PHYSIOGRAPHIC FEATURES AND CHANGES IN RAINFALL PATTERN OF KERALA

Thesis submitted to the partial fulfilment for the award of the degree of

DOCTOR OF PHILOSOPHY

in

METEOROLOGY

by

P. K. PRADEEP KUMAR, M.Sc.

PHYSICAL OCEANOGRAPHY AND METEOROLOGY DIVISION

SCHOOL OF MARINE SCIENCES

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

COCHIN - 682 016

December 1994

C E R T I F I C A T E

This is to certify that the thesis entitled **Physiographic Features and Changes in Rainfall Pattern of Kerala** is a bonfide record of the research work done by Sri. P. K. Pradeep Kumar, M. Sc., in the Physical Oceanography and Meteorology Division, Cochin University of Science and Technology. He carried out the study reported in this thesis, independently under my supervision. I also certify that the subject matter of the thesis has not formed the basis for the award of any Degree or Diploma of any University or Institution.

Certified that Sri. Pradeep Kumar has passed the Ph. D. qualifying examination conducted by the Cochin University of Science and Technology in January 1992.

Cochin 682 016
December 28, 1994

K. MOHAN KUMAR
Supervising Guide

PREFACE

Physiographic features, such as mountain barriers, altitude, latitude, distance from the sea, etc., are the major factors that control the climate of a region. Barriers, depending on their orientation and elevation cause forced ascent of air and thereby provide mechanism for cloudiness and precipitation. Orographic lifting is the major cause for the widespread rainfall over Kerala region.

Kerala experiences rainfall for nearly nine months in a year in the form of monsoon rain and thunder showers. The fluctuation in annual rainfall of Kerala is much less than that compared with other parts of the Indian sub-continent. The hills and mountains of the Western Ghats located on the eastern boundary of the State provide orographic lifting for the southwest monsoon winds resulting in heavy precipitation over the western slopes and good rain over mid- and low lands. Northeast monsoon also contribute to the annual rainfall, especially in the southern parts of the State.

Systematic studies correlating the precipitation pattern with the physiographic features and the spatial variability in rainfall have not been much documented in this region. The intention of the present thesis work is to find out possible association of the rainfall distribution of Kerala with the orographic features and the influence of latitudinal and altitudinal effects. The outcome of the study is expected to improve our understanding on the various hydrological analysis needed for assessing the water potential of Kerala and can effectively be utilised for judicious planning of the water resources of the region.

The thesis is divided into eight chapters. In Chapter 1, apart from the general introduction, the physiographic features, geology and soil types and the climatology of Kerala are explained in detail. Climatological mean values of temperature, wind, humidity and cloudiness obtained from five selected regions of the State are also presented. Detailed literature review on the topic of physiographic influence on the precipitation pattern conducted on various parts of the globe have been presented in Chapter 2. Studies on the variation of precipitation with elevation at different locations in India have also been included. A brief review of the climatological aspects of Kerala is included in this chapter.

There are about 450 raingauge stations in Kerala, which are maintained by different agencies. The present condition of most of the raingauge stations, the major problems and defects encountered, the important points to be kept in mind while installing/maintaining a raingauge and some of the remarkable events experienced by the present researcher are described in Chapter 3.

Chapter 4 deals with the effects of mountain barriers and hilly terrains on the rainfall pattern of Kerala. The methodology adapted for the study is mentioned in this chapter. The Kerala region is divided into 3 zones, south, central and north, and studied the changes in the rainfall intensities with respect to change in altitude of the station. The major outcome of the study is that maximum rainfall is noted not at the peak of the mountain, but at the western slopes, much below the peak. Isohytes are found parallel to the Western Ghats with a steep decrease to both sides from the pockets of heavy rainfall.

Effects of latitude and altitude on the annual as well as seasonal rainfall have been discussed in Chapter 5. Annual as well as southwest monsoon rainfall showed positive and significant variation with increase in latitude, whereas the northeast monsoon rainfall decrease with increase in latitude. The altitude effect is not found to be statistically significant on the rainfall distribution.

The study on the spatial variability of the seasonal cycle on rainfall have been made using harmonic analysis and the results are discussed in Chapter 6. The amplitude of annual oscillations are associated with annual mean precipitation pattern. Coastal stations in Kerala showed a linear increase in the amplitude of annual oscillation with latitude. Semi-annual amplitudes are rather weak compared to the amplitude of annual oscillation in precipitation.

Studies on the rainfall interception in the dense forest at Peruvannamuzhi, 75 km northeast of Kozhikode city, during the monsoon season in 1986 have been discussed in chapter 7. The results revealed that 10.5% of the total incident rainfall has been lost as interception. The correlation between throughfall and interception loss has been estimated and discussed in this chapter.

The last chapter provides an overall summary and conclusions of the studies reported in the earlier chapters. The list of reference is included at the end of the thesis.

C O N T E N T S

CHAPTER 1

INTRODUCTION

1.1 SCOPE OF THE STUDY

Physiography is the description of the physical features of the geography of an area which includes the natural phenomena of that region. Mountain barriers, altitude, latitude, land and water masses, are major factors of climatic control. To understand the weather and climate of a region, an adequate knowledge of the physiography is very important. Barriers, depending on their orientation and elevation cause forced ascent of air and thereby provide mechanism for condensation and precipitation. Orographic precipitation is responsible for most of the heavy rains in Kerala. The greatest amount of precipitation falls on the windward side, and the leeward side often has very little precipitation. Orographic barriers tend to increase both cyclonic and orographic precipitation because of increased lifting involved. The precipitation is composed of showers and steady rainfall. The variation of precipitation with elevation is affected by fluctuation of wind, orientation of the hill, slope, etc.

Although Kerala has got a large coverage under hilly terrain and forest, only very few scientific studies have been conducted in these regions. The need for the development of hilly region has been strongly felt by the Government of India and, therefore, more emphasis has been given in the Five Year Plans for hill area development. The economy and prosperity of Kerala region mainly depend on the seasonal rainfalls. In the form of monsoon rains or thundershowers, Kerala experiences rainfall for nearly nine months in a year. The fluctuations in annual rainfall of the State are much less than for other parts of Indian sub continent. The mean annual rainfall for Kerala State as a whole is nearly 3500 mm which is more than that for any other States in India. The major part of the rainfall is received during the southwest monsoon months (June-September). The hills and mountains of the Western Ghats at the eastern boundary of the State, which have an average elevation of 1 km, provide orographic lifting for the southwest monsoon winds, resulting in heavy precipitation over their slopes and very good rainfall over the mid-lands and low lands. The northeast monsoon season and the hot weather period also contribute to the annual rainfall, especially in the southern parts of the State.

An understanding of rainfall and physiography permits an evaluation of the inter - relationship of hydro-meteorological factors and the limitations of the empirical methods developed for the solution of hydrological problems. The decisive factor determining the quantity and character of stream flows of the State is climate, which is not only through precipitation and evaporation, but also through physiography, soil, vegetation, etc. Systematic studies correlating the precipitation pattern to the physiographic and other parameters have not been well documented in this region. Detailed analyses on the effect of mountain barriers and orography on rainfall distribution, latitudinal and altitudinal variation in seasonal and annual rainfall, variability and trends in rainfall pattern, rainfall in the forest region, etc., have been carried out in the present study. The results of the study may considerably help in various hydrologic analysis needed for assessing the water potential of Kerala as well as judicious planning of the water resources of the State.

1.2 KERALA - A GENERAL PICTURE

When India became free, Kerala was made up of two princely states, Travancore and Cochin. Malabar was under the direct administration of the British. One of the first steps taken by independent India was to amalgamate small states so as to make them viable administrative units. In pursuance of this policy the Travancore and Cochin states were integrated to form Travancore - Cochin State on July 1, 1949. But Malabar remained as part of the Madras Province. Under the States Re-organization Act of 1956, Travancore - Cochin State and Malabar were united to form the State of Kerala on November 1, 1956.

Kerala is a small coastal State, situated in the southwest peninsular part of India (Fig.1.1). It lies between latitudes 8° 15'N and 12° 50'N and between longitudes 74° 50'E and 77° 30'E. It has an area of 38863 sq.km which represents only 1.18 per cent of the total area of India (Table 1.1). But it supports a population of 29011237 which is 3.43 per cent of the total population of the Country (Census 1991). The disproportion between its area and population is reflected in the density which in 1991 was 747 persons to the sq.km. This is the second highest density among the States of the Union, higher density being registered only by the State of West Bengal which is 766.

Table 1.1 :- **Kerala at a glance (as per the Census of 1991)**

Area	-	38863 sq.km
Capital	-	Trivandrum
Language	-	Malayalam
Population	-	29011237
Males	-	14218167
Females	-	14793070

For administration purpose the State is divided in to 14 districts. District-wise area are given in Table 1.2.

