNOFF – SEASONAL (CMS)

Trivandrum it is only 15 cms. and Palghat, only 12 cms. Runoff during the winter season decreases from 20 cms. in the central coastal region to 5 cms. in the Ghats.

vi. Surface Flow

Surface flow or overland runoff is that water which travels over the ground surface to reach a channel. It is an important element in the formation of flood peaks. According to the assumption of the technique followed in its computation, surface flow can occur only after the potential demands of the atmosphere and the soil are satisfied.

As the major percentage of annual rainfall and surplus occurs in the southwest and northeast monsoon seasons, the surface flow also is restricted to these periods. The mean annual surface flow varies from less than 30 cms. at Trivandrum to around 100 cms. in extreme northern portions of Kerala (Fig. 5.21A). Over central Kerala, the surface flow is about 50 cms. It increases to 60 cms. around Alleppey and Calicut and to 70 cms. around Punalur. Seasonally, (Fig. 5.22) the flow increases from less than 20 cms. in the south to 100 cms. in the north. Most parts of the State exhibit 50 cms. of surface flow while for Palghat, it is only 35 cms.. During October - November months, surface flow increases from 3 cms. in the north to

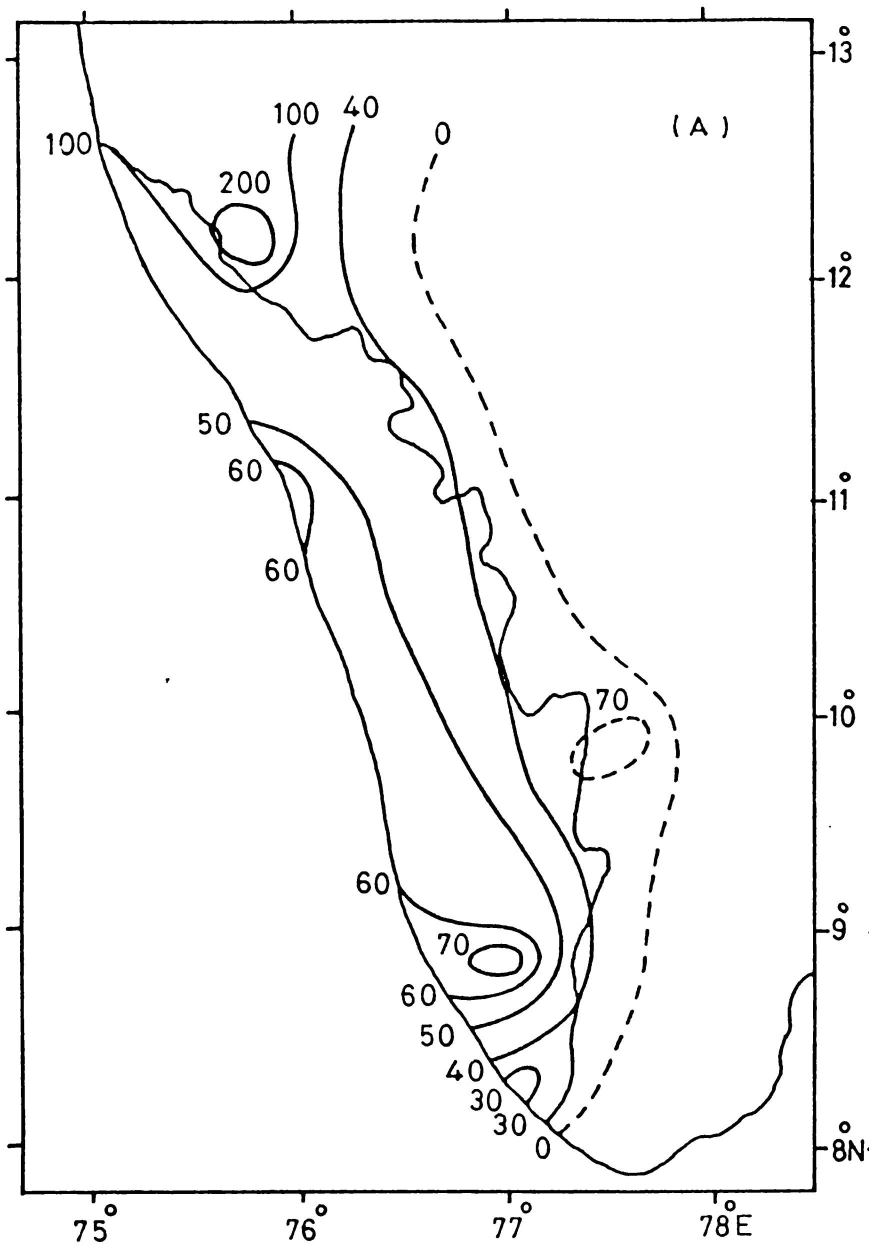

FIG5.21A SURFACE FLOW – ANNUAL (CMS)

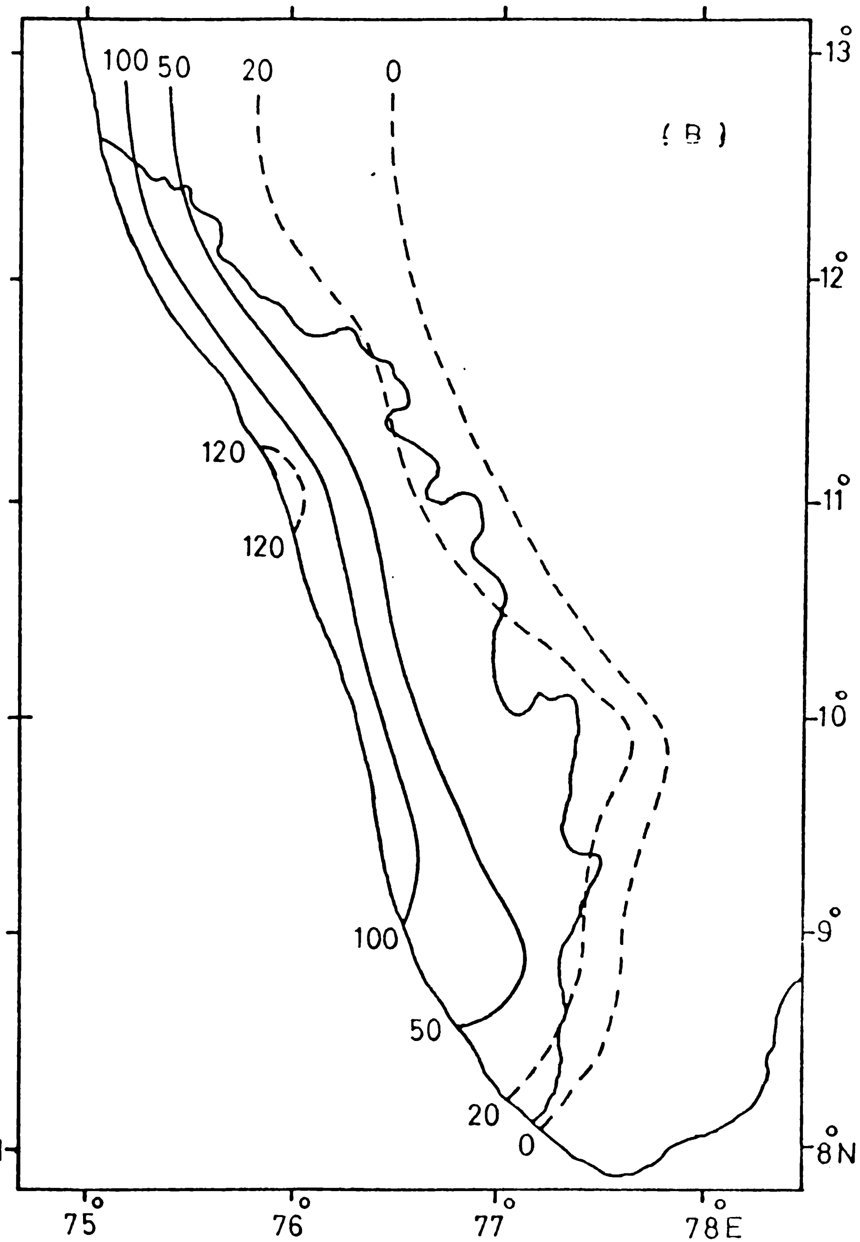

FIG5.21B GROUNDWATER FLOW – ANNUAL (CMS)

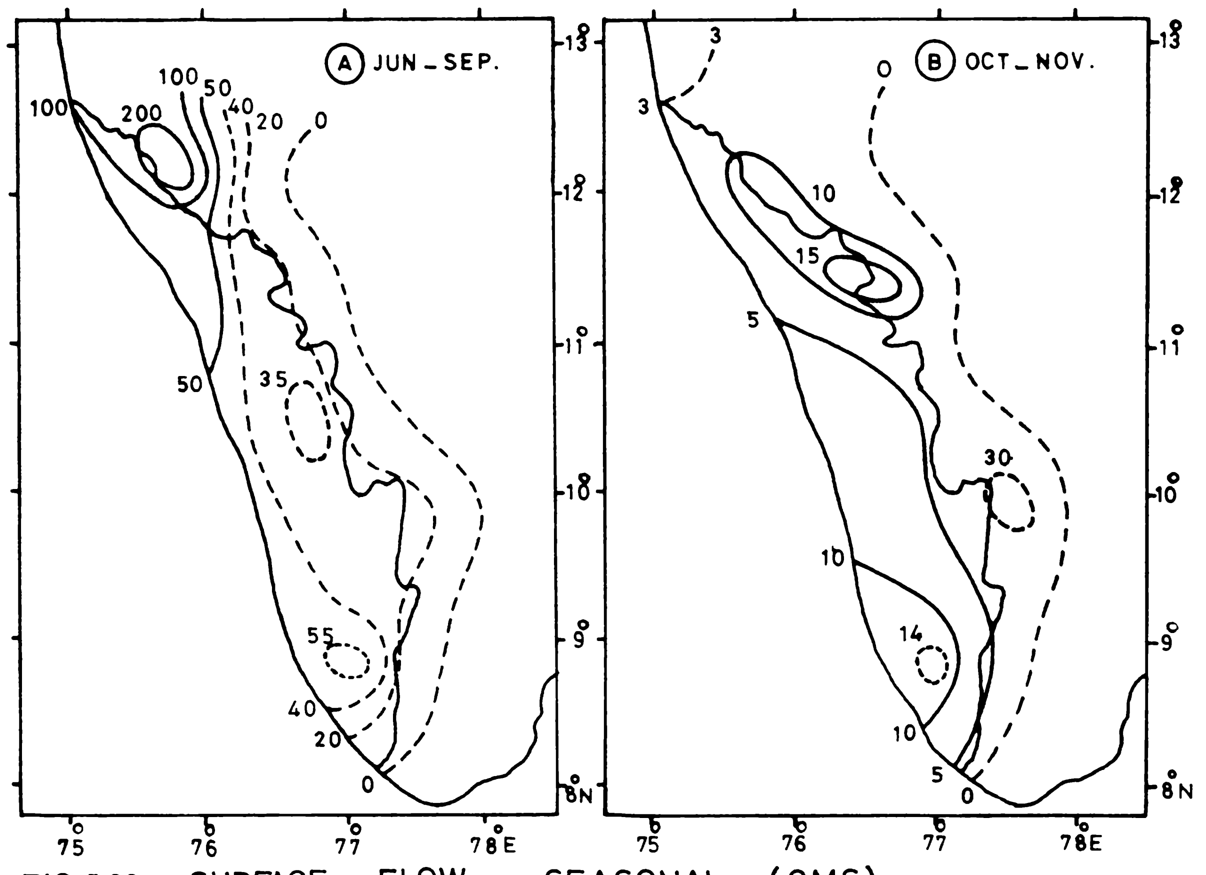

FIG. 5.22. SURFACE FLOW - SEASONAL (CMS)

10 cms. around Alleppey and Punalur. Surface flow again decreases towards the south.

vii. Underground Flow

Underground flow represents the flow of water in the underground regions to reach the channel. It depends upon the amount of recharge and the underground characteristics of the area. According to the water balance concepts, only after the soil moisture condition is satisfied, the water can pass into the groundwater reservoir. In view of the increasing need for water for irrigation, industries and domestic use, appraisal of groundwater resources is very important.

In general, the mean annual groundwater flow is more than 100 cms. along the coast and between 20 cms. and 50 cms. in the Ghats region (Fig. 5.21B). The southern districts of Kerala have very small groundwater flow (20 cms.). Calicut experiences a groundwater flow of 120 cms. whereas for Palghat it is only 28 cms.. Considering the seasonal distribution (Fig. 5.23), the groundwater flow during pre-monsoon and winter months is quite small, being about 3 cms. to 15 cms. over the State. A small pocket around Alleppey has however, a groundwater flow of 20 cms.. During the monsoon months, the groundwater

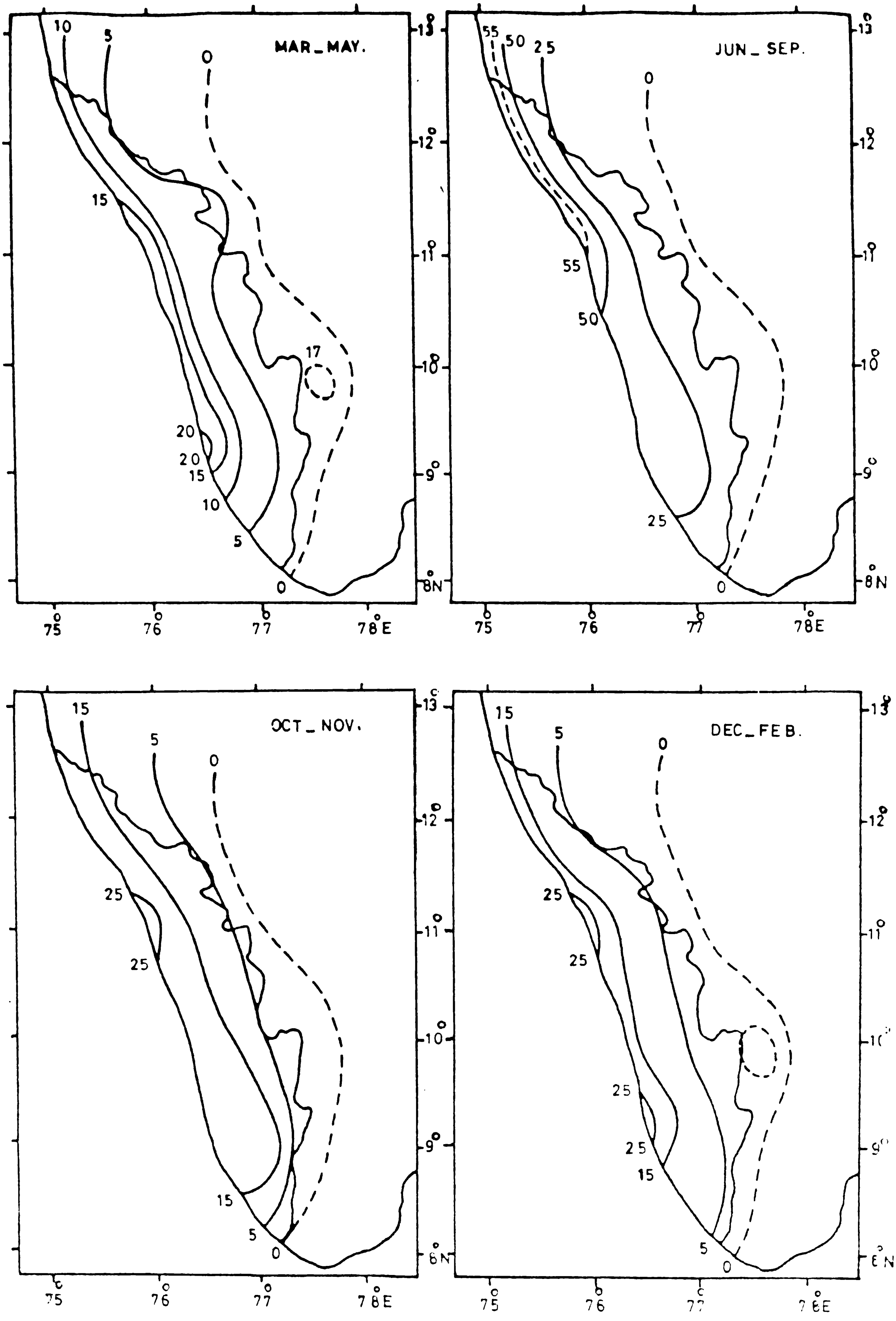

FIG.5.23. GROUNDWATER FLOW – SEASONAL

increases to between 10 cms. around Trivandrum and 25 cms. in the central districts of Kerala to about 50 cms. or more in the northernmost part of the State. In the following seasons, the groundwater flow shows an all-round decrease over the State with a maximum value of 25 cms. at Calicut. During December - February, the pattern does not change much from the previous season.

viii. Total Discharge

Total discharge is the sum of surface flow and underground flow. During the pre-monsoon and winter months, the surface flow is insignificant and hence the total discharge in these two seasons is equal to the underground flow alone. During the southwest monsoon period (Fig. 5.24), the total discharge varies from around 25 cms. at Trivandrum to nearly 150 cms. over the northern parts of the State. The variation is from 15 cms. to 25 cms. during October - November; the central coastal zone exhibits a discharge of more than 30 cms. with a maximum of 35 cms. around Alleppey.

ix. Water Detention

According to the water balance concepts, water that goes into the underground region after surface flow has occured is detained there and is added to the next months water surplus for further contribution

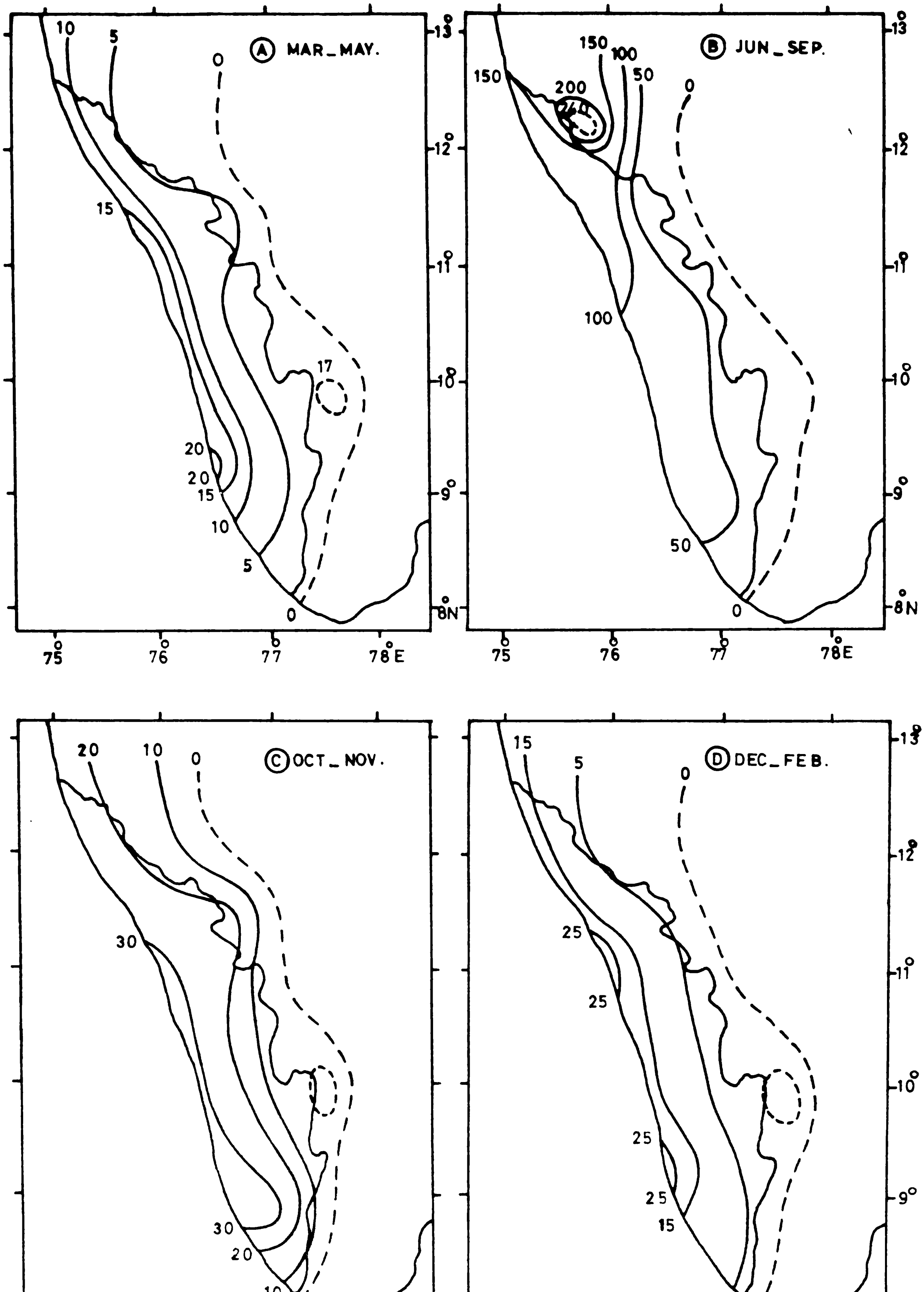

FIG. 5.24. TOTAL DISCHARGE - SEASONAL (CMS)

to runoff and detention again.

The seasonal detention values (Fig. 5.25) reveal only the status of the detained water at the end of every season since the runoff calculations are based on the cumulative technique. Water detention is insignificant in the pre-monsoon season. Around 4 cms. of water is detained in the central coastal area only. Higher detention values are noted during the southwest monsoon season, with values increasing from 50 cms. around Trivandrum and 150 cms. around Alleppey to more than 200 cms. around Calicut. During October - November, the central coastal area exhibits 60 cms. of water detention which decreases to 30 cms. in the northern districts and to 10 cms. at Trivandrum district. In the winter season, detention decreases, varying from 30 cms. in the central coastal area to less than 10 cms. at the northern and southern districts. In all these seasons, lee side of the Ghats exhibits no water detention.

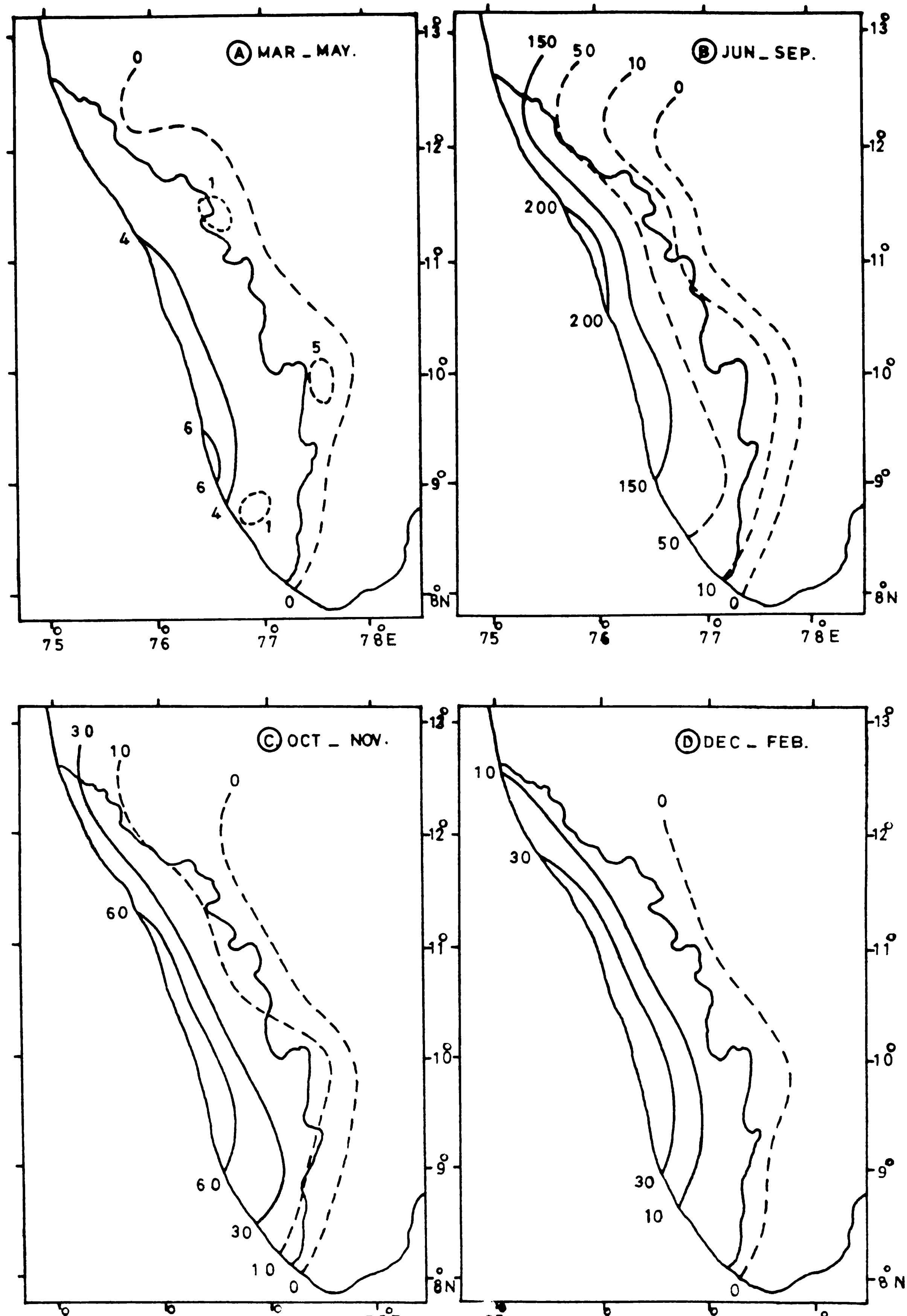

FIG. 5.25. WATER DETENTION – SEASONAL (CMS)

SECTION III. ANALYSIS OF DROUGHTS

Eventhough Kerala has the maximum annual rainfall for any State in India, the variability of rain producing systems, especially in the southwest monsoon season gives rise to large water deficiencies in some years and increased water surpluses in others. These water deficits could result in droughts and consequently adversely affect the predominantly agriculture-based economy of the State. In recent years, droughts have had crippling effects on the already meagre fiscal resources ear-marked for developmental programmes. Relief measures to mitigate the severity of the droughts would necessarily entail a reduced pace of development. In the present Section, the drought climatology of the State has been studied in an attempt to project the undeniable fact, that, a region with fairly large water surpluses and ground-water resources can and does experience periods of water shortages too.

As stated earlier, water balance method employing the book-keeping procedure of Thorhthwaite & Mather (1955) has been used to study the frequency and severity of droughts as suggested first by Subrahmanyam (1958). The climates of different stations inside the State have been categorised to study the relative occurrences of droughts in these climatic zones. Only two types of climates are observed inside the State - moist subhumid and humid. The stations, their moisture index values and types of climate in which they are included are given below (Table 5.1).