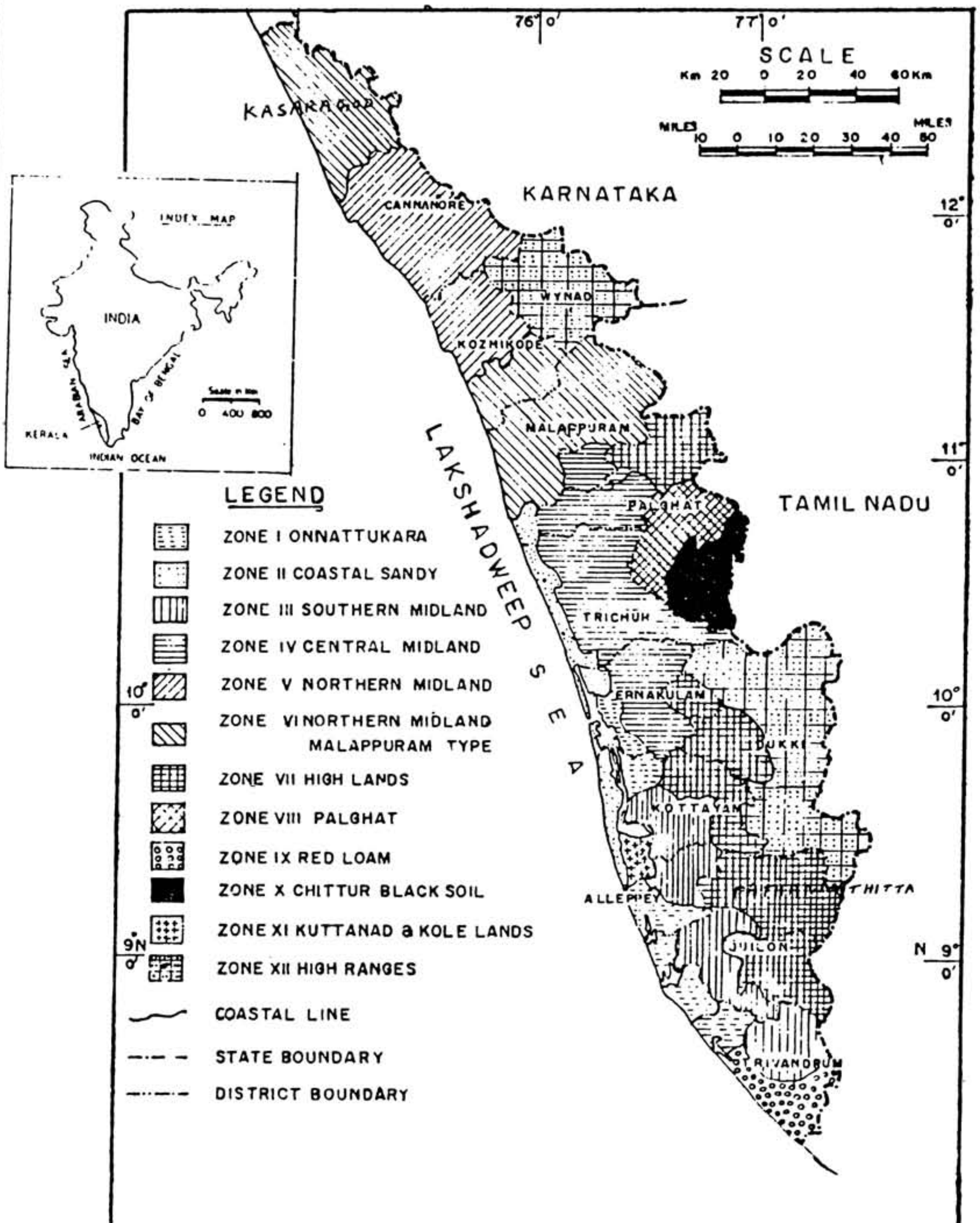


Fig.1.1 AGRO-CLIMATIC ZONES OF KERALA STATE

(FIRST APPROXIMATION)

(SOURCE :- KERALA IN MAPS, BUREAU OF ECNOMICS & STATISTICS)

Table 1.2 : District-wise area

	District	Area(sq.km)
1.	Thiruvananthapuram (Trivandrum)	2192
2.	Kollam (Quilon)	2579
3.	Alappuzha (Alleppey)	1256
4.	Pathanamthitta	2731
5.	Kottayam	2204
6.	Idukki	4998
7.	Ernakulam	2408
8.	Thrissur (Trichur)	3032
9.	Palakkad (Palghat)	4480
10.	Malappuram	3548
11.	Kozhikode (Calicut)	2345
12.	Wynad	2132
13.	Kannur (Cannanore)	2997
14.	Kasaragod	1961

1.3 PHYSIOGRAPHIC FEATURES OF KERALA

Kerala is an elongated coastal State lies along a 590 kilometer sun-drenched coastline of the Arabian sea, banked inland by the mountain-rimmed border of the craggy Western Ghats. In between the high Western Ghats on the east and the Arabian sea on the west, this narrow green patch of land lies in the north - south direction. The width of the State varies from 35 to 120 km; with an average of about 65 km. Even within this small width, the topography and physical characteristics change distinctly from the east to west. Kerala State is surrounded by Dakshin Kannad (South Canara), Mercara and Mysore District of Karnataka State in the north, Nilgiri, Coimbatore, Madurai, Ramanadhapuram, Tirunelveli and Kanyakumari District of Tamil Nadu in the east and south, and by the Arabian sea in the west.

The meteorology of Kerala is profoundly influenced by its orographical features (Fig.1.2). From the low-lands adjoining the western sea-board, the landscape ascends steadily towards the east to the mid-lands and further on to the high-lands sloping down from the Western Ghats. The mountain ranges which form a natural wall separating Kerala from the adjoining States, have an average elevation of about 1 km with peaks rising to over 2 km. The highest of these peaks is Anai Mudi (2695 m) at the crest of Anamalai (Elephant Hill) in Devikulam area of Idukki District. Eastwards from Anamalai, run the Palani Hills (in the Madurai District of Tamil Nadu) on which the well known hill station of Kodaikanal (2506 m) is located. A southern off-shoot from anamalai is the Cardamom Hills of south Kerala, on which is located the hill station of Pirmed (1067 m) which experiences very heavy rainfall during the southwest monsoon. To the

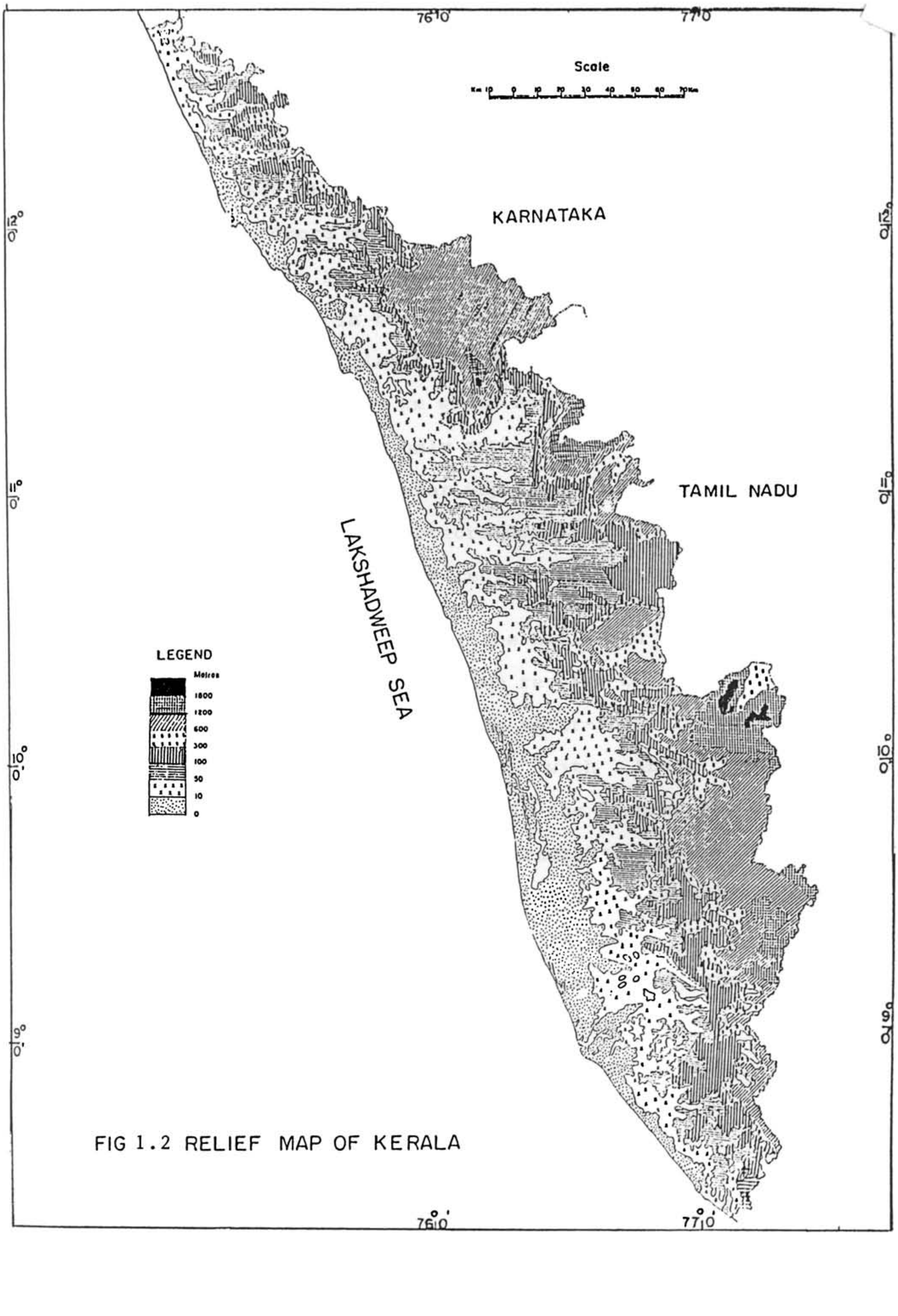


FIG 1.2 RELIEF MAP OF KERALA

north of Anamalai are the Nilgiris, whose highest peak is Doda Betta (2640 m) in the Ootacamund area. The Nilgiris merge with the Coorg mountains which divide the northern parts of Kerala from Karnataka. The Anamalai and Nilgiris are the tallest mountains in the Western Ghats skirting the west-coast of peninsular India. A remarkable feature is Palghat Gap (Fig.1.3) of about 25 km width between the Anamalai and the Nilgiris which is the only marked break in the mountain wall. Due to this particular Gap there are considerable variation in the values of meteorological parameters of this region, comparing to the other regions of Kerala.

The western slopes of the hills and mountains at the eastern border of Kerala which receive copious rainfall during the monsoon months form the water-sheds for a large number of rivers which together with their numerous tributaries cut across Kerala to join the Arabian Sea or one of the backwaters that form an attractive feature of the western sea-board. The biggest of these is the Vembanad Lake which opens into the Arabian Sea at the Cochin port. There are 41 west flowing rivers and 3 east flowing rivers, having a length of 15 km or more. Features of the important rivers (Fig. 1.4) of Kerala are shown in the following Table 1.3.

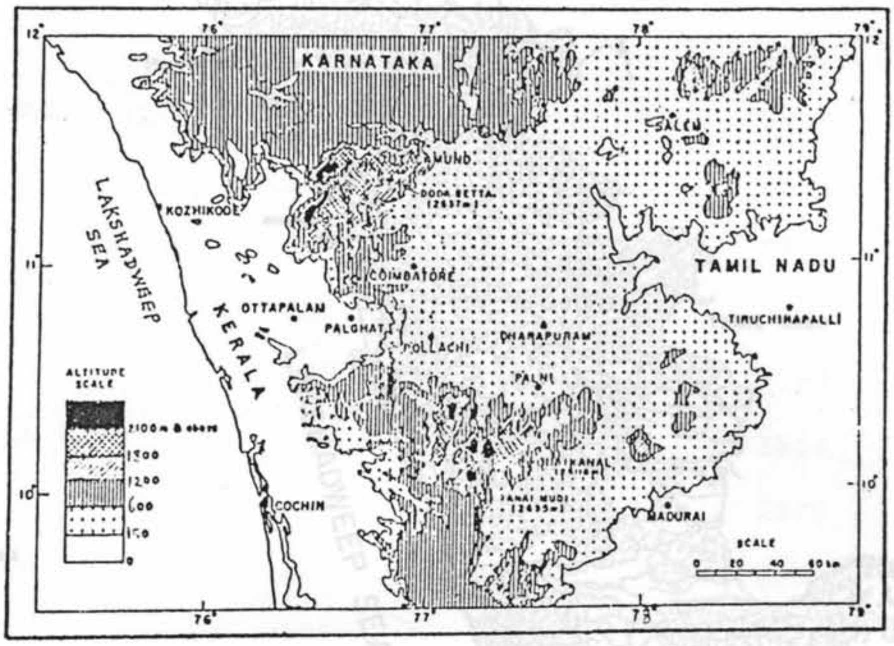


Fig. 1.3 PALGHAT GAP AREA

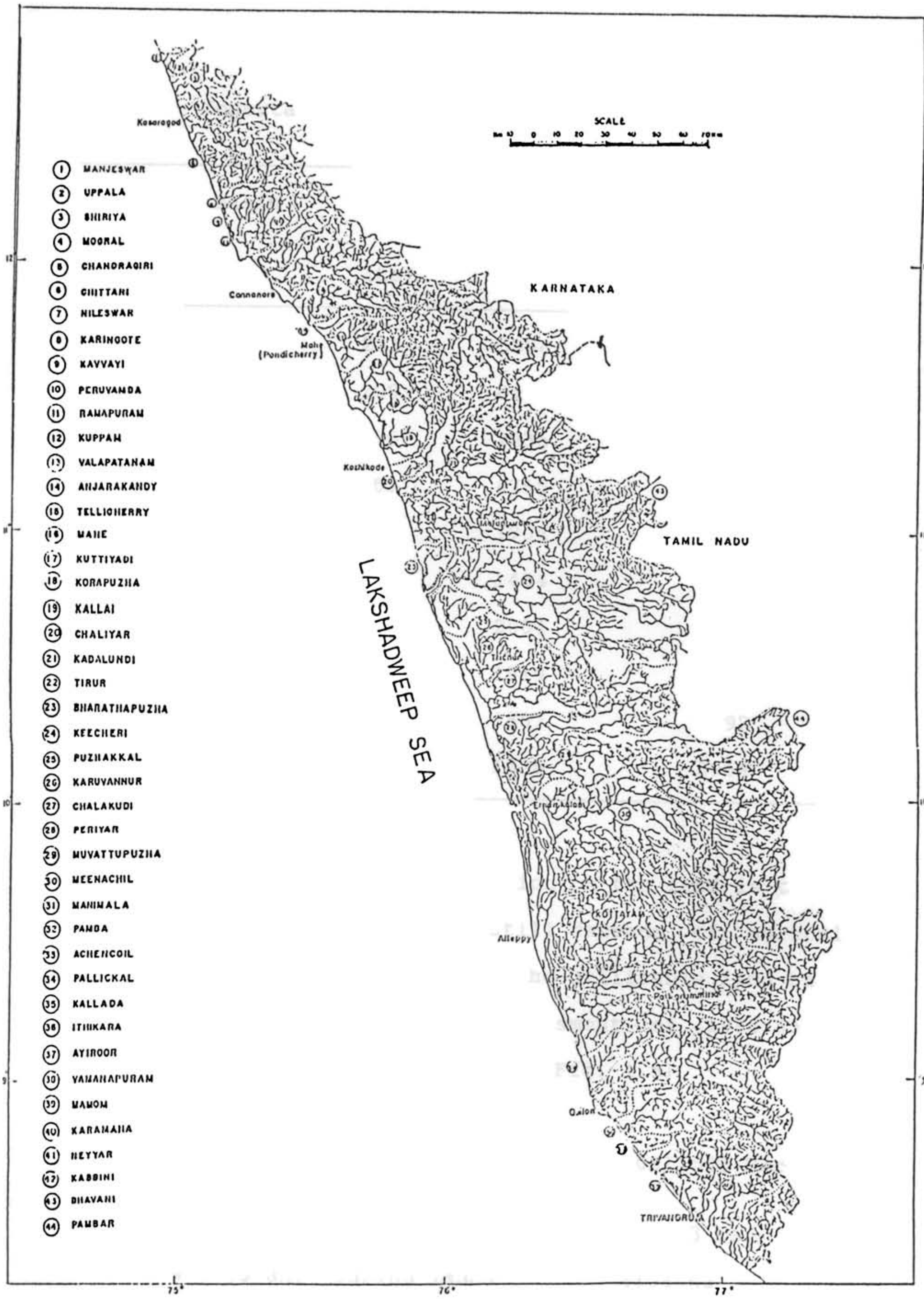


FIG 1.4 DRAINAGE MAP OF KERALA

Table 1.3 :- Important river basins of Kerala

Name of River basin	Length (km)	Catchment area (sq.km)	Average annual yield (Million m^3)
Periyar	244	5398	11607
Bharathapuzha	209	6186	7478
Pamba	176	2235	4641
Chaliyar	169	4765	7759
Chalakudy	130	1704	3121
Achencovil	129	1484	2287
Muvattupuzha	121	2004	3814
Kallada	121	1919	2270
Valapattanam	110	1867	4092
Chandragiri	105	1538	3964

The pressure of population on the land is too much, especially since the majority still depends of agriculture for their livelihood. Almost all the utilisable land has been utilised. According to an assessment of 1984-85, the utilisation of land is as follows: (Fig. 1.5)

Forest lands	-	10811509 Hectares
Land put to non-agricultural use	-	279703 ha
Pastures and grazing lands	-	4158 ha

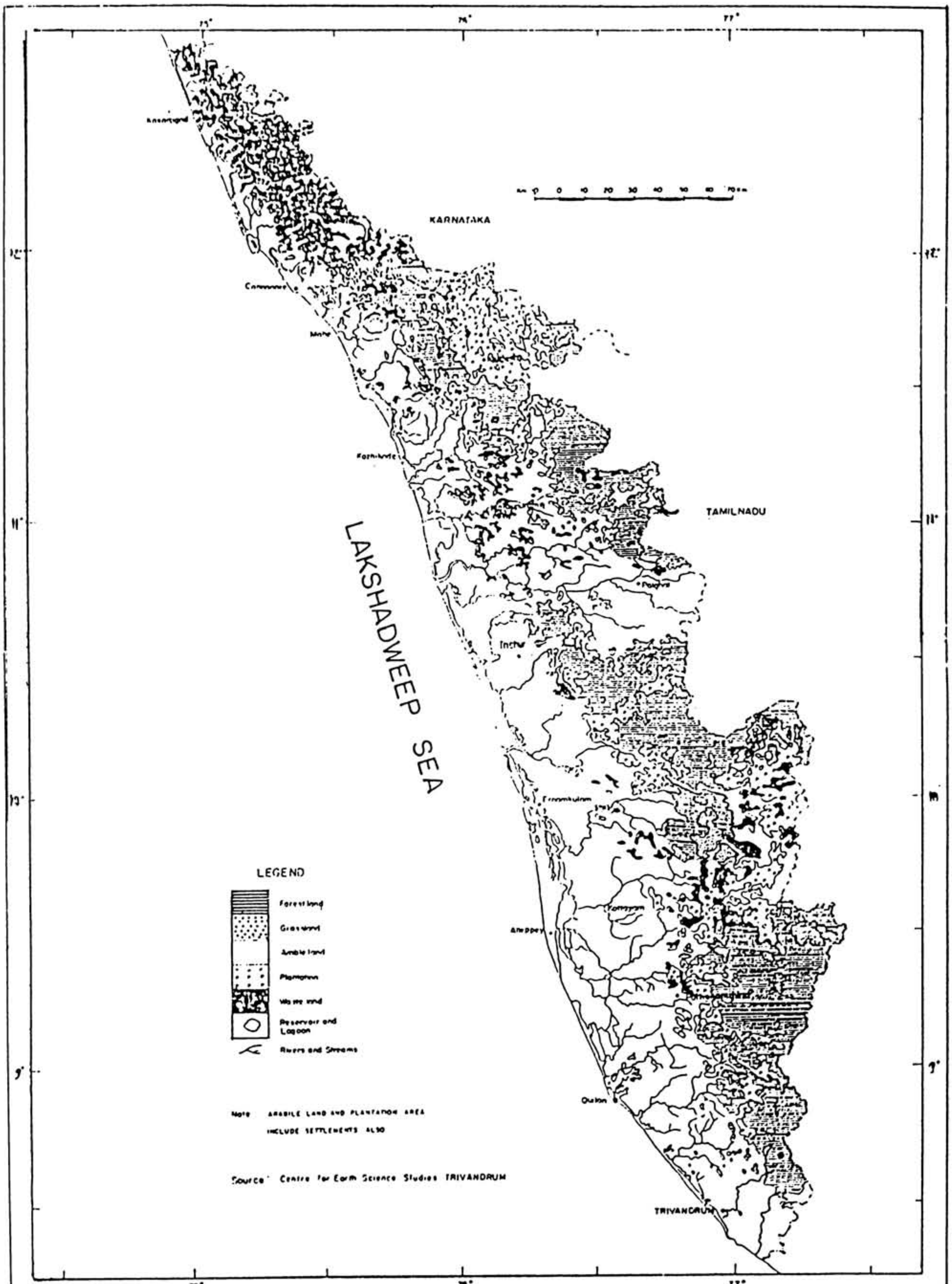


FIG1.5 LANDUSE PATTERN IN KERALA

Miscellaneous tree crops	-	51039 ha
Cultivable, Waste, fallow land, etc.	-	199077 ha
Barren and non-cultivable land	-	85688 ha
Net area sown	-	2184423 ha

1.4 GEOLOGY AND SOIL OF KERALA

1.4.1 Geology

Geologically, the State can be divided into 4 major distinct zones, each zone having a more or less north-south alignment (Fig.1.6).