TABLE 5.1

Categories of Climate in the Study Area

Station	Moisture index (%)	Climate
Trivandrum	13.0	Moist subhumid (C_2)
Palghat	19.9	Moist subhumid (C_2)
Punalur	71.0	Humid (B_3)
Cochin	80.0	Humid (B_4)
Alleppey	88.0	Humid (B_4)
Calicut	88.0	Humid (B_4)

The stations Trivandrum and Palghat experience moist subhumid climate because these two stations receive less rainfall compared to other stations, due to the orography of the Ghats. Occu-rrences of droughts and their severity for individual stations are discussed below.

i. Drought Climatology of Trivandrum

In a period of 79 years (1901 - 1979), Trivandrum experienced 35 droughts which include 4 disastrous, 7 severe, 12 large and 12 moderate droughts (Table 5.2). The I_a values show wide fluctuations, with departures from the median ranging from-52% to +56% (Fig. 5.26). The decennial frequency of droughts at Trivandrum (Fig. 5.28) was maximum during 1961 - 1970, with 7 years of droughts including 3 severe, 3 large and 1 moderate droughts. The decade 1911 - 1920 experienced only 1 disastrous and 1 large drought while the number of drought years were 3 during 1921 - 1930, with 2 of them disastrous and 1 severe. The trend of aridity (the difference between the two half-period averages of the aridity indices) at this station (Table 5.3) is found to be positive (+1.1). This is in variance with earlier findings (Sarma, 1974 and Ram Mohan, 1978) that stations in the moist subhumid zones of South India generally exhibit a decrease in aridity.

ii. Drought Climatology of Palghat

As in the case of Trivandrum, this moist subhumid station receives less rainfall compared to other stations in Kerala. In a period of 35 years (1944 - 1979), Palghat experienced 19 droughts

TABLE 5.2

Drought Years in Kerala State

Station	Period of study	Years of Drought: Disastrous	Severe	Large	Moderate	Total
Trivandrum	1901-1979	4 (1911, 1923, 1928, 1976)	7 (1921, 1931, 1949, 1953, 1964, 1966, 1968)	12 (1903, 1904, 1906, 1917, 1935, 1944, 1953, 1961, 1967, 1969, 1974, 1979)	12 (1902, 1936, 1940, 1945, 1947, 1948, 1951, 1952, 1955, 1965, 1972, 1973)	35
Palghat	1944-1979	1 (1952)	7 (1945, 1950, 1953, 1967, 1974, 1978, 1979)	6 (1949, 1964, 1968, 1969, 1973, 1975)	5 (1946, 1947, 1954, 1956, 1957)	19
Punalur	1957-1979	2 (1971, 1972)	1 (1959)	3 (1961, 1967, 1973)	5 (1965, 1969, 1974, 1976, 1977)	11
Cochin	1901-1979	1 (1935)	10 (1902, 1905, 1906, 1913, 1914, 1923, 1927, 1959, 1976, 1979)	15 (1903, 1909, 1916, 1917, 1918, 1920, 1932, 1936, 1945, 1943, 1949, 1953, 1964, 1965, 1971)	17 (1901, 1911, 1912, 1926, 1938, 1941, 1951, 1955, 1958, 1961, 1962, 1963, 1968, 1969, 1972, 1977, 1978)	43
Alleppey	1945-1979	1 (1945)	4 (1949, 1966, 1967, 1969)	3 (1951, 1965, 1976)	8 (1952, 1953, 1958, 1959, 1960, 1962, 1972, 1979)	16
Calicut	1901-1979	2 (1953, 1964)	12 (1906, 1941, 1971, 1928, 1935, 1958, 1959, 1966, 1971, 1973, 1974, 1978)	8 (1912, 1913, 1927, 1931, 1950, 1952, 1957, 1979)	12 (1907, 1908, 1911, 1916, 1919, 1922, 1923, 1930, 1939, 1951, 1961, 1972)	34

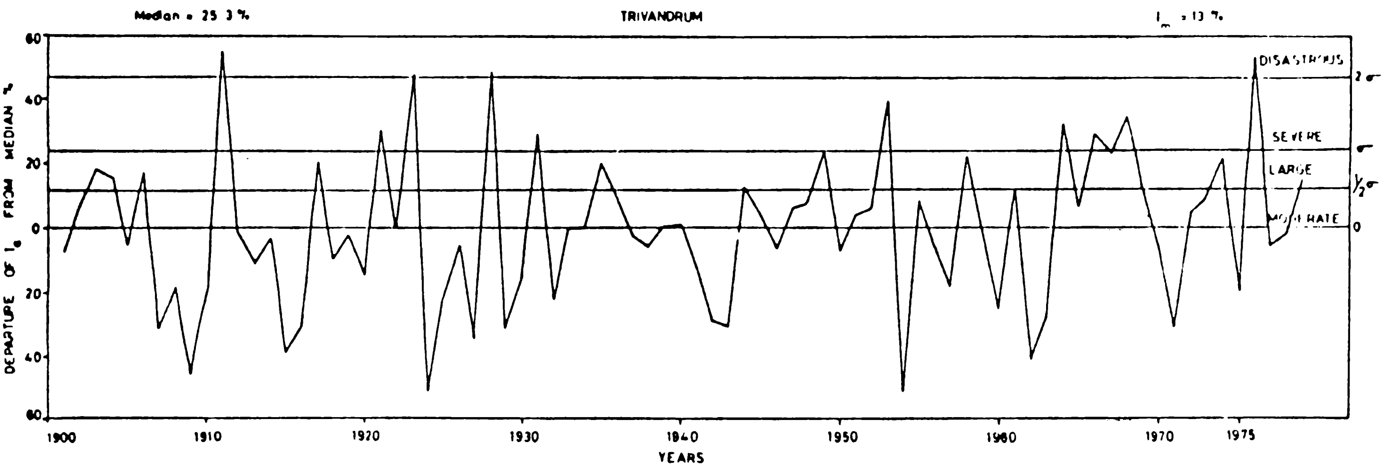

FIG. 5.26. YERLY MARCH OF ARIDITY INDEX

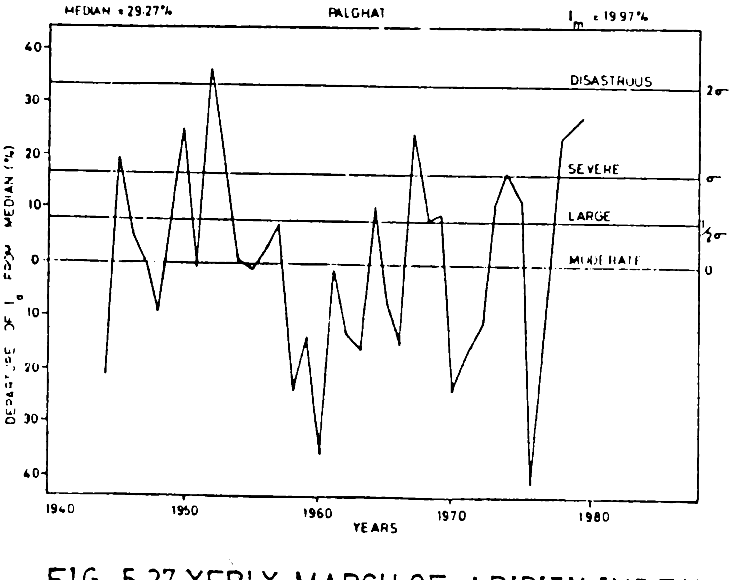

FIG. 5.27. YERLY MARCH OF ARIDITY INDEX

TABLE 5.3

Trends of Aridity

Station	Period of Study	Mean of first half period I	Mean of second half period II	Trend II - I
Trivandrum	1901 - 79	24.6	25.7	+1.1
Palghat	1944 - 79	31.4	27.9	-3.5
Punalur	1957 - 79	12.8	16.2	+3.4
Cochin	1901 - 79	19.4	18.4	-1.0
Alleppey	1901 - 79	17.2	18.6	+1.4
Calicut	1901 - 79	27.4	28.6	+1.2

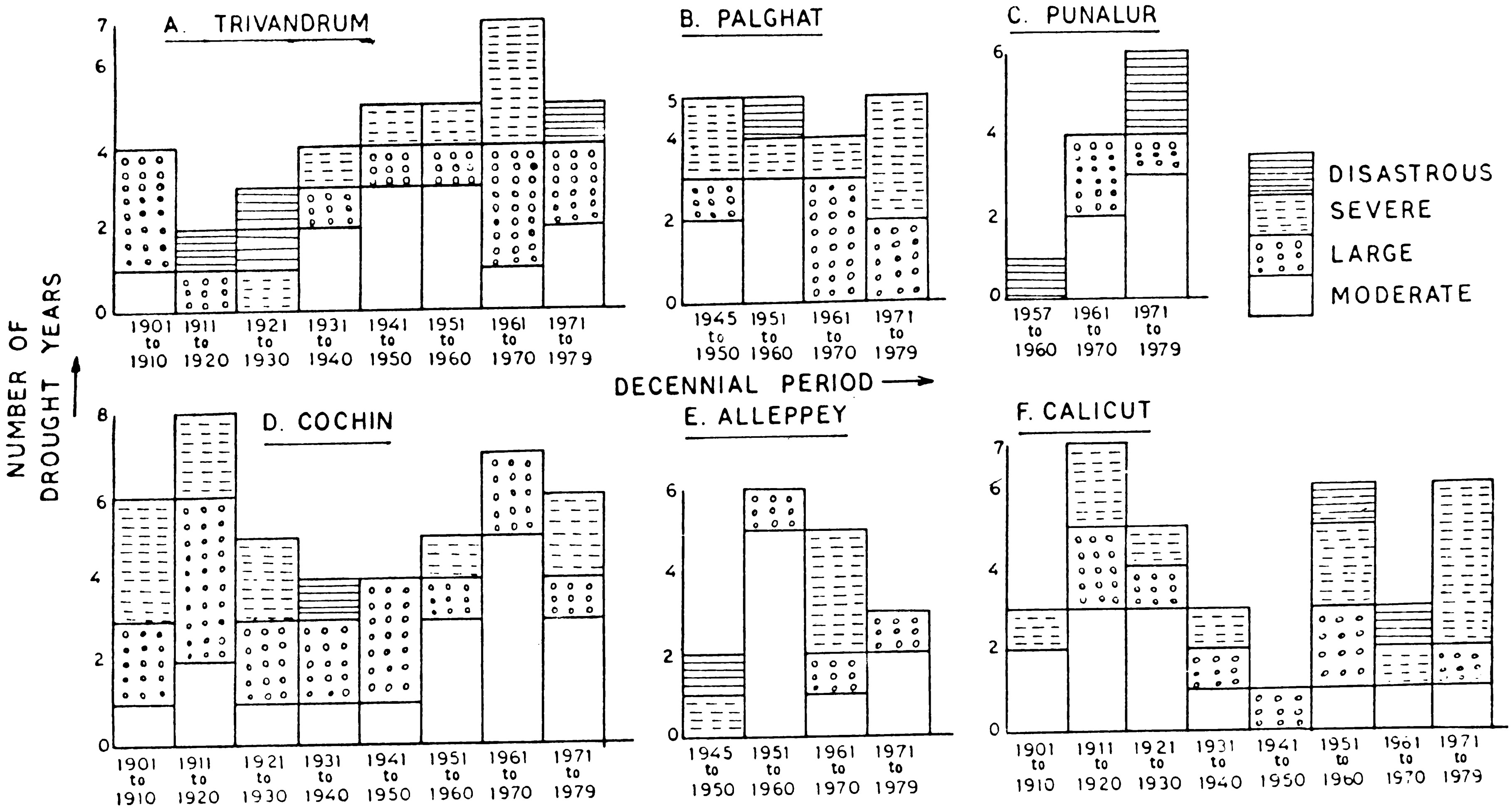

FIG. 5.28. FREQUENCY OF OCCURRENCE OF DROUGHTS

including 1 disastrous, 7 severe, 6 large and 5 moderate droughts. The decennial frequency of droughts show that the decade 1961 - 1970 was better compared to other decades. In this decade only 1 severe and 3 large droughts occurred at Palghat, while 5 droughts occurred in each of the other decades. Departures of I_a from the median (Fig. 5.27) are vide, ranging from -37% to +38% and the trend of aridity is -3.5, indicating a decreasing tendency of dryness.

iii. Drought Climatology of Punalur

Punalur is the only station experiencing B_3 type of humid climate in the State. In a period of 23 years (1957 - 1979) for which data is available, 11 droughts struck Punalur including 2 disastrous, 1 severe, 3 large and 5 moderate droughts. The decade 1971 - 1979 was the driest decade at Punalur. In a period of 9 years, the station faced 2 disastrous, 1 large and 3 moderate droughts. Wide fluctuations in the aridity pattern of the station is noticeable from the departures of I_a from median (Fig. 5.29) which range from -45% to +103%. The trend of aridity (+3.4) shows an increasing tendency of dryness.

iv. Drought Climatology of Cochin

During the study period of 79 years (1901 - 1979), this humid station experienced 43 droughts