The classifications are :

1. Crystalline rock consisting of representative of the Archaean group (oldest rock group).

2. Residual laterite formed by the decomposition in situ of the Archaean crystallines.

3. The Warkalli formations - lignite bearing sedimentary beds with a laterite capping.

4. Recent formations consisting of alluvial, marine and lacustrine deposits. The backwater tracts come in this zone.

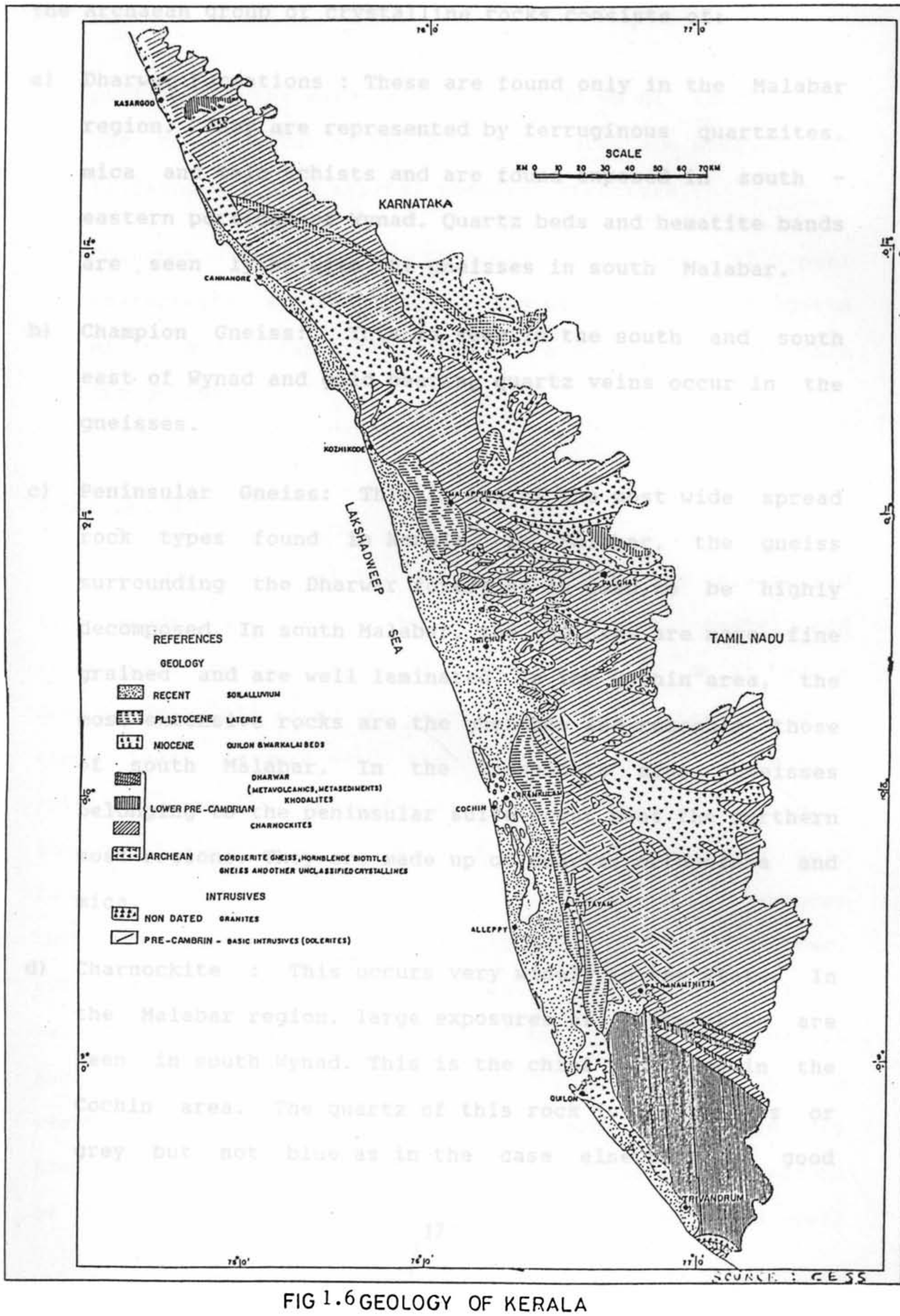


FIG 1.6 GEOLOGY OF KERALA

The Archaean group of crystalline rocks consists of:

a) Dharwar Formations : These are found only in the Malabar region. They are represented by ferruginous quartzites, mica and talc schists and are found exposed in south - eastern portions of Wynad. Quartz beds and hematite bands are seen lying with the gneisses in south Malabar.

b) Champion Gneiss: This is seen in the south and south east of Wynad and gold bearing quartz veins occur in the gneisses.

c) Peninsular Gneiss: This is one of the most wide spread rock types found in Kerala. In Malabar, the gneiss surrounding the Dharwar formation is seen to be highly decomposed. In south Malabar, the gneisses are more fine grained and are well laminated. In the Cochin area, the most extensive rocks are the gneisses and resemble those of south Malabar. In the Travancore area, gneisses belonging to the peninsular suite occur neat the northern most regions. They are made up of quartz, orthoclase and mica.

d) Charnockite : This occurs very widely in the State. In the Malabar region, large exposures of charnockite are seen in south Wynad. This is the chief rock type in the Cochin area. The quartz of this rock is colourless or grey but not blue as in the case elsewhere. A good portion of the Western Ghats is made up of Charnockite. The charnockites of the Travancore area are mostly well foliated and show typical gneisses structure.

e) Closepet Granite : Archaean intrusives of post charnockite age are found in two places in the Kalpetta hills and Sultanbathery. These are younger in age than the gneisses.

1.4.2 Soils :

The soils of the State can broadly be classified into sandy, alluvial, laterite, red, black, peaty, and forest-hill soils (Fig. 1.7). The sandy soils occur as a narrow belt all along the coast. Varying in texture from sandy loans to pure sand, they are highly porous with low retentive capacity. The alluvial soils are transported soils and cover almost the entire tract of Kuttanad and the Kole lands of Trichur and Mukundapuram taluks. Heavy in textures they are generally well supplied with organic matter, nitrogen and potash but are deficient in phosphate and lime. Laterite soils are, by far, the most important group found in Kerala and cover the largest area. They are formed by the weathering of acidic rocks under alternate wet and dry tropical conditions. These are generally developed in regions of heavy rainfall and high temperature. Porous and well

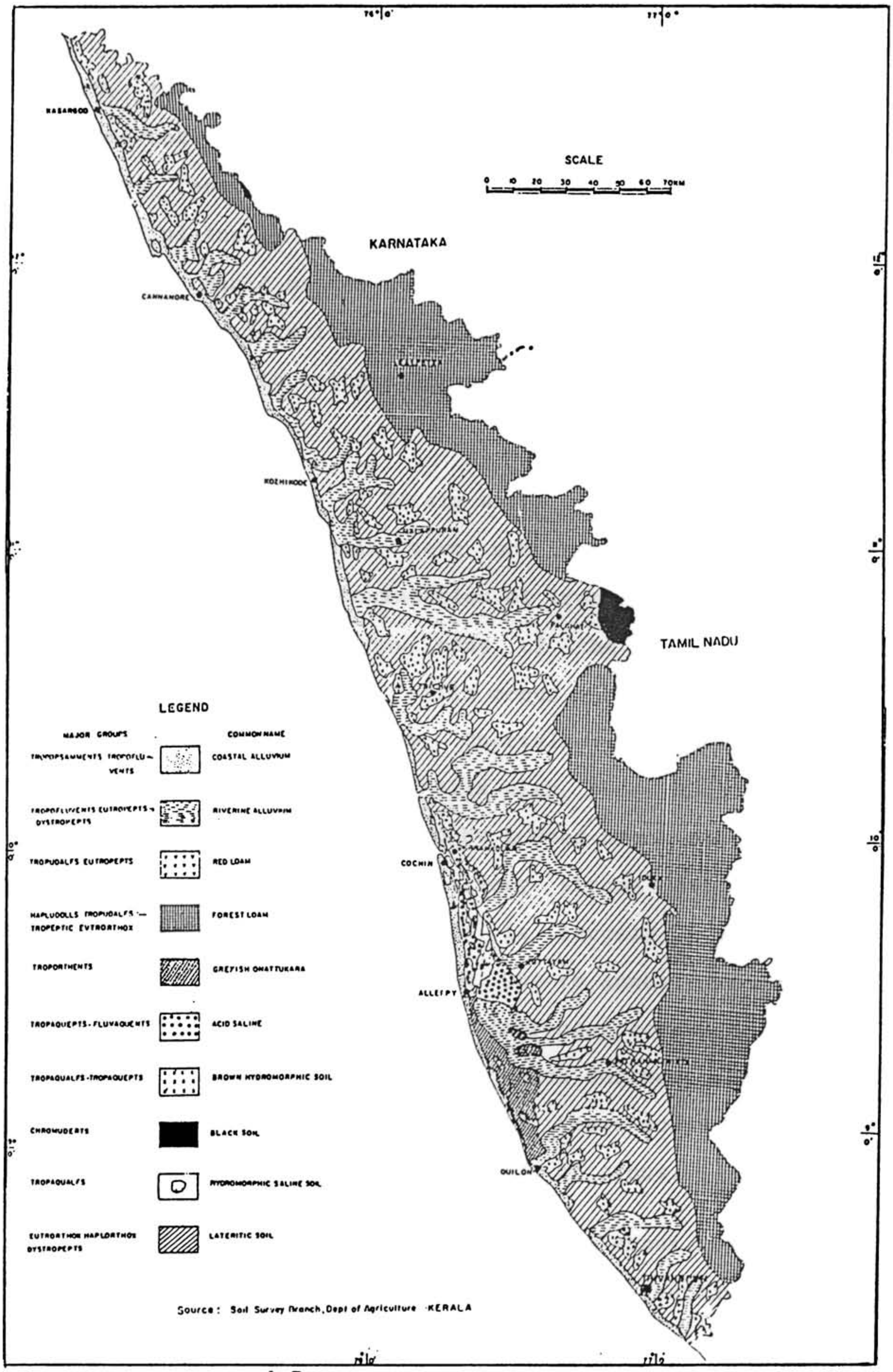


FIG 1.7 SOIL TYPES OF KERALA

drained, their capacity for retaining water and fertilizers is somewhat poor. Laterite soils are usually of low fertility. Those found in the hills are gritty and shallow, but in the plains it is deeper, finer texture containing fair quantity of organic matter and deficient in phosphate, potash and lime. Though laterite soils are of low natural fertility they respond well to cultivation and judicious application of fertilizers.

In some parts of Kerala where rainfall is only less than 2000 mm, the soils have not developed into true laterites. There is an accumulation of iron and aluminium in these soils and they show many of the properties of laterites. Peaty or Kari soils occur in the taluks of Ponnani, Kanayannur, Vaikam, Chertala, Ambalapuzha and Kuttanad. These are clayey soils with poor aeration and drainage. They are characterized by a deep black colour, high content of organic matter and very strong acidity. The failure of crops in Kari lands is largely due to the production of free sulphuric acid. Due to annual inundation with salt water, there is considerable accumulation of soluble alkali salts in these soils which further complicate their fertility problems. On the whole, these soils are noted for their poor fertility and low yields of crops.

Forest - hill soils are formed in about 26% of the area of the State. They are characterised by a surface layer of organic matter derived from forest growths. These soils are rich in nitrogen but extremely poor in bases due to heavy leaching. When the forest are cleared, these soils gradually undergo laterisation. Plantation crops such as tea, cardamom, and rubber are extensively grown on cleared forest soils. In Chittur and Palakkad taluks, black soils are also found covering a small area. These soils are neutral or slightly alkaline in reaction. Cotton is the main crop grown in these soils.

1.5 FORESTS OF KERALA

A number of definitions exist for the term 'forest', each catering to a specified objective. A general definition is 'an area primarily set aside for the production of timber and other forest-produce or maintained under woody vegetation for certain indirect benefits which it provides'. The term forest is believed to have originated from the Latin word 'foris' meaning outside, referring to the village fence or boundary covering the entire uncultivated and untended land. An ecological definition of forest is 'a plant community predominantly of trees and other woody vegetation usually with a closed canopy'. More often a legal definition is used according to which a forest is 'an area of land proclaimed to be a forest reserved, protected under a forest law' (KFRI, 1981).

The exact information on the extent of forests in Kerala is not available, as the values differ from reports to reports. As per the report of the task force on Forest Resources of Kerala State, published by Government of Kerala in 1973, the figure was 9400 sq.km. The administration report of the Forest Department for the year 1977-78 gives the total area of the forests as 11320 sq.km, of which 9161 sq.km are reserve forests and the rest as private forests. Considering the fact that encroachments and diversion of forest land for other purposes have been continued, the actual forest area would be far less than 9400 sq.km. (KFRI, 1981). Percentage of forest area to geographical area according to Kerala Forest Department (Kerala Forest Statistics, 1982) is 29.34 per cent. Centre for Earth Science Studies (1984) reported that the area under forest in Kerala in 1905 was 17120.82 sq.km (44.07% of the geographical area), in 1965 it was 10726.56 sq.km (27.71%) and in 1973, 6627.72 sq.km (17.06%). Department of Public Relations, Government of Kerala (1988), in their publication, A Handbook on Kerala, it is mentioned that the total area under forest in Kerala is 10815.09 sq.km, about 28 per cent of the total area of the State. There is also an area of 1122 sq.km of vested forests. One principal reason for the discrepancy seems to be that the Forest Department includes all areas which are legally categorised as reserves, although some of these are not under its de facto control (KFRI, 1981).

1.5.1. Forest Types:

The forests in the State come under the broad category of tropical forests and form the western extremity of the Indo-Malayan rain forest formation. On account of the variation in precipitation, temperature, altitude, etc., the forests in Kerala are characterised by extreme floristic diversity. The major types of forests in Kerala are:

(i) evergreen and semi-evergreen forests,
(ii) moist deciduous forests,
(iii) dry deciduous forests and
(iv) Montane sub-tropical and temperate forests.

In addition to these natural types, extensive areas have been converted into man-made forests. Fig. 1.8 gives a general idea of the forests of Kerala.

1.5.1.(a) Evergreen and semi-evergreen forests:

The tropical evergreen and semi-evergreen forests are chiefly found in Thenmala, Achencoil-Kakki belt, Periyar, Sholayar, Attappady, Silent Valley, New Amarambalam and Wynad. The total area of the evergreen forests has been estimated as 4750 sq.km. (KFRI, 1981). As pointed out earlier, the present area would be far less than the above, as large tracts have been utilised for hydro-electric projects, settlements and even to raise man-made forests.

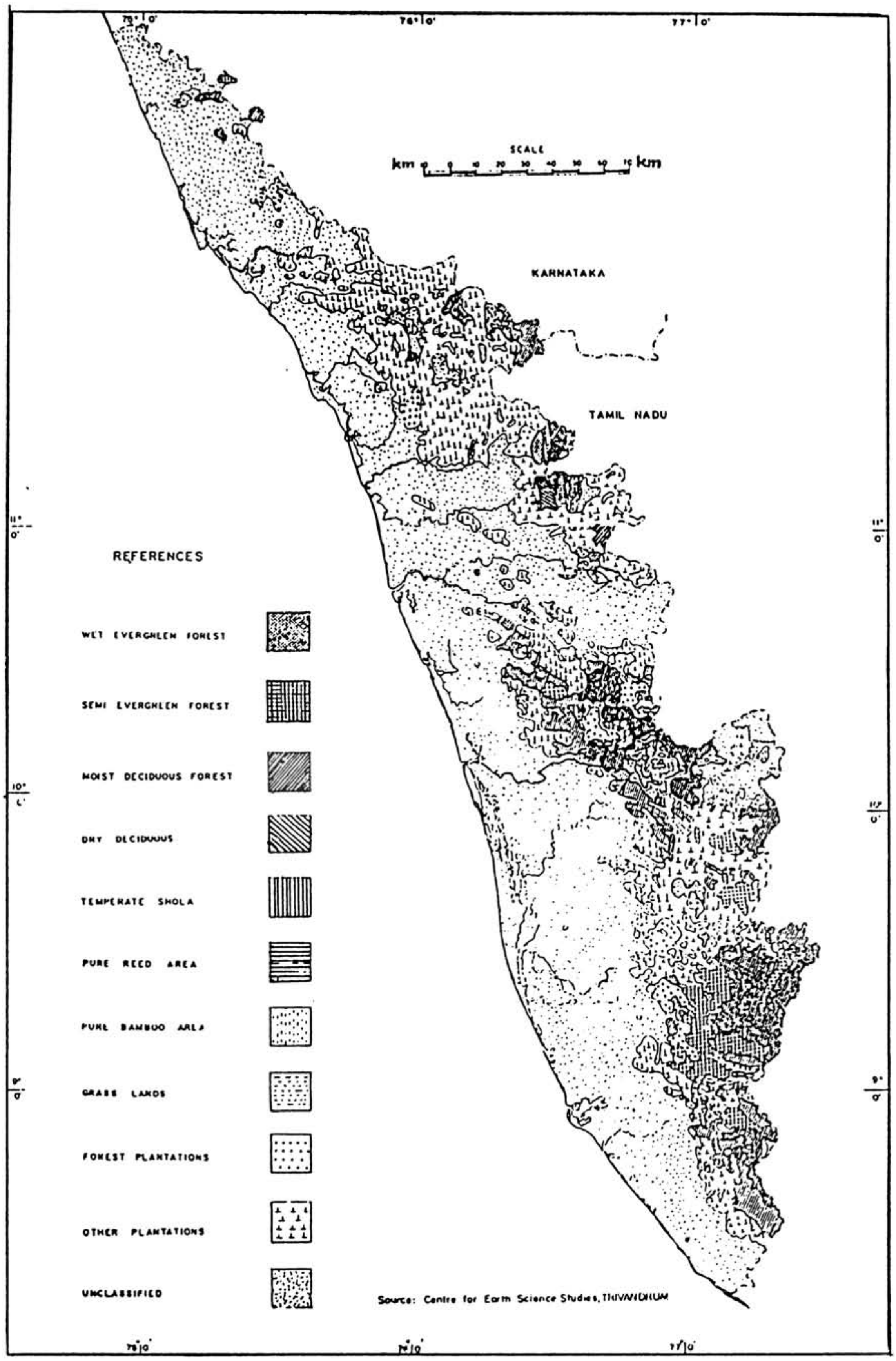


FIG 1.8 FORESTS OF KERALA

Typically an evergreen and semi-evergreen forest has a multi-storeyed structure with the dominants reaching a height of 40 metres or even higher. Important species that occur in the top canopy are Acrocarpus fraxinifolius, Antiaris toxicaria, Calophyllum spp, Cullenia exarillata, Dichopsis ellipticum, Dipterocarpus indicus, Hopea parviflora, Mesua ferrea, etc. Evergreen forests are grouped under sub types primarily based on the dominant associations. Some of the associations found in the evergreen forests of Kerala are:

1. The Cullenia -- Palaquium association
2. The Palaquium - Mesua association
3. The Poeciloneuron -- Palaquium association
4. The Mesua -- Calophyllum association
5. The Vateria -- Culllenia association
6. The Mesua -- Culenia association
7. The Reed -- Calophyllum association
8. The Reed -- Poeciloneuron association

The important species in the second storey are Actinodaphne hookeri, Baccaurea courtallensis, Canarium strictum, Cinnamomum zeylanicum, Elaeocarpus spp., Holigarna spp, Nephelium longane, etc. The third storey consists mostly of shruby species such as Euonymus angulatus, Lea sumbucina, Clerodendrom infortunatum, Vernonia spp., etc. On account of the heavy shade, the forest floor is devoid of undergrowth and is usually covered with a thick layer of leaf litter at various stages of decomposition. By improving the physical qualities, particularly the porosity of the soil, the leaf litter plays an important role in regulating the surface run off. The semi-evergreen forests occur as a transitional zone between the moist deciduous and the evergreen forests. Micro climatic factors, especially the availability of moisture during summer has led to the existence of semi-evergreen patches along stream banks and protected valleys.

1.5.1.(b). **Moist deciduous forests:**

As in the case of other forest types, no estimate is available on the exact area under moist deciduous forests. It has been estimated the area as 3140 sq.km (KFRI, 1981). This, however has undergone considerable changes over the last decade primarily due to the diversion of land for non-forestry purposes, and the extension of plantations. Moist deciduous forests are less inaccessible, and their proximity to habitations makes them extremely vulnerable to the various anthropic disturbances. Moist deciduous forests form a closed high forest in which the dominant species are deciduous. From the point of view of wood production, these forests play an important role. Important timber species are Tectona grandis, Dalbergia latifolia, Pterocaropus marsupium, Artocarpus hirsuta, Adina cordifolia, Xylia xylocarpa, Lagerstroemia lanceolatea, Grewia tilifolia, Bombax ceiba, etc. Another economically important constituent in the moist deciduous forest is Bamboos. On account of the unsystematic exploitation coupled with the luke warm approach to extending the area by artificial regeneration, the bamboo resources in the State is getting depleted at a very rapid rate.

1.5.1.(c). Dry deciduous forests:

The dry deciduous forests are seen in the rain shadow region of the Western Ghats and extend over an area of about 170 sq.km. As far as floristic diversity is concerned this is an inferior type. Important species found are Santalum album, Anogeissus spp. and Bamboos.

1.5.1.(d). Montane temperate forests:

The climatic conditions at higher elevation in the Western Ghats have helped the formation of montane wet temperate forests or what are popularly known as Sholas. They usually occur in protected valleys of the hills and form a thick mass of tangled growth. Although they are not commercially valuable, especially from the point of timber production, ecologically they play an important role, more specifically in the hydrological cycle. Between the Shola patches there are extensive grass lands. Vast stretches of these grasslands have been converted into plantations.

1.5.1.(e) Man-made forests:

Kerala is a pioneer in raising man-made forests. By 1978 the total area of plantations under the control of the Forest Department was about 1350 sq.km. In addition, the Kerala Forest Development Corporation has also planted extensive areas with Eucalyptus. Although several species have been raised, teak continues to be the most important species. At the beginning of 1978, teak covered an area of about 68,500 ha or more than half of the area under plantations. Other species raised in mixture with teak are Bombax ceiba, Ailanthus triphysa, Euodia lunaankenda, etc. Due to the poor performance of these species, in effect most of these plantations contain only teak.

1.6 GENERAL CLIMATE OF KERALA

From the standpoint of weather and climate, the year in Kerala can be divided into the following four seasons :

(i) Winter (January - February)

(ii) Hot weather Period (March - May)

(iii) Southwest Monsoon (June - September)

(iv) Northeast Monsoon (October - December)

Winter season is characterised by minimum cloudiness and rainfall. Hot weather period, March to May is uncomfortable due to high temperature and humidity. Thunderstorm activity is quite high during this season. The southwest monsoon months constitute the principal rainy season, while the northeast monsoon, which as a matter of fact, is the retreating phase of the southwest monsoon, is the secondary rainfall season. The climate is pleasant from September to February.

1.6.1 Sea Level Pressure:

The normal MSL pressure at 0830 hrs at five selected stations of Kerala are shown in Fig. 1.9. The seasonal variation of atmospheric pressure over the State takes place in a systematic manner with maximum pressures during January and minimum pressures during May -June. The pressure gradient over the State generally remains weak except during late summer and in the monsoon season. The annual range of pressure is less than 5 mb. The total diurnal range of pressure increases from the coast to the inland regions and this is also within about 5 mb. The maximum in the diurnal range of pressure is seen in the month of February when clouding is almost minimum. June and July with maximum clouding have the minimum diurnal range. In all the seasons, the pressure gradients over the State is in the east-west direction. The pressure decreases from west to east

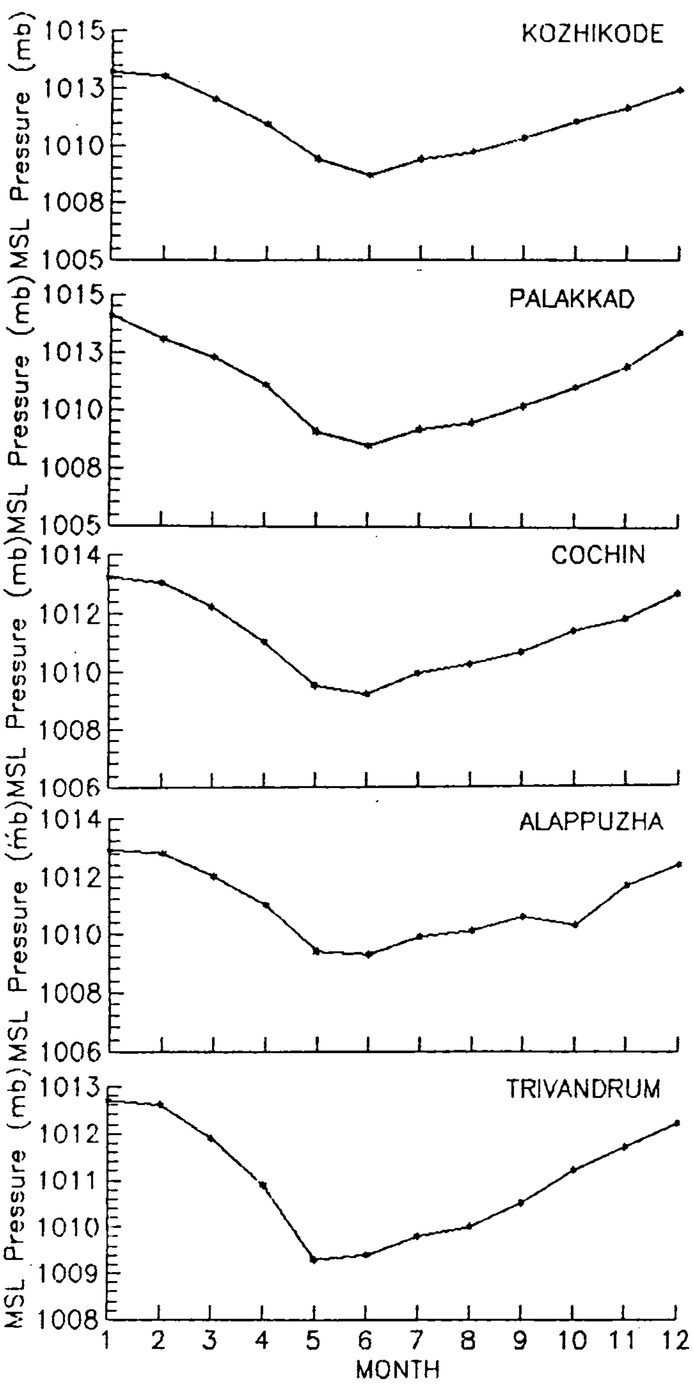


Fig. 1.9 Normal MSL Pressure at 0830 hrs.

except during the period from about middle of October to beginning of March, when reverse gradient prevails.

1.6.2. Winds

In general, winds are quite strong during afternoons when the thermal circulation is best developed and weak during night. Fig 1.10 shows the values of monthly mean daily wind speed in mps. for five selected stations of Kerala. The predominant wind direction in the morning (M) and evening (E) of the stations are given in Table 1.4.

The winds over the States are seasonal, only in the region of Palghat Gap where winds are predominantly from the east in the period from November to March and from west in the rest of the year. In other parts of the State, flow of wind is mainly governed by differential heating of land and water mass together with mountain wind. Only during July and August, strong monsoon period, prevailing conditions do not permit the diurnal cycle of winds to exist. With these exceptions, winds have westerly components during the day and easterly components during the night through out the year.