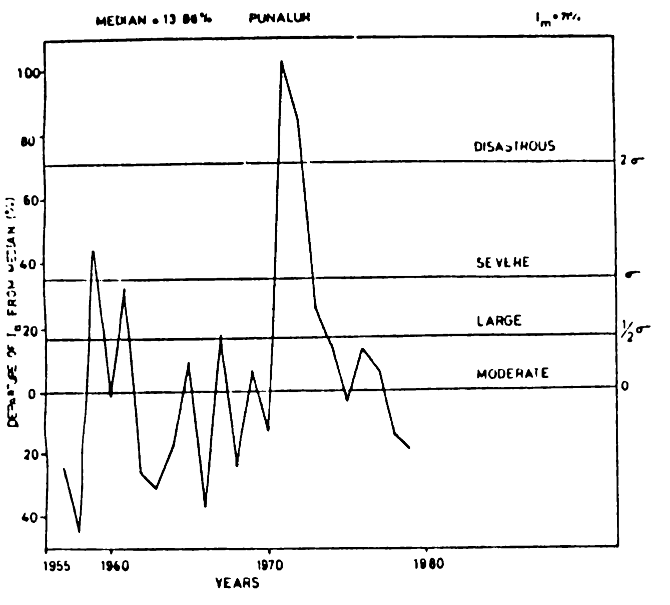

FIG. 5.29. YERLY MARCH OF ARIDITY INDEX

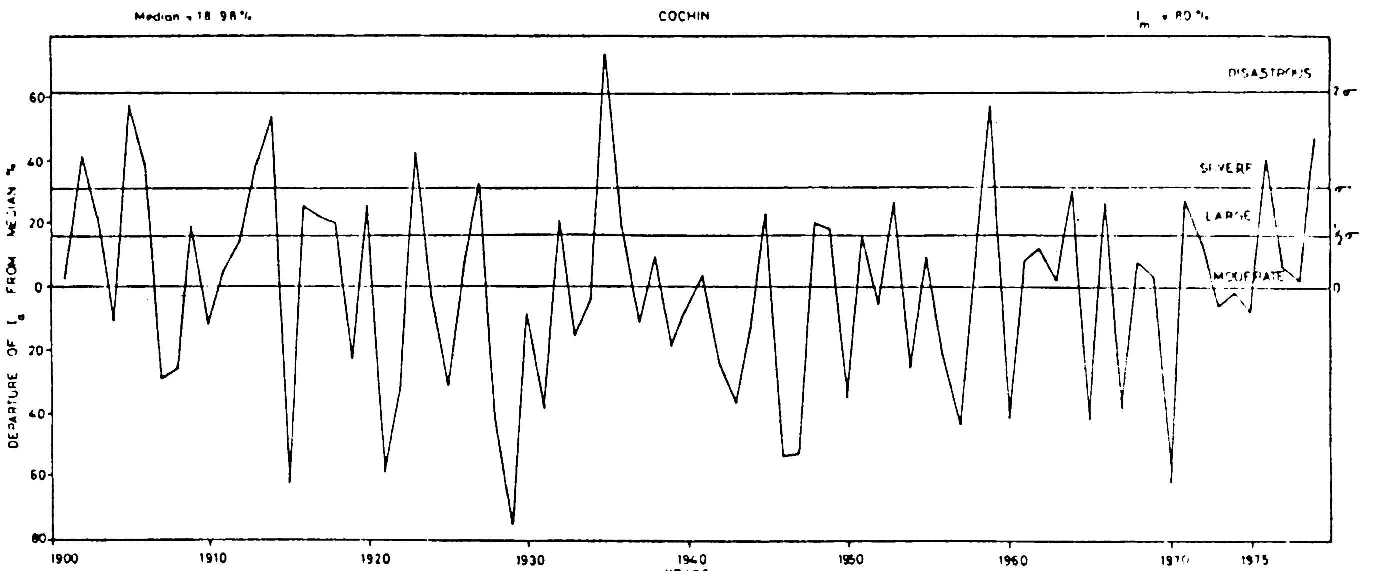

FIG. 5.30. YERLY MARCH OF ARIDITY INDEX

including 1 disastrous, 10 severe, 15 large and 17 moderate droughts. The extreme negative departure of I_a from the median, -75% occurred at Cochin in 1929 (Fig. 5.30) and the extreme positive value of 74% was recorded in 1935. Considering the frequency of drought years, the decade 1911 - 1920 had the largest number of drought years (8) inclusive of 2 severe, 4 large and 2 moderate droughts. A minimum of 4 years of drought occurred here in all the decades. Out of the 4 humid stations, only Cochin (-1.0) shows a decreasing tendency of dryness.

v. Drought Climatology of Alleppey

In a period of 35 years, Alleppey (a humid station) experienced 16 droughts which include 1 disastrous, 4 severe, 3 large and 8 moderate droughts. The extreme values of the aridity index from the median (Fig. 5.31) occurred at Alleppey within a period of 2 years, +77% in 1945 and -80% in 1947. The number of droughts was largest at Alleppey during 1951 - 1960 when 1 large and 5 moderate droughts occurred here. The number in the next decade (1961 - 1970) was only 5, but 3 of them were severe and 1 large. An increasing tendency of dryness is noticed here from the positive trend in aridity (+1.4).

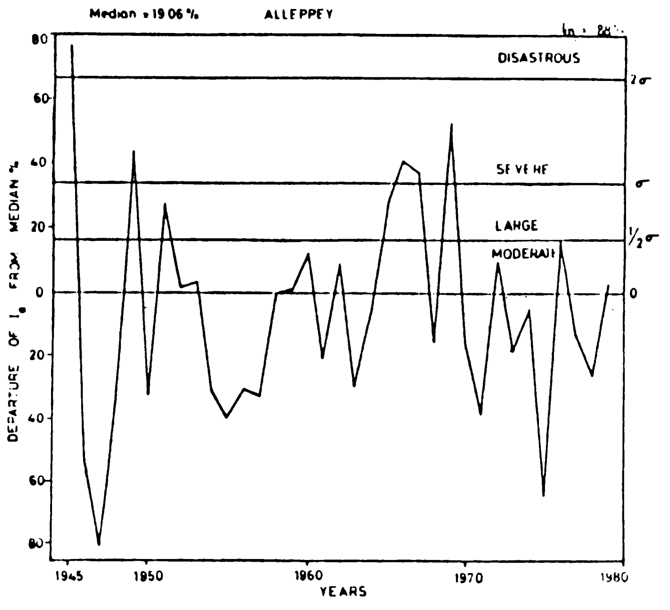

FIG. 5.31. YERLY MARCH OF ARIDITY INDEX

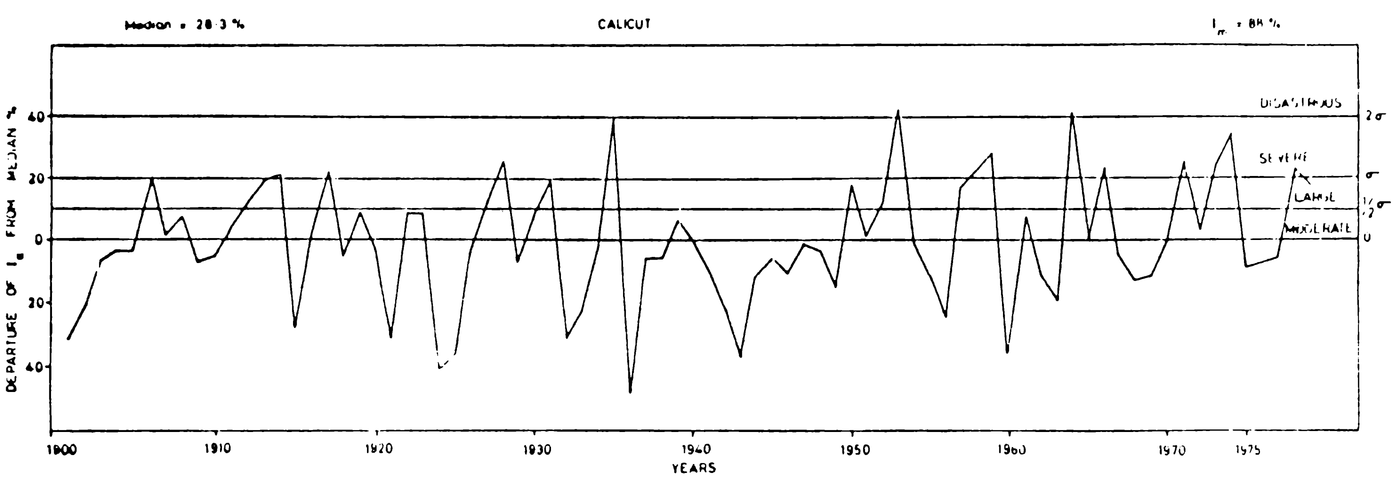

FIG. 5.32. YERLY MARCH OF ARIDITY INDEX

vi. Drought Climatology of Calicut

Comparing the periods of study and number of drought occurrences, this humid station experienced the minimum frequency of droughts. During the 79 years of study, only 34 droughts occured here which include 2 disastrous, 12 severe, 8 large and 12 moderate droughts. The deviations in the aridity indices were comparatively small, with values ranging from -49% to +40% only (Fig. 5.32). The decennial frequency of droughts at Calicut was maximum during 1911 - 1920 when 2 severe, 2 large and 3 moderate droughts occured. The frequency gradually decreased in the following decades, with 1941 - 1950 experiencing only one large drought. The trend of aridity is positive (+1.2) here, showing an increasing tendency towards dryness.

SECTION IV. CLIMATIC SHIFTS AND WATER BALANCE

Most regions are generally stable climatologically in the sense that their meteorological parameters do not show large long-time changes. But they do experience year to year fluctuations in temperature and rainfall. However, as air temperature and duration of sunshine are highly conservative in the tropics, the thermal regime of the climate doesn't show much year to year variability. On the other hand, rainfall characteristically exhibits wide variations in magnitude as well as durations. Such wide variations are even more pronounced in regions such as Kerala, that are dependent on the monsoons for their precipitation. As a consequence, the water budget shows large fluctuations from one year to another and sometimes the normal climatic regimes shift to a more humid or less humid category. In order to study such fluctuations in moisture regimes, moisture index (I_m) variations for the various stations have been plotted and summarized results are presented in Table 5.4.

The study of water balances in the years of extreme climatic shifts is of immense practical use in drought climatology and water-use planning. A critical examination of the comparative values of the elements of water balance reveals the acuteness of distress

TABLE 5.4

Climatic Shifts in Kerala

Station	Number of shifts								Variations within the category		
	Per-humid	Humid				Moist Subhumid	Dry Subhumid	Total	Wetter	Drier	Total
	A	B_4	B_3	B_2	B_1	C_2	C_1				
Trivandrum	0	1	2	5	15	-	29	52	8	19	27
Palghat	0	1	2	3	9	-	5	20	2	14	16
Punalur	2	4	-	5	5	0	0	16	2	5	7
Cochin	20	-	18	11	8	2	0	59	20	-	20
Alleppey	8	-	8	7	1	2	0	26	5	4	9
Calicut	19	-	18	15	7	0	0	59	9	19	28

felt during the years of severe dryness and water deficit. In the present study also, the water balances of all stations in extreme wet and dry years are compared with the climatic water balance of each station.

i. Trivandrum (Moist Subhumid, C_2)

Violent year to year fluctuations are observed in the march of I_m at Trivandrum (Fig. 5.33). In the study period of 79 years, this station experienced 52 shifts in its climate, of which 29 were towards the dry subhumid (C_1) category. The 23 shifts towards the wetter category comprises 1 to B_4, 2 to B_3, 5 to B_2 and 15 to B_1. The station remained in its own moisture regime on 27 occasions during which there were 19 deviations towards drier direction and 8 towards the wetter.

During the normal year, at Trivandrum, water surplus occurs during June-August and October-November as the station receives rainfall from both monsoons (Fig. 5.34). Water deficit occurs during January-April and in December. In the wet year (1933), when the climate shifted to B_4 category, the rainfall increased by 65% and surplus by 250% (Table 5.5). Soil moisture accretion took place in April and surplus occured from May onwards and lasted till the end of