1.6.3. Temperature :

Day temperatures are more or less uniform over the plains through out the year except during monsoon months when

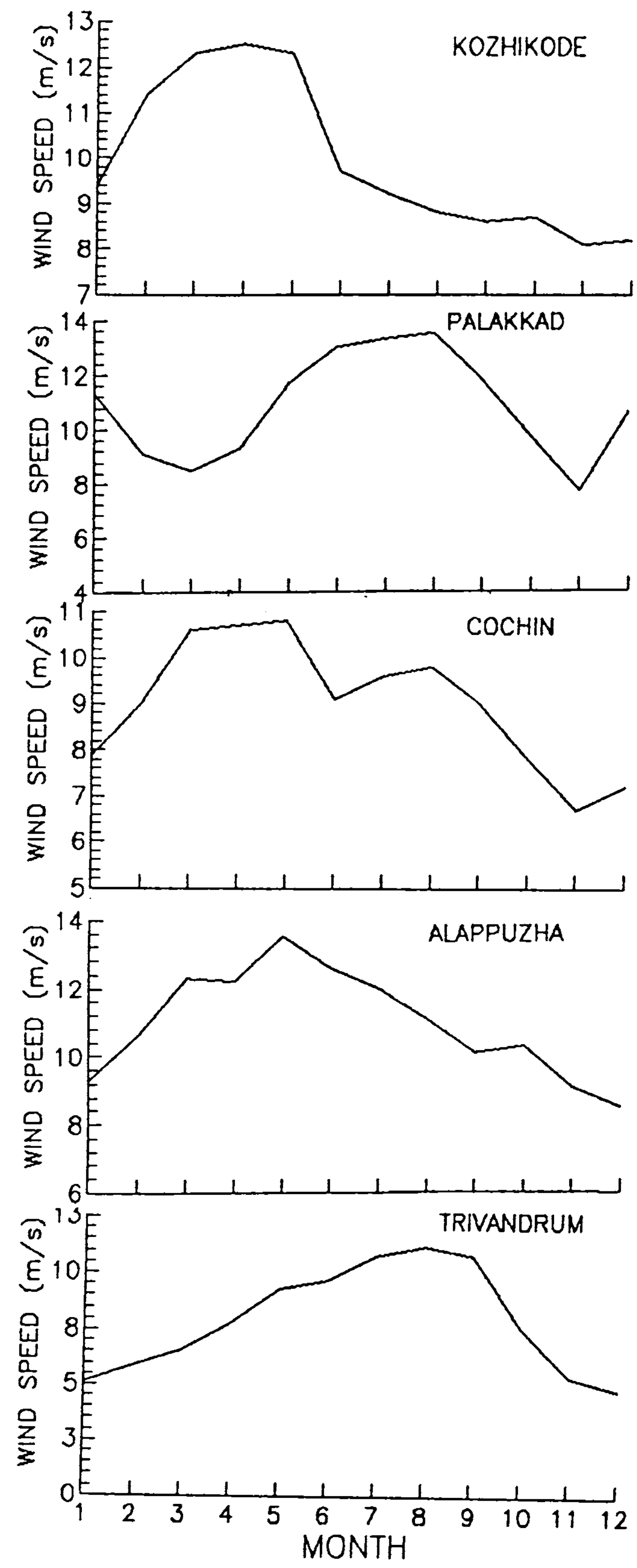


Fig. 1.10 Monthly mean daily wind speed

Table 1.4: Predominant wind direction in the Morning (M) and Evening (E) at the five stations of Kerala.

Station		J	F	M	A	M	J	J	A	S	O	N	D
Kozhikode	(M)	E	E	E/ NE	NE/ E	NE/ NW	NE/ E	VAR	NW	NW	E	E	E
	(E)	W	W	W/ NW	W/ NW	W/ NW	W/ NW	NW/ W	NW	NW/ W	W/ NW	W	W
Palghat	(M)	E	E	E	W	W	W	W	W	W	W	E	E
	(E)	E	E	W/E	W	W	W	W	W	W	W	E	E
Cochin	(M)	NE/ E	NE/ E	NE	NE	NE/ E	E/ NE	VAR	VAR	NE/ E	NE/ E	E/ NE	NE/ E
	(E)	W	W	W	W	W/ NW	W/ NW	NW/ W	NW/ W	NW	W	W	W
Alleppy	(B)	E	E	E/ NE	E/ NE	E	NW	NW	NW	NE/ NW	E/ NE	E	E
	(E)	W/ NW	W	W	NW/ W	NW	NW	NW	NW	NW	W/ NW	W	NW/ W
Trivand-rum	(M)	NE	NE	NE/ N	N	N/ NW	NW/ N	NW	NW/ N	NW/ N	N/ NW	C/ NE	NE
	(E)	SW	SW	SW	W	NW/ W	NW	NW	NW	NW	NW/ W	SW/ W	SW

E - Easterly, NE - Northeasterly, SE - Southeasterly
W - Westerly, NW - Northwesterly, SW - Southwesterly
N - Northerly, S - Southerly, C - Calm
VAR - Variable

these temperatures drop down by about 3 to 5 °C. Both day and night temperatures are lower over the plateau and at high level stations than over the plain. Day Temperatures of coastal places are less than those of interior places. March - April are the hottest months with a mean maximum temperature of about 33 °C.

Mean maximum temperature is minimum in the month of July when the State receives plenty of rainfall and the sky is heavily clouded. The mean maximum temperature for the entire State in July is 28.5 °C, varying from about 28 °C in the north to about 29 °C in the south. The night temperature is minimum in January when clouding is also minimum. For the State as a whole, the mean minimum temperature is about 22.5 °C in January, varying from 22 °C in the north to 22.6 °C in the south. At hilly stations, the values are much lower. Fig 1.11 illustrates the monthly mean maximum and minimum temperatures for Kozhikode, Cochin, Trivandrum, Palakkad and Alappuzha.

Maximum day temperature rises gradually from July onwards till April. Night temperature starts rising gradually from January onwards till May and it has a secondary minimum in July when the State receives plenty of rain. The increase in maximum temperature in the period from July to April-May vary from 3.2 °C to 9.8 °C, depending upon the nearness of the sea from the place. Inland stations experience higher

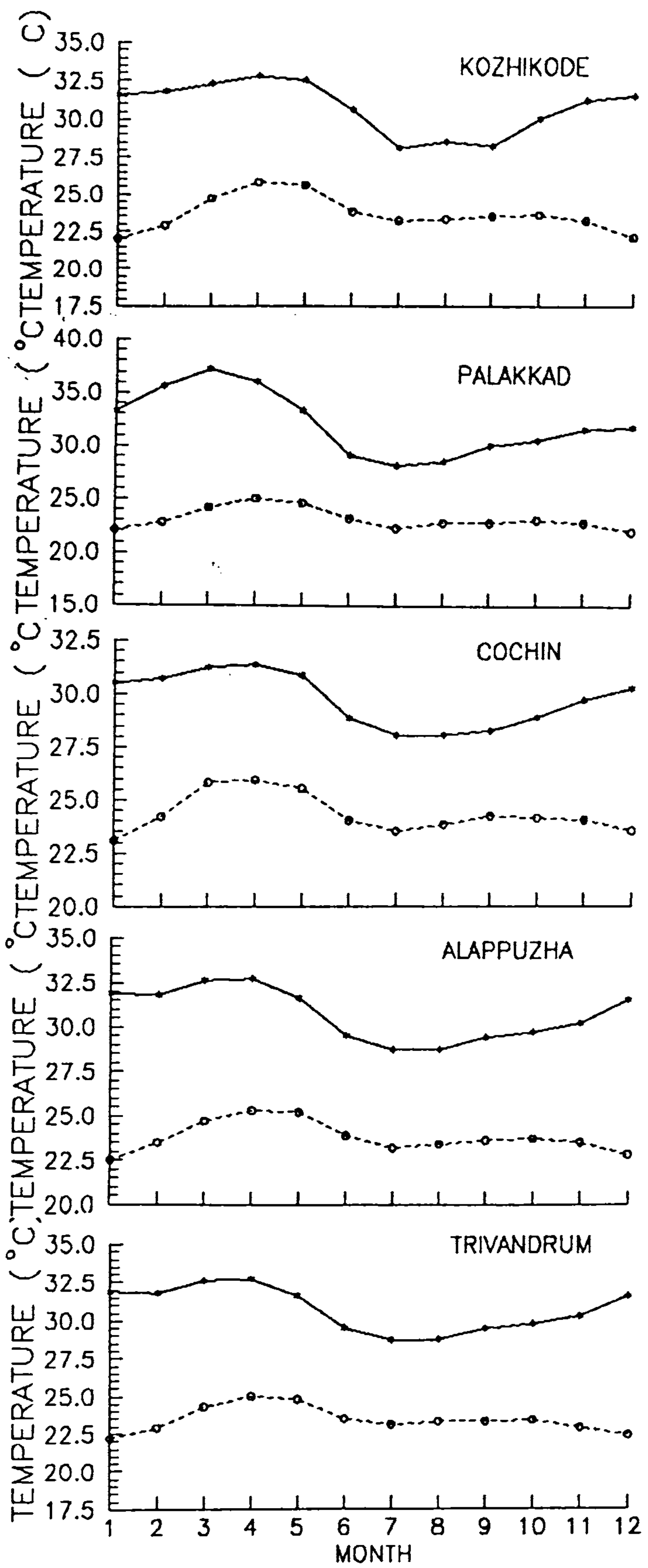


Fig. 1.11 Monthly mean maximum and minimum temperature

maximum temperatures than the coastal stations. From May onwards, both the maximum and maximum temperatures start falling, the latter vary rapidly while the former slowly. From the beginning of May to end of July the maximum temperatures fall by about 5.5 °C to 2.5 °C whereas the minimum temperature falls by about 2..5 °C to 3.6 °C from May to January. July and August have the smallest diurnal range of temperature (about 5.3 °C) in the State. The diurnal range increases rapidly after the withdrawal of S.W.Monsoon. During the period from December to March, the diurnal range is of the order of 8.5 °C to 9.5 °C, being the greatest in January.