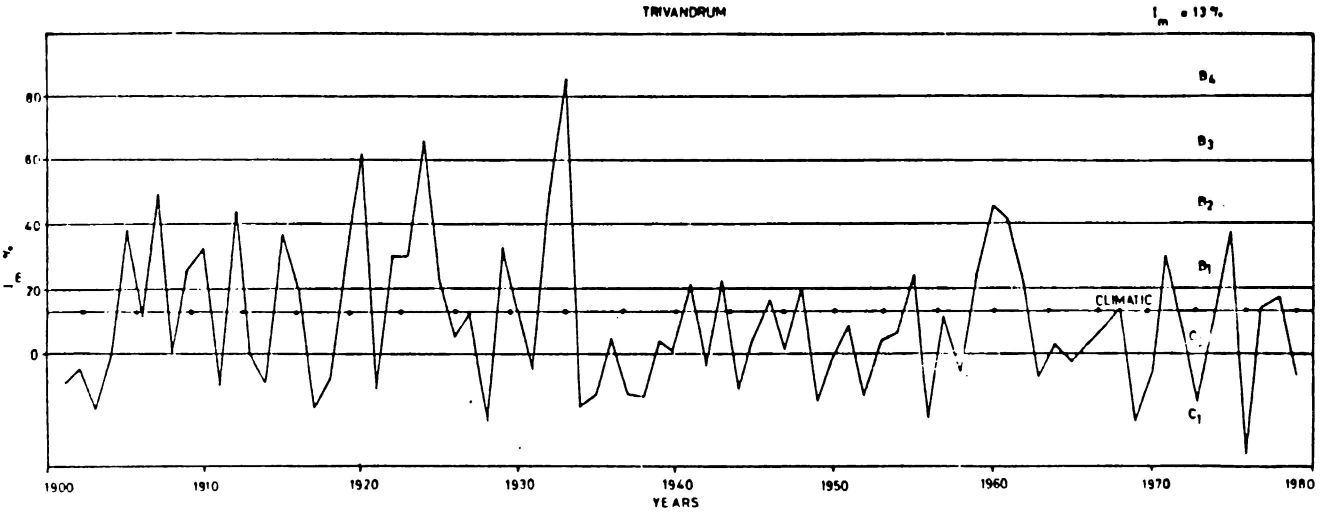

FIG. 5.33 CLIMATIC SHIFTS

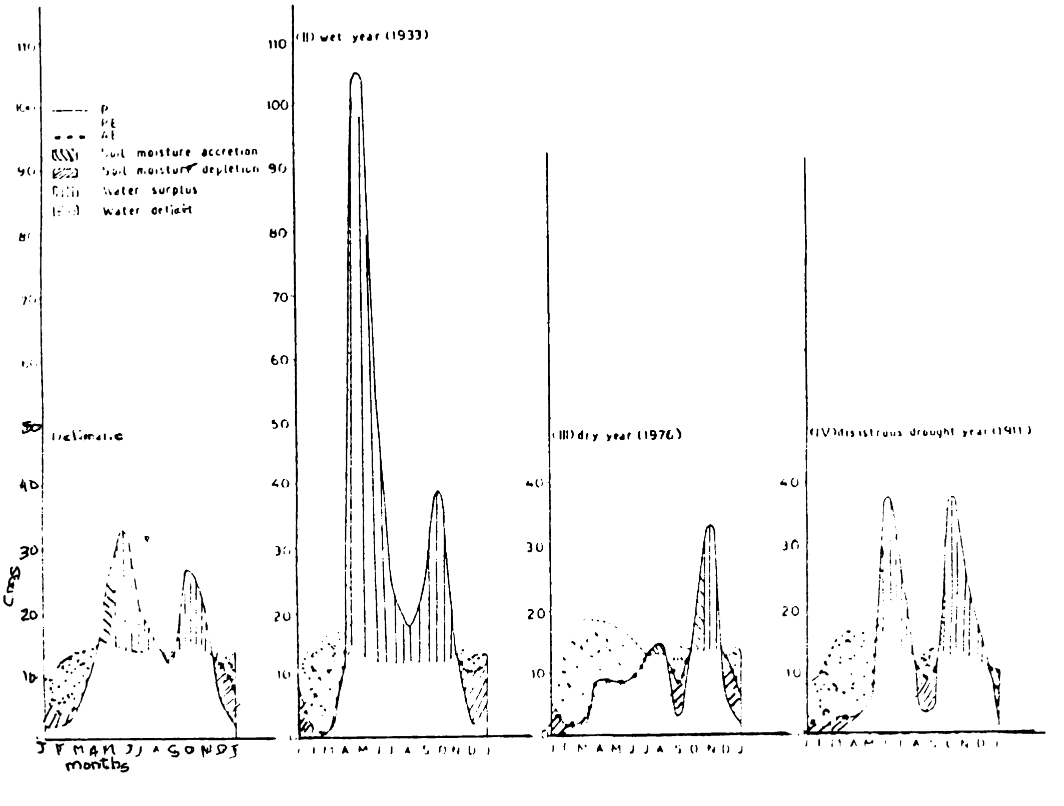

FIG 5.34 · WATER BALANCE OF TRIVANDRUM

TABLE 5.5

Elements of Water Budget

Category of the year	Rainfall (cm) (P)	Water Need (cm) (P.E.)	Water Deficit (cm) (E.D.)	Water Surplus (cm) (W.S.)	Moisture Index (%) (Im)	Category of Climate
		TRIVANDRUM				
Normal	183.9	171.9	29.9	51.9	13.0	C_2
Wet (1933)	303.6	165.1	41.7	182.4	85.2	B_4
Dry (1976)	112.7	176.6	68.4	14.7	-30.4	C_1
Disastrous drought (1911)	157.5	165.7	65.2	49.2	-9.7	C_1
		PALGHAT				
Normal	209.1	174.3	42.6	77.4	19.9	C_2
Wet (1961)	333.0	171.3	50.8	218.3	97.8	B_4
Dry (1952)	150.7	177.0	72.5	51.6	11.8	C_1
		PUNALUR				
Normal	298.9	168.0	16.6	135.8	71.0	B_3
Wet (1960)	359.9	175.0	24.2	207.4	104.7	A
Dry (1965)	223.9	173.4	26.3	65.1	22.4	B_1
Disastrous drought (1971)	278.9	168.7	47.4	153.9	63.1	B_3
		COCHIN				
Normal	326.3	173.8	21.7	174.2	80.0	B_4
Wet (1967)	473.6	175.3	20.7	337.3	180.6	A
Dry (1918)	204.5	182.3	41.3	63.3	12.1	C_2
Disastrous drought (1935)	211.6	173.3	57.4	92.7	20.4	C_2
		ALLEPPEY				
Normal	310.0	171.8	21.7	160.0	88.0	B_4
Wet (1975)	407.1	147.4	10.1	244.8	159.2	A
Dry (1965)	204.4	181.1	44.1	62.7	10.3	C_2
Disastrous drought (1945)	285.1	165.8	56.1	167.8	67.4	C_2
		CALICUT				
Normal	328.3	178.9	32.5	186.9	88.0	B_4
Wet (1961)	496.2	178.5	53.9	380.2	182.8	A
Dry (1976)	216.2	178.2	47.1	86.9	22.3	B_1
Disastrous drought (1953)	248.3	189.3	74.8	136.2	32.4	B_1

November. It is interesting to note that the water deficit also increased in this year by 80%. This is because practically no rainfall was received from January to March during the year. In the dry year (1976), rainfall decreased by 39% and water deficit rose to 125% of the normal. Water surplus decreased by 45% in this year and it occurred only in the month of November. The climate was shifted to dry subhumid (C_1) category in 1976. Though Trivandrum experienced 4 disastrous droughts, the severest of them was in 1911. This was so as the rainfall was below normal by 14%, water deficiency was more by 118% and water surplus was less by 5%. Compared to the dry year (1976) discussed above, the rainfall was nearer to the normal, water deficit was lower and water surplus was higher. This reinforces the idea that intensity of droughts or magnitude of shifts is not based on rainfall totals alone, but on its distribution over time. The water balance approach justifies its standing as being more rational and realistic because it clearly brings out this aspect.

ii. Palghat (Moist Subhumid, C_2)

Palghat exhibited 15 shifts in its climate in a period of 36 years (1944 - 1979), of which 5 were towards dry subhumid (C_1) and 15 were towards humid - 1 to B_4, 2 to B_3, 3 to B_2 and 9 to B_1 (Fig. 5.35).

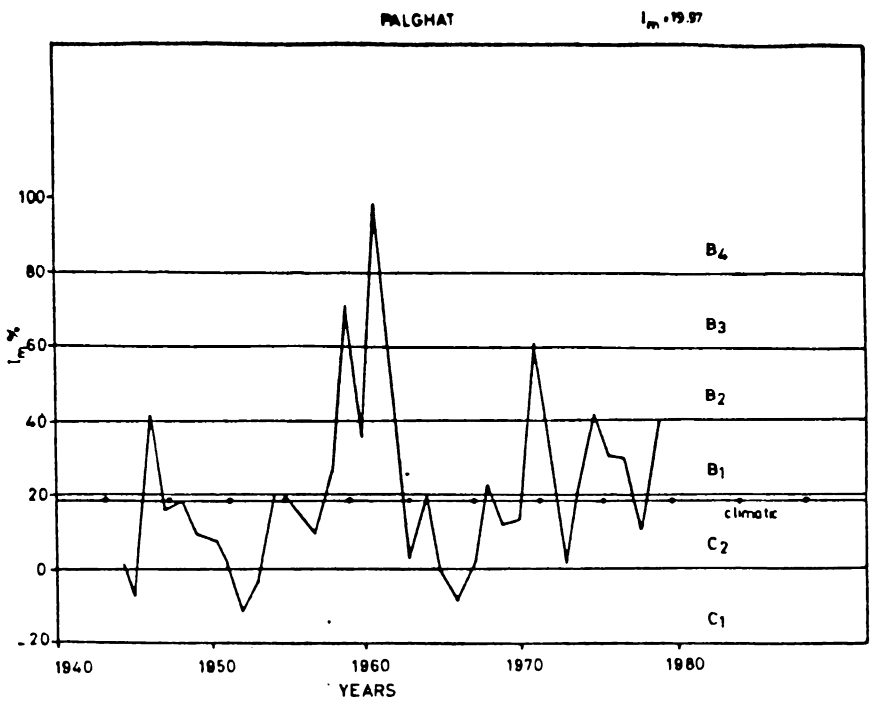

FIG. 5.35.CLIMATIC SHIFTS

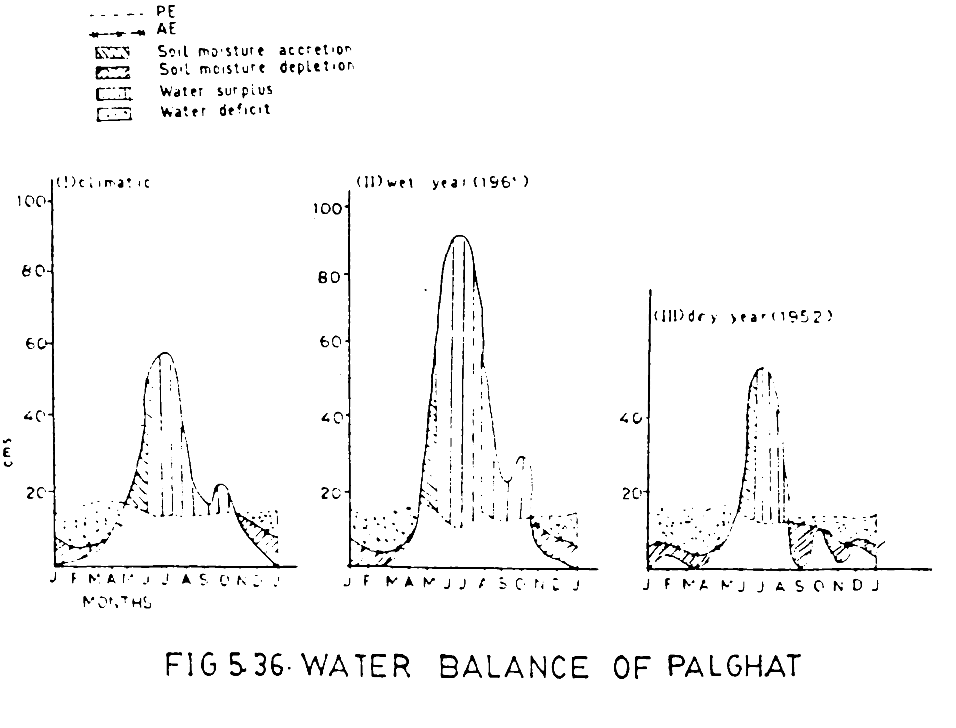

FIG 5.36. WATER BALANCE OF PALGHAT

The station remained in its own climatic category on 16 occasions, in which 14 deviations were in the drier direction. This is mainly because the normal moisture index (19.9%) of the station is close to the humid limit and therefore any small shift in the wetter direction would categorize it into the humid category (B_1).

At Palghat, water surplus is observed during June-October in the normal year and water deficit is seen in non-monsoon months (Fig. 5.36). The surplus became 3 times the normal in the wet year (1961). But, though P.E. was lower than normal, the deficit rose to 20% above normal because of the improper distribution of rainfall in different months. The year 1952 was the driest and also a disastrous drought year as rainfall was deficient by 25% and water deficit was above normal by 30%. Water surplus occurred in July and August, but was 25% less than normal. Climate shifted to the fourth humid (B_4) category in the wet year (1961) and to dry subhumid (C_1) category in the dry year (1952).

<u>iii. Punalur (Humid, B_3)</u>

During a study period of 23 years, 16 shifts in the climate (Fig. 5.37) were experienced at Punalur, 6 in the wetter direction (2 to perhumid, A and 4 to

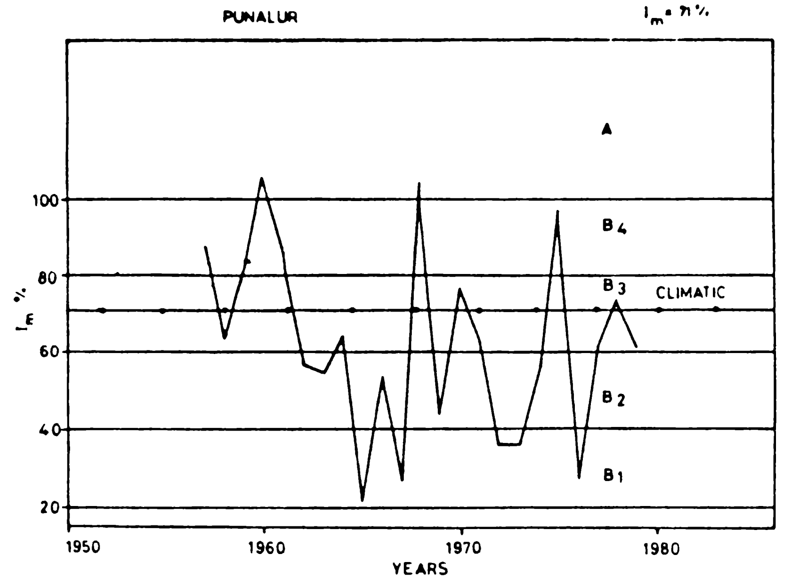

FIG. 5.37 CLIMATIC SHIFTS

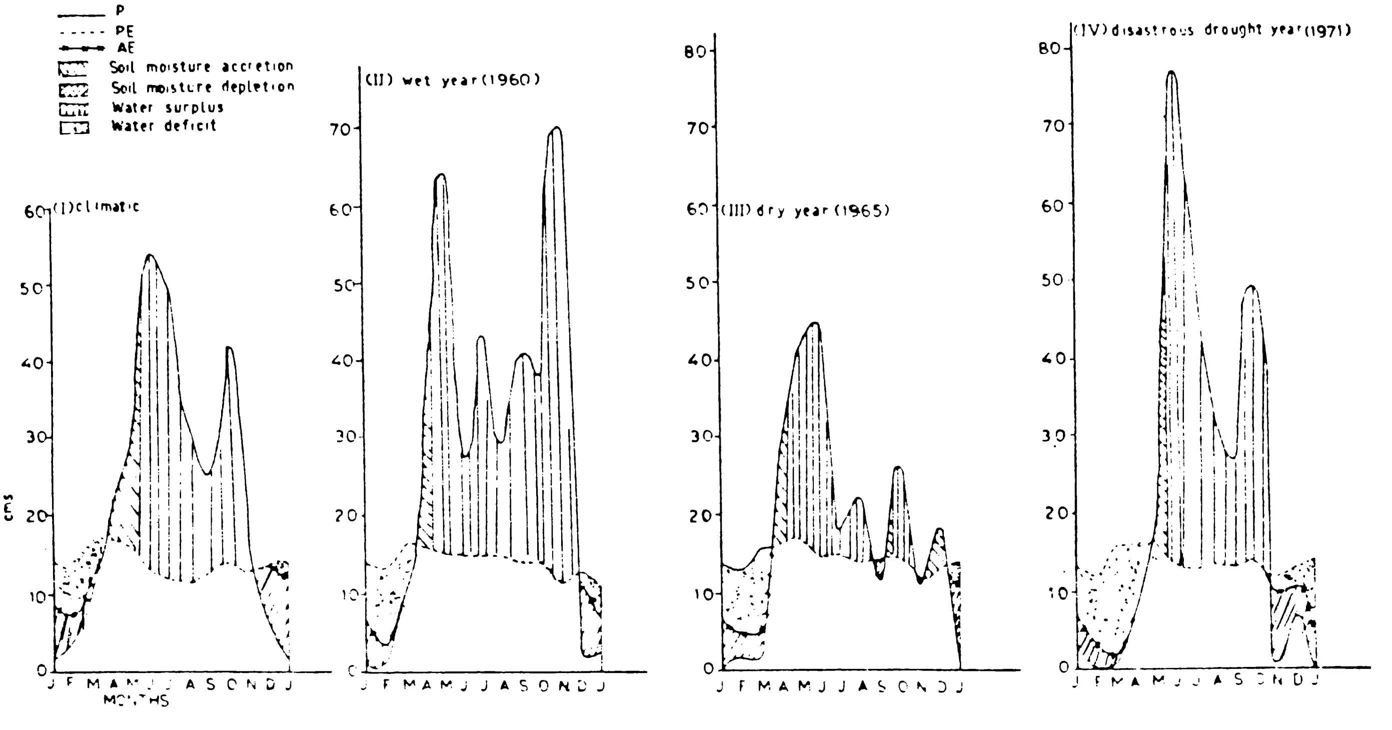

FIG 5.38 WATER BALANCE OF PUNALUR

fourth humid, B_4) and 10 in the drier direction (5 to B_2 and 5 to B_1). The station adhered to its own climatic regime in 7 years during which there were 5 deviations towards the drier direction.

In the normal year, water deficit occurs at Punalur during January to March and in December (Fig. 5.38) and a surplus of 135.8 cms. occurs during June to November months. In the wet year (1960) when the climate shifted to perhumid (A) category, rainfall increased by 20% and surplus by 50%. Interestingly, deficits also rose by 50%. The year 1965 was the driest year in which rainfall decreased by 33% and water surplus by 50%. The water deficit increased by 50% of the normal and the climate shifted to B_1. The more severe of the two disastrous droughts occured in 1971. Rainfall in this year was just below normal, but deficit rose 3 times the normal. Water deficits were higher by about 80%, but water surpluses increased by as much as 136%. The climate showed no shift in the disastrous drought year (1971).

<u>iv. Cochin (Humid, B_4)</u>

Of the 59 climatic shifts that occurred at Cochin in 79 years (Fig. 5.39) 20 were to perhumid(A), 18 to B_3, 11 to B_2, 8 to B_1 and 2 to moist subhumid (C_1). As the station is at the exact boundary

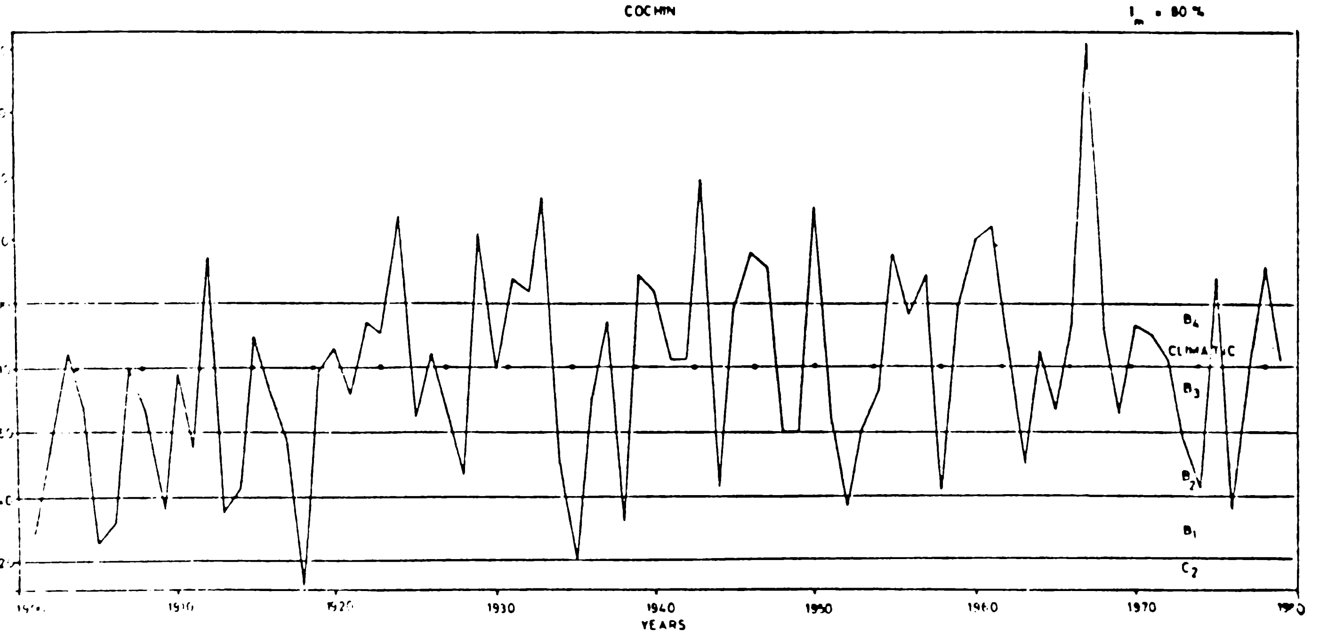

FIG. 5.39. CLIMATIC SHIFTS

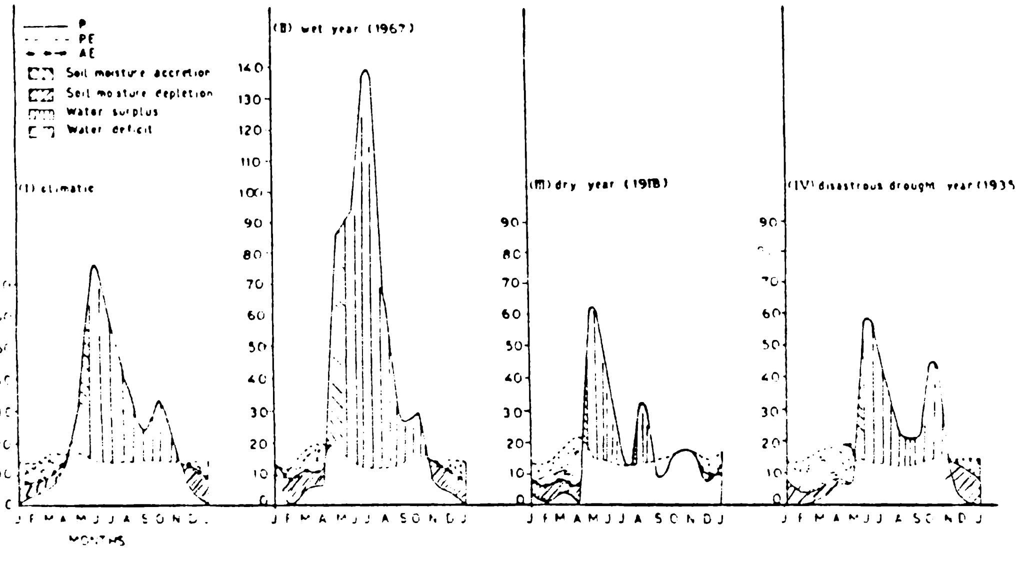

FIG 5.40. WATER BALANCE OF COCHIN

(I_m = 80.0%) between the third (B_3) and fourth (B_4) humid climates, all the 20 variations within its own climate category (B_4) were towards the wetter direction only.

During the normal year, water deficiency exists during 5 months - January to April and December - at Cochin, totalling an amount of 22 cms. (Fig. 5.40) and a surplus of 174 cms. is spread over the rest of the year. In the wet year (1967) when the climate shifted to perhumid (A) category, the rainfall increased by 45% and surplus by 100% from the normal, but water deficit remained almost normal. Rainfall decreased by 37% in the dry year (1918) and water surplus by 33%. Water deficit rose to twice the normal in this year. Interestingly, rainfall and water surplus were slightly higher in the disastrous drought year (1935) than in the dry year, but the water deficit increased to about thrice the normal. The climate shifted violently to the moist subhumid (C_2) category in the dry and disastrous drought years.

v. Alleppey (Humid, B_4)

At Alleprey, 26 shifts were observed in its climate - 8 to perhumid (A), 8 to B_3, 7 to B_2, 1 to B_1 and 2 to moist subhumid (C_2) categories (Fig. 5.41). Climatic variations within its category were 9, of which 5 were towards the wetter direction.

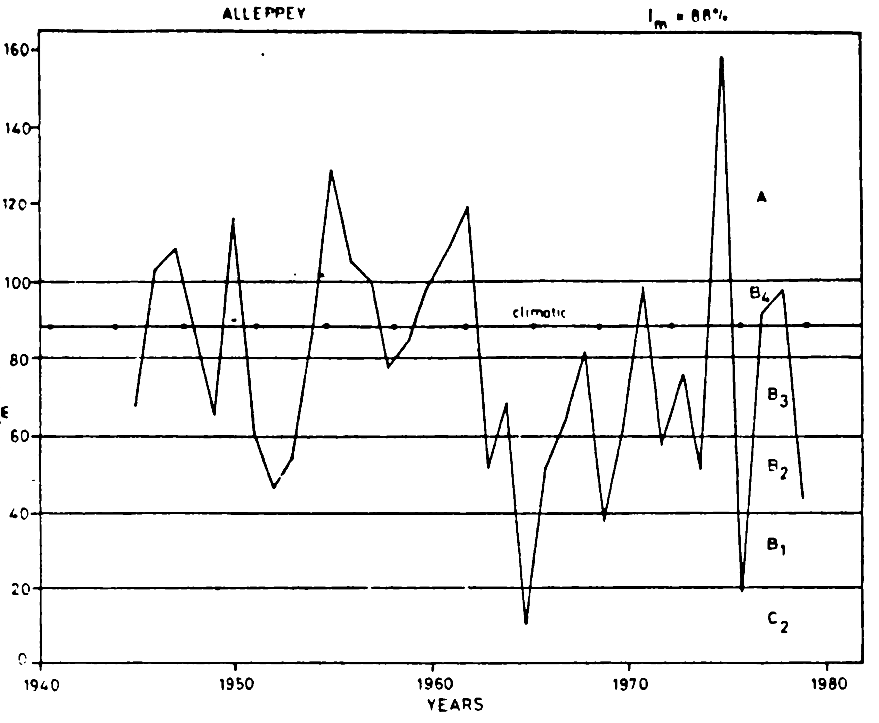

FIG. 5.41. CLIMATIC SHIFTS

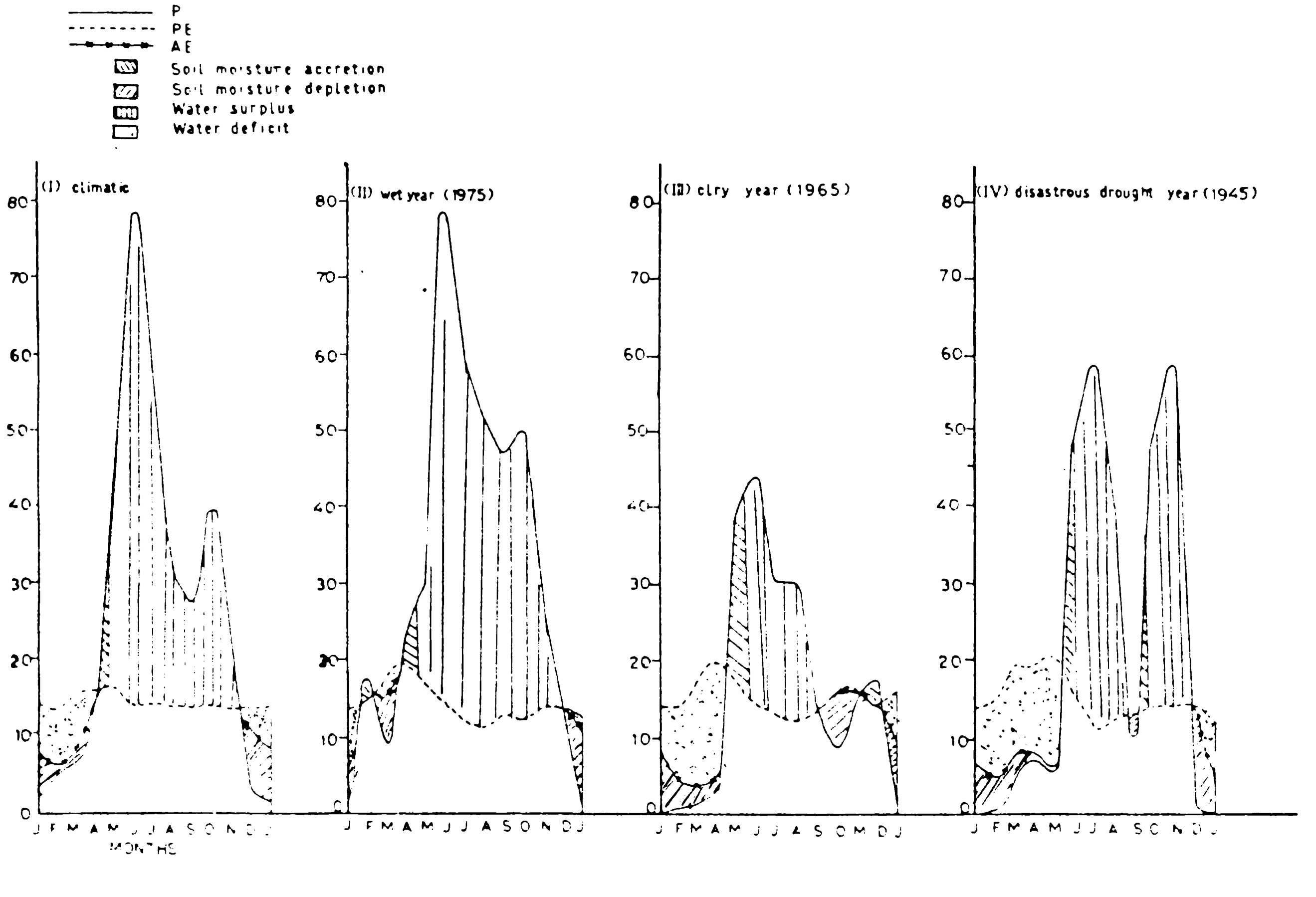

FIG 5.42. WATER BALANCE OF ALLEPPEY

At this station, water deficiency exists in 5 months - January to April and December - totalling 22 cms., (Fig. 5.42) in the normal year. An annual water surplus of 174 cms. occur here. The deficiency came down to 50% of the normal in the wet year (1975) when rainfall increased by 30%. The water need (P.E.) decreased by 14%, surplus increased by 53% and the climate shifted to the Perhumid category. Rainfall decreased by 34% in the dry year (1965) and surplus by 61% whereas the deficit increased by 50%. Rainfall was only 10% below normal in the disastrous drought year (1945), but deficiency was nearly 3 times the normal. The annual water surplus also was above normal. Two peaks of rainfall were observed, around July and around November. Both in the dry and disastrous drought years, the climate shifted to the moist subhumid (C_2) category.

vi. Calicut (Humid, B_4)

Climate shifted on 59 occasions at Calicut during the study period of 79 years, of which 19 shifts were to the wetter category of perhumid and the rest towards less humid categories which include 18 to B_3, 15 to B_2 and 7 to B_1 (Fig. 5.43). The climatic regime showed 28 fluctuations in its own category at this station, of which 19 were towards

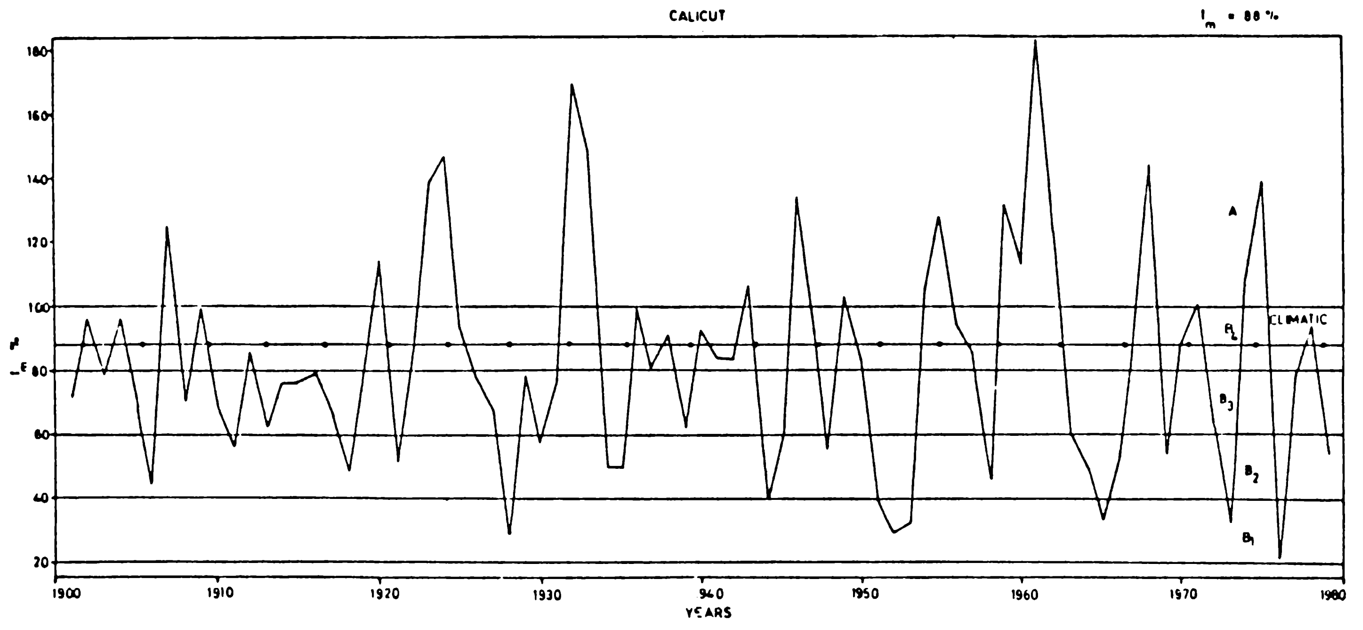

FIG. 5.43. CLIMATIC SHIFTS

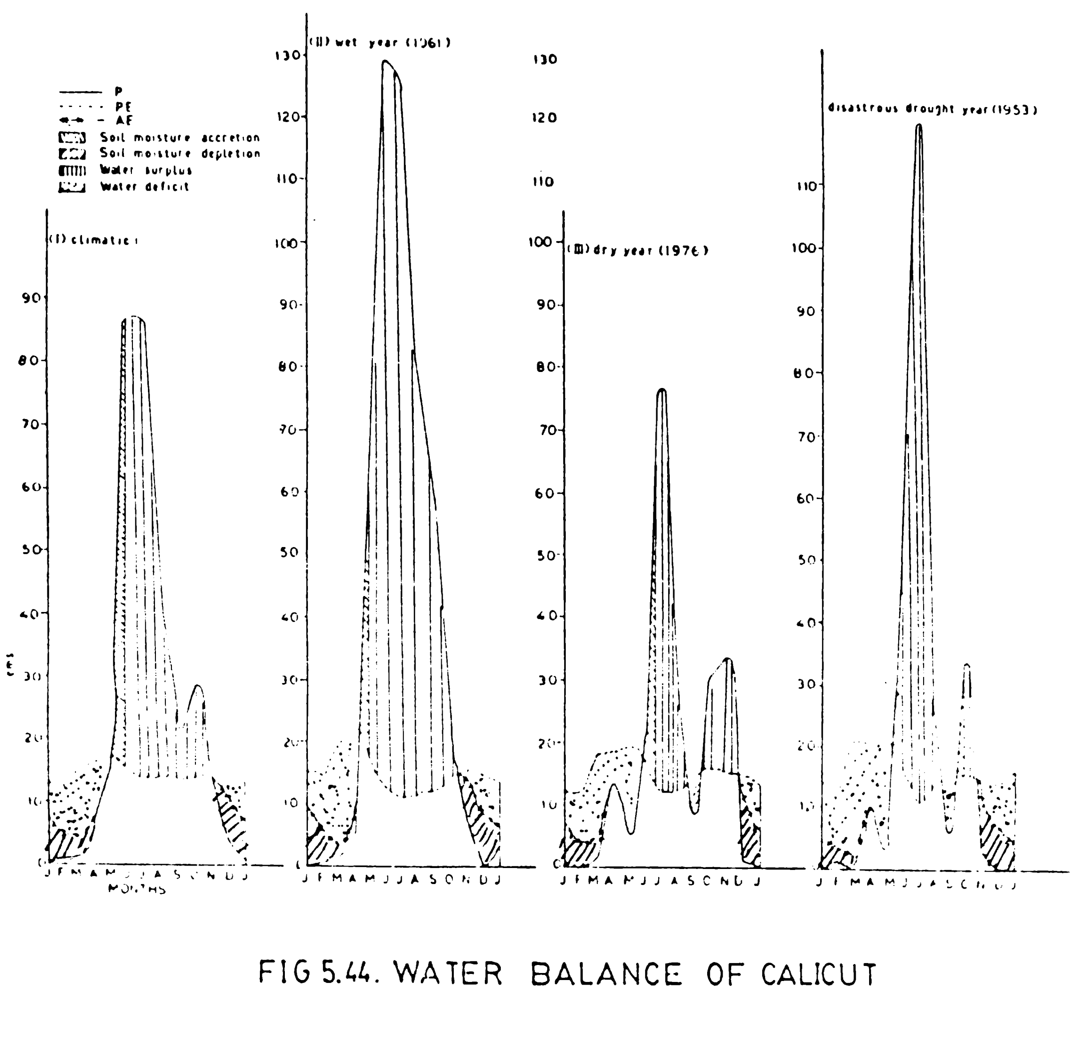

FIG 5.44. WATER BALANCE OF CALICUT

the drier direction.

A large annual water surplus of 187 cms. occurs at Calicut during the normal year (Fig. 5.44), but there also exists a water deficiency of 32.5 cms. which occurs in a period of 5 months - January to April and in December. Rainfall exceeded the normal by 51% in the wet year (1961) and water surplus was 2 times the normal and the climate shifted to the perhumid (A) category. However, water deficit also showed a 60% increase. In the dry year (1976), rainfall decreased by 34% and surplus by 53% whereas water deficit increased by 45%. The year 1953 was a disastrous drought year in which rainfall decreased by 25% and surplus by 27% while the deficit rose by 130% of the normal. In both the dry year and disastrous drought year, the climate shifted to the first humid (B_1) category.

CHAPTER VI

RESULTS AND DISCUSSIONS

The detailed hydrometeorological studies of Kerala State in relation to the hydroclimatology of the Western Ghats have in this investigation, projected the rich abundance of water resources in Kerala State due to the munificence of the plentiful southwest monsoon rains. It is expected that the salient results of the present study would be of practical use to help in harnessing more of this natural resource than is being done at present.

Considering the entire Western Ghats region, the coastal belt between the Arabian Sea and the Ghats is the second rainiest region in India. In general, this region receives more than 300 cms. of rainfall in an year; with exceptions being the Maharashtra sub-region and the southernmost part of Kerala sub-region where the annual rainfall ranges from 150 to 250 cms. only. Most of the rainfall is received during the southwest monsoon season, especially over the northern sections of the Ghats. In the other seasons, rainfall is insignificant in the northern regions though the Kerala sub-region gets rains during October - December months. Also, it has been observed that the number of rainy days are more in the Kerala sub-region (120) compared to the north (approximately 45). Studies of the seasonality of rainfall reveal that rainfall is more seasonal (less uniformly distributed) in the northern regions of the Ghats. Also, rainfall is more uniformly distributed throughout the year in the elevated regions of the Ghats than in the plains. The indices of water availability suggest that about 20% to 40% of the rainfall in the Ghats region is available for exploitation. Along the southern coast, the availability is higher at 40% which further increases to 60% in the central and northern coastal areas. On the lee side of the Ghats, water from rainfall is almost fully lost due to evaporation which is evidenced by the high water availability index figures. Surplus water that runs off and is available for exploitation during the southwest monsoon season is more in the central coastal area of the Ghats region than any other. Some water surplus and runoff occur in the Kerala sub-region and adjoining Karnataka in the other three seasons too.

It is, thus, clear that fairly large potential for harnessing water exists throughout the length of the Ghats, but restricted to the western portions:

a significant part of this is now flowing west to meet the Arabian sea. Proper harnessing of this water is very important because, in spite of heavy rainfall and large water surpluses, there also exist water deficiencies in the pre-monsoon and winter months, especially in the Maharashtra sub-region of the Ghats. The surplus water during the southwest monsoon months can be tapped for diversion to agriculture, industry or any other land use depending on the morphology of the place. In doing so, annual and seasonal variabilities of rainfall and water surpluses should, of course, be taken into account.

Large areas on the eastern side of the Ghats experience water scarcity throughout the year. Therefore, if water now going wastefully into the sea can be stored in minor reservoirs and diverted to these drier regions on the eastern sides of the Ghats, it would lead to the general improvement of the economy of the region.

As the eastern boundary of Kerala is fully flanked by the Western Ghats, the entire State comes under the influence of its orography, resulting in heavy rains and enough water surpluses and the emergence of 44 rivers and a continuous chain of lagoons and backwaters. The different types of soils and land forms result in a diversity of vegetation and land use.

The State receives rainfall from both the monsoons and most of it occurs during the southwest monsoon (50% at Trivandrum district to 80% at Kasaragod district). In the other three seasons, southern districts generally experience more rainfall than the northern districts. As mentioned earlier, the number of rainy days in Kerala is fairly large - about 100-120 and most of them are during the southwest monsoon season, being about 45 days around Trivandrum district and 90 days around Kasaragod district. The intensity of rainfal is also more in the northern districts than in the southern districts. On an average, it varies from around 2 cms/rainy day in the south to 3cms/rainy day in the north. On a seasonal basis, the intensity is the highest (2.6 cms/rainy day) during the southwest monsoon period and the lowest (1.9 cms/rainy days) during the pre-monsoon period, for the State as a whole. Studies on the precipitation ratio and rainfall variabilities suggest that the annual rainfall is more stable and therefore more reliable compared to the seasonal rainfall. Generally, stations experiencing high rainfall exhibit more stability of rainfall than the low rainfall stations. Among the seasons, rainfall is most stable (least variable) during southwest monsoon period and least stable (most variable) during winter months. The probable (97.5%) maximum limit of rainfall over the State varies from 250 cms. in the south to 450 cms. in the north and the minimum limit, 100 cms. to 250 cms. No periodicity is observed in the occurrences of rainfall dapartures in the drier or wetter directions. Moreover, no wet or dry spells continued in Kerala for a period of more than 5 consecutive years.

Studies on the water balance parameters point out that on an average, there exists an annual water need (P.E.) of more than 170 cms. in the whole State whereas the actual evapotranspiration (A.E.) ranges from 130 cms. to 150 cms. Though the annual rainfall of nearly 300 cms. is much higher compared to the water need, water deficiencies exist in certain months of the year because of the non-uniform distribution of rainfall throughout the year.

As has been noted earlier, water deficits are experienced in the pre-monsoon and winter months, while water surpluses are observed during the other two seasons. The probable (97.5%) maximum limit of water deficiencies vary from 60 cms. in the coastal area around Alleppey and Cochin to 70 cms. in the rest of the State and the probable minimum limit varies from 10 cms. to 30 cms.

The annual water surpluses vary from 50 cms. over Trivandrum district to 200 cms. over Kasaragod district. About 75% of the surplus occurs during the southwest monsoon months, for the State as a whole. The annual water surplus can be a maximum of 100 cms. over Trivandrum district, increasing to 350 cms. in the extreme north and a minimum of as low as zero around Trivandrum increasing to 120 cms. in the extreme north, in 97.5 years out of 100.

Though there is no surplus water during pre-monsoon and winter months, runoff occurs in all the seasons, though the amounts are small in the months of water deficits compared to the other months. As in the case of rainfall and water surpluses, most of the runoff occurs in the southwest monsoon months. In all seasons, runoff is small in Trivandrum district, compared to the rest of the State. The runoff is more in the coastal area between Alleppey and Calicut in all the seasons except the southwest monsoon season when it is more in the northern districts of Kerala.

The runoff appears as both surface flow and underground flow. The surface flow occurs only in the months of water surplus while the underground flow occurs in all the months. Annual surface flow varies from 30 cms. in the southern parts of Kerala to 100 cms. in the extreme north, of which 90% occurs during the southwest monsoon season. During the northeast monsoon period, the southern districts experience about 10 cms. of surface flow which is even smaller in other regions.

The mean annual underground flow is more than 100 cms. along the coast and between 20 cms. and 50 cms. in the Ghats region and 20 cms. in the southern districts, and most of it occurs during the southwest monsoon season. The investigation reveals that on an annual basis, the surface flow exceeds the underground flow in the highlands of Kerala State whereas in the plains, the underground flow is much higher than the surface flow, especially over the southern and central coastal districts.

The water which is detained in the soil after surface flow has occurred is accumulated and added to the water surplus to appear as runoff. The detention is found to be more in the coastal areas. It is more in the southwest monsoon season and is insignificant during the pre-monsoon months except in the coastal regions.

Though Kerala experiences very high amounts of rainfall, the occurrences of drought conditions are not uncommon, as is evidenced by the studies of the drought climatology. It is observed that all stations in Kerala have experienced droughts in about 50% of the years of study. Cochin experienced 43 drought years (including 1 disastrous drought) in a period of 79 years, but the severity of droughts was more at Trivandrum - 4 disastrous drought years out of 35 in the same period. Punalur has the record of 2 consecutive years of disastrous droughts (1971 and 1972). Of the 6 stations selected, only Cochin and Alleppey shows a decreasing tendency of dryness. Of the other stations, Punalur shows the maximum trend (+3.4%) towards the drier conditions.

From the comparison of individual years of droughts and decennial frequencies of droughts at different stations, it is noted that there is no evidence of any spatial coherence of droughts over the State. In other words, droughts do not necessarily occur at the same time in the different districts of the State. Further, even if many parts of the State experience droughts in the same year, they are not of the same intensity. For example, the year 1976 was the driest year when the departure of annual rainfall was -156% of the standard deviation (Chapter V, Section I). However, Palghat and Calicut did not experience droughts during this year. But the other stations were affected by droughts of one or the other category. In the other years too, when disastrous droughts occurred at any of the stations, the other regions did not necessarily experience droughts. This is in variance with the results of Subrahmanyam and Ram Mohan (1979), that disastrous droughts over Tamil Nadu, though least frequent has the highest spatial coherence, as they generally arise out of very large water deficiencies and must be a result of large scale anomalies in the general circulation over the region. They also observed that large and severe droughts exhibit increasing spatial coherence in that order and result due to water deficiency arising from anomalies in the circulation patterns of the atmosphere affecting the areas. Moderate droughts, on the other hand have the least spatial coherence since these are a result of minor fluctuations or departures of the annual moisture regime from the average water balance. Therefore it appears that most droughts over Kerala State, even disastrous ones, are due to local variations in rainfall in different parts of the State rather than large scale anomalies in the general circulation over the region. Since droughts have a definite life cycle - an origin, spread as well as decay - studies of the actual synoptic patterns during periods of deficient rainfall are necessary to enable isolation of weather anomalies leading to occurrence of droughts. The importance of such investigations cannot be over-emphasized because every drought has adverse effect on the economy of the region under its influence. Subrahmanyam and Sastri (1971) have reported that a moderate drought of prolonged duration could have more crippling effect than a severe one of brief duration.

Studies of the climatic shifts show that the moisture regimes of different parts of the State have undergone wide fluctuations, pointing towards both drier and wetter directions. Only two types of climates are observed in Kerala - moist subhumid (Trivandrum and Palghat) and humid (Punalur - B_3, Cochin - B_4, Alleppey - B_4 and Calicut - B_4). Intercomparisons of climatic shifts of different stations are difficult as the data available are of different periods. The water balance studies of the extreme dry and wet years and the year of disastrous drought reinforce the idea that it is the distribution of rainfall, not the total amount that determines the water deficiencies or surpluses of a region. It is also seen that even in disastrous drought years, water surpluses do not altogether cease, but water deficiencies rise to high values compared to their normals. Similarly, even in the wettest years water deficiencies do exist while water surpluses increase considerably. These inferences are of great practical significance in the conservation and rational utilization of available water resources.

All these studies point out that the State of Kerala, in spite of its heavy rainfall and rich water resources, does experience periods of water deficiency and droughts. Proper agricultural planning and careful exploitation of the water resources is of urgent need in the light of the increasing population, growing industrial sector and the ever increasing need for water. It is also essential to formulate measures for proper and judicious use of surface water. Overgrazing, clear felling and careless land management practices all result in soil erosion which seriously affects the agricultural productivity and also water storage potential of reservoirs. Therefore, soil conservation measures to reduce erosion and proper agricultural practices are of utmost importance.

Large surface flow occurs in Kerala during active monsoon months, a large part of which is now flowing west to join the Arabian sea, before it is fully utilized. Of the over 70,000 Mm^3 runoff from the State's rivers, only 5% has been put to use so far in providing irrigation and generating hydel power through 30 odd dams over the last 40 years. The other 95% of surface flow is being annually wasted into the sea. It is imperative that this wastage is avoided and the water now running off is stored either in a network of reservoirs or artificially recharged to underground regions. It may be stressed here that the large water surpluses of the Ghats cannot be gainfully exploited by additional large hydrological projects because of the short lengths of the river basins in addition to the steep slopes of the Ghats. For example, in the pockets of heavy rainfall such as Pirmed in Idukki district and Vythiri in Calicut district, a number of minor irrigation facilities can be resorted to, rather than large irrigation projects.

Large projects would also entail the reduction of the already depleted forest cover of the region which may have serious ecological implications (the Silent Valley Project was given up for precisely these reasons). Therefore, a network of minor projects can be developed to effectively counter the problems arising from water deficiencies over some parts of the State during certain months of the year.

It is gratifying to note that the Kerala State Committee on Science, Technology and Environment has identified 57 sites in the State where micro and mini hydel projects with a total capacity of 70 MW could be built. Such small hydel plants require lower investments and are easy to operate and need very little maintenance. Further, since these projects would supply power to the locality, long transmission lines would be unnecessary and therefore, line -losses were minimal. Additionally, these projects do not create any environmental damage whatsoever.

Of the sites identified, 16 are in Idukki district, 9 in Trivandrum, 5 each in Malappuram, Palghat, Trichur and Ernakulam, 4 in Calicut, 3 in Quilon, 2 each in Wynad and Kasaragod and 1 in Cannanore districts.

However, the surface water flow occurs mainly due to rainfall and therefore can be only as reliable as rainfall. Therefore, groundwater is a viable alternative for a dependable and safe source of water. The occurrence and behaviour of groundwater depends on the geology and the climatology of the region. Both factors should be carefully assessed because of the high costs involved in drilling for water. More groundwater can be expected in the hard terrain than in the weathered layer, as the evaporation draws heavily on the groundwater stored in the weathered layer. More than 90% of the State exhibits a rugged topography and a large percentage of the rainfall escapes as runoff. The coastal sandy belt and alluvium permits 20% infiltration while it is 15% in the laterite and only 5% in the eastern highlands.

For the State as a whole, the annual recharge to the groundwater is 11800 MCM. But, 50% of this is lost as ground outflow and the rest is available for annual developments. Considering the yields, in the coastal area with a width of 10-15 km. from Varkala to Ponnani, the water table varies from 0.5 m. to 3.5 m. below ground level at artesian conditions. In the midlands, depth of water table varies from 5 m. to 15 m. with a good yield and in the eastern highlands, it varies from 5 m. to 10 m., and with poor yield. The present exploitation of groundwater for various purposes is only 801 MCM (about 15% of the potential). The main source is dug wells, about 200 - 300/km^2 in the coastal area. The density is much low in the midlands and highlands. The exploitation of groundwater is more important in the northern part of the State, which, inspite of heavy rainfall, experiences large water deficiencies during certain periods.

Exploitation of groundwater can be increased through tube wells, provided the geomorphological conditions are favourable. However, detailed studies on the stratigraphy of the area must be made so that the available groundwater can be tapped at the right place and in the right quantities. Care should be taken to make sure that overexploitation is not resorted to as a lowering of water table may lead to seawater intrusion in coastal areas.

If even a part of the abundant water potential is tapped, large areas of cultivable waste land, especially in the Western Ghats region where lack of irrigation facilities is the major constraint, can be made productive. At present, the irrigated area covers only about 10% of the net area sown. Expansion of irrigation facilities from both surface water as well as underground water resources in an integrated manner can bring out agricultural development. Other steps such as increasing the intensity of cropping and diversification by multicropping in irrigated areas will enable fuller use of the available moisture. Since it is evident that the topography, soil and climate of the Western Ghats section of the State are best suited to forestry and plantations, attempts should be made to increase the area under productive forestry or plantation. In the context of national as well as regional development, the tapping of hydel power potentials of the rivers in Kerala is essential. Multipurpose projects are more advisable, as they can meet the needs of both irrigation and electric power generation.

Kerala has a large number of rivers, lakes, streams and other inland water bodies some of which could be integrated into an inland waterways network to provide cheap and reliable transportation. These water bodies also provide good scope for the development of inland fisheries which can generate employment to large numbers. Also, the beautiful landscape with a number of rivers and streams, reservoirs and dams, forests and plantation and above all, the moderate climate of the State provide excellent scope for the development of tourism as a major industry.

The suggestions emanating from the results of this investigation have been arrived at after taking into account the needs as well as the potentials of the different regions of the State.

The present investigation, on the whole, points to the need for detailed hydrometeorological studies on a more intensive scale over shorter periods of time. The water balance methods could be profitably used so that the needs of the State could be rationally assessed and effective development strategies judiciously planned.

More studies would be necessary at the Taluk or block level as the problems of the State vary from area to area, depending on physiographic and land use patterns. For instance, detailed studies on 1) droughts, their origin, spread and decay as well as synoptic features which cause them and 2) surface and subsurface flows on a smaller timescale, would be necessary. The enormous water surplus during the southwest monsoon season produces floods and water-logging of the soil. Flood conditions are to be analysed to take measures to prevent the widespread damages associated with floods and to construct better drainage systems.

As water is a precious natural asset of the Western Ghats region in general and of Kerala in particular, it would be in order to utilize the available water resources for the development of the entire region without administrative and political restrictions. A regional water grid as part of a national water grid would go a long way to harness the surplus waters after meeting the requirements of the region for the development of the drier areas of South India on the eastern side of the Ghats.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The present thesis envisages a hydrometeorological study of Kerala State in relation to the Western Ghats, using various statistical techniques and the water balance concepts first developed by Thornthwaite.

The first chapter of the thesis gives general introduction where the purpose and scope of the study have been given.

Chapter II discusses the importance of hydrometeorological studies in general and of water balance in particular, in planning for the overall development of any region. The first Section of this Chapter includes a review of literature in this field and the second Section, the basic concepts, criteria and the method of evaluation of water balance. The methods employed in the present study to analyse rainfall, to study the climatic shifts and to delineate droughts have also been detailed in this Section.

Chapter III consists of the presentation of various geographical features of Kerala - the location, topography, climate, land use, soil types, vegetation types, agriculture, slope, natural regions and the inland water resources.

An introduction to the physiography of the Western Ghats and detailed hydroclimatic studies of the Western Ghats region which includes analysis of rainfall and the study of water balance elements form Chapter IV.

In Chapter V, a detailed hydrometeorological study of Kerala State is made. Section I of this Chapter includes the analysis of rainfall while the second Section deals with the study of water balance parameters. The third Section consists of the drought climatology of the State and Section IV comprises the yearly climatic shifts and water balances in extreme dry and wet years in the State.

Discussion of the results of the study and suggestions for optimum utilization of the available water resources for the overall development of the Western Ghats region in general and Kerala in particular are made in Chapter VI.

Detailed hydrometeorological studies in the present investigation reveal that the narrow coastal belt between the Arabian Sea and the Western Ghats has a rich water potential that is exploitable for various purposes. The Ghats region has large water surpluses and the consequent runoff that can be made use of for the development of the entire Ghats region and of the drier interior of the Indian peninsula lying east of the Western Ghats.

In the State of Kerala, the orography of the Western Ghats results in the copious rainfall and enough water surpluses that appear as 44 rivers and a number of lagoons and backwaters. However, water deficits do exist over many parts of the State during the drier months of the year. The co-existence of both water surpluses and water deficits at different times of the year in different portions of the State is an important feature of the hydrometeorology of the State.

The study also reveals that, in spite of the heavy rainfall and large water surpluses, the State does experience drought conditions on many occasions: all the 6 stations selected for the drought study experienced droughts in about 50% of the years. It is found that there is no evidence of any spatial coherence of droughts over the State and the droughts over Kerala may be due to local variations in rainfall.

Year to year variations of rainfall have resulted in wide fluctuations in the moisture regimes of different parts of the State towards both drier and wetter conditions. The studies of the water balances in such years of extreme climatic shifts reinforce the idea that it is the distribution of rainfall, not the total amount that determines the water deficiencies or surpluses of a region. It is also observed that water surpluses do occur even in disastrous drought years but the deficiencies increase enormously. Likewise, water deficits do occur in the wettest year too, but water surpluses increase considerably.

It is suggested that optimum utilization and careful management of the water resources are very important in the development of the Kerala State which is blessed with enough water potential. The large water surplus during the southwest monsoon season results in significant surface and subsurface flows during the months June to November. These constitute utilizable water resources and may be harnessed for use during the other months of the year. The large surface flow that is going into the Arabian Sea can be stored in reservoirs or artificially recharged to underground to meet water needs of the drier months. It is also suggested that small check dams are more suitable in the Ghats than large hydrological projects because of the short length of river basins and steep slopes of the Ghats. The need of exploiting ground-water depending on the geological conditions is also stressed in view of the ever increasing need for water.

Proper water management and increased irrigation facilities would lead to large areas of cultivable waste lands being made productive. Intensity of cropping and diversification by multicropping would also be feasible with increased water availability leading to all-round agricultural development.

More studies are necessary in the Taluk or block levels. More detailed studies are recommended on (a) the different aspects of droughts - origin, spread and decay - and the synoptic features which cause them and (b) the surface and subsurface flows on a smaller time-scale and (c) the occurrences of floods in the State.

A regional water grid as the part of a national water grid is suggested to overcome the administrative and political restrictions in harnessing the water potential of the Western Ghats region for the overall development of South India.

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