1.6.4. Humidity:

Over the entire Indian subcontinent the moisture content of the atmosphere is minimum during the winter months and maximum during the summer monsoon months. The annual variations over Kerala are less than over north India. At the coastal stations of Kerala the monthly mean relative humidity at the surface is the order of 75% in the morning during the winter months and increases to about 90% in the monsoon months. The relative humidity and hence the moisture content, decrease rapidly from coastal to high-lands during the winter months. During the monsoon period, the spatial variation in moisture content is less due to the upward transport of moisture by convective activity. Fig 1.12 gives the

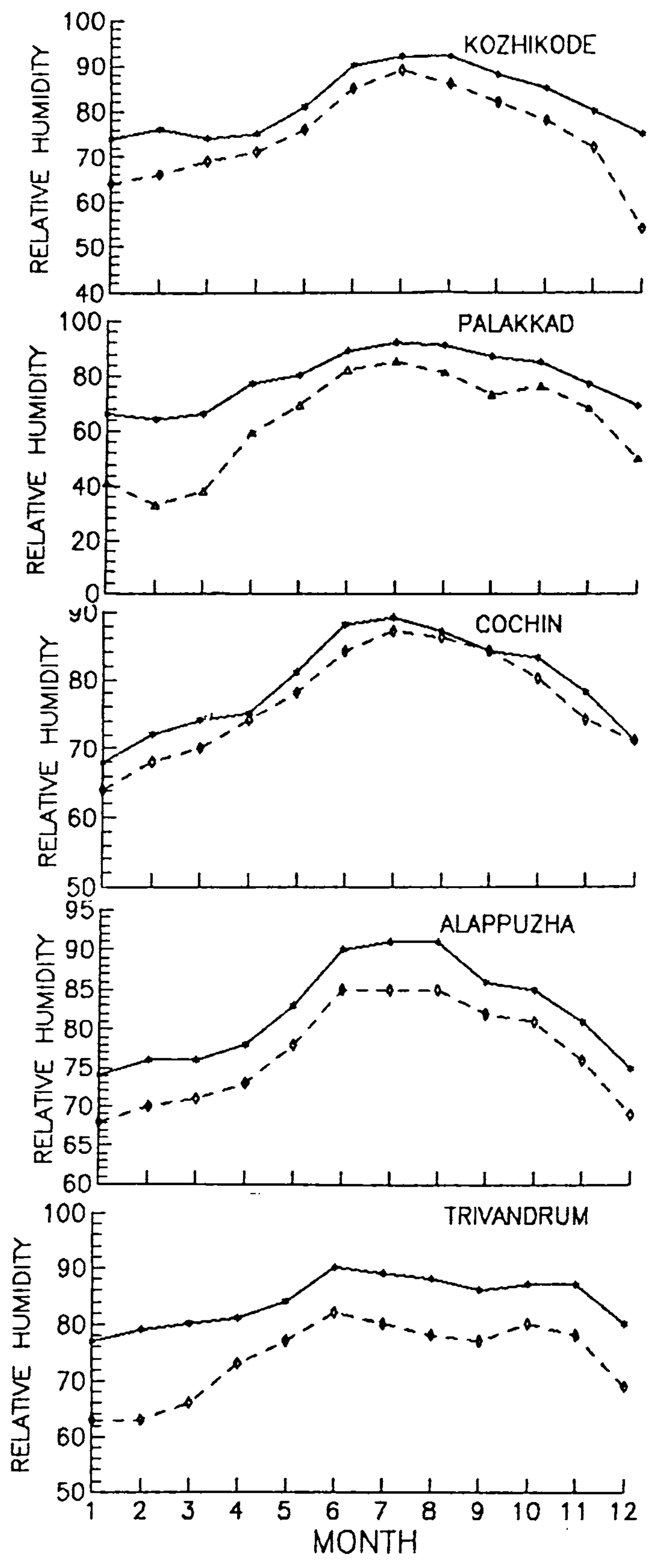


Fig. 1.12 Mean monthly relative humidity (%) at 0830 hrs.(continuous) and at 1730 hrs (dashed)

variations in relative humidity in the morning and evening for the selected stations of Kerala. During the period January to March afternoon humidities reduce to 60-63%, varying from 35% in the interior to 71% in the coastal area. The diurnal variation in relative humidity during this period is maximum and ranges from 4 to 16% depending upon the proximity of the sea. The humidity in the monsoon period rises to about 90% for the State as a whole and diurnal variation in this period is minimum and ranges from 2 to 12%. Maritime influence playing most important role in governing this variation.

1.6.5. Cloudiness :

Fig 1.13 shows the mean monthly cloud amounts at 0830 and 1730 hrs for Kozhikode, Palakkad, Cochin, Alappuzha and Trivandrum. Minimum cloudiness prevails over the State in the period January to March when the sky remains cloudless for 12 to 13 days per month towards the extremely southern parts of the State. During this period about 3 Oktas of sky remain cloudy in a month. The cloudiness varies from 3.9 Oktas of sky towards the northern coast to 2.3 Oktas of sky towards interior and southern most parts of the State. Mornings are more cloudy than evenings except at the southern-most and interior of the State where afternoons are more cloudy than the mornings. During the monsoon season skies are heavily clouded especially during June and July

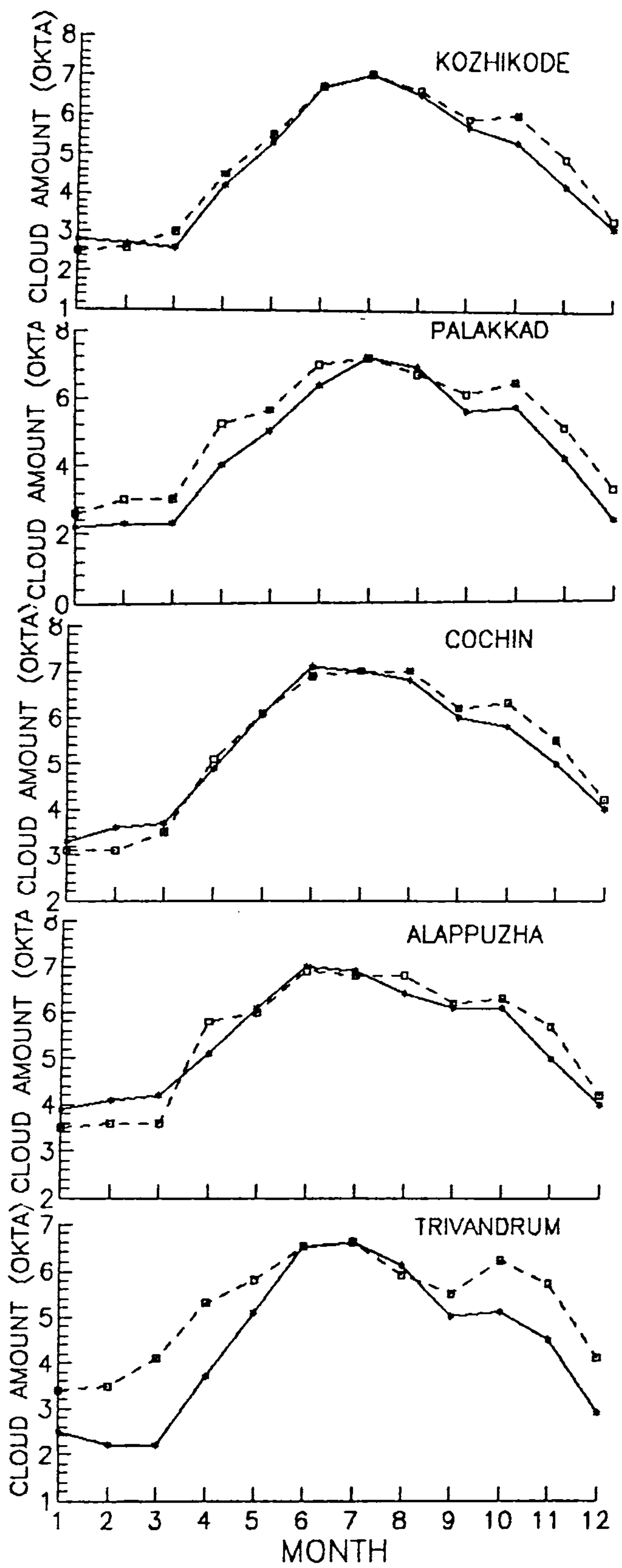


Fig. 1.13 Mean monthly cloud amounts at 0830 hrs (continuous) and 1730 hrs (dashed line)

when about 7 Oktas of sky remain covered with cloud in a month. On and average, in each of these two months the sky remains overcast for more than 16 days per month and is not generally found clear even for a single day. In this season, mornings and evenings are equally cloudy. Cloudiness starts decreasing from August and continues till September. A secondary maximum of cloudiness is observed in the State in October - November during the northeast monsoon period. Again it decreases from November till January - February when the cloudiness in the State is minimum.

1.6.6. **Rainfall :**

The total annual rainfall in the State varies from about 4500 mm over the northern parts to about 2000 mm in the southern parts. The southwest monsoon, locally known as 'Edavapathi', (June - September) is the principal rainy season. During this season the State receives about 73% of its annual rainfall. Southwest monsoon rainfall decreases from north to south and varies from 85% in the northern Districts to 54% in southern District. Rainfall in the northeast monsoon, locally known as 'Thulavarsham', (October - December) and hot weather season (March to May) constitute 7-25% and 10-20%, respectively. Northeast monsoon rainfall increases from north to south and varies from 7% of the annual rainfall in northern districts to 25% in southern most district. In Fig. 1.14, the normal monthly rainfall over the five selected stations in the State are given. Detailed studies on the season-wise and annual variations in rainfall and their spatial and temporal variabilities have been carried out and are presented in this thesis.

1.6.7. Cyclonic Storms and Depressions :

The geographical position of the State is such that it mainly experiences the influences of storms and depressions during the months of November and December. Chances of storms and depressions affecting the State during the month of May are very less. During the period from 1891 to 1970, only three storms affected the State in May (IMD 1986). Out of them the two originated in the Lakshadweep Sea in the years 1932 and 1941 crossed the coast near about 11 °N, and moved in eastward direction. The other one originated in the Bay of Bengal in the year 1932 crossed the east coast, south of Madras, weakened into a depression and moved in the westward direction. After passing over Kerala it again entered into the Lakshadweep Sea near Mangalore. Most of the Bay storms originate in the area bounded by 10° - 15° N latitudes and 82° - 95° E longitudes, move initially in a northwestward or northward direction and then recurve towards the northeast. In the Lakshadweep Sea, storms of this month generally move towards northwest.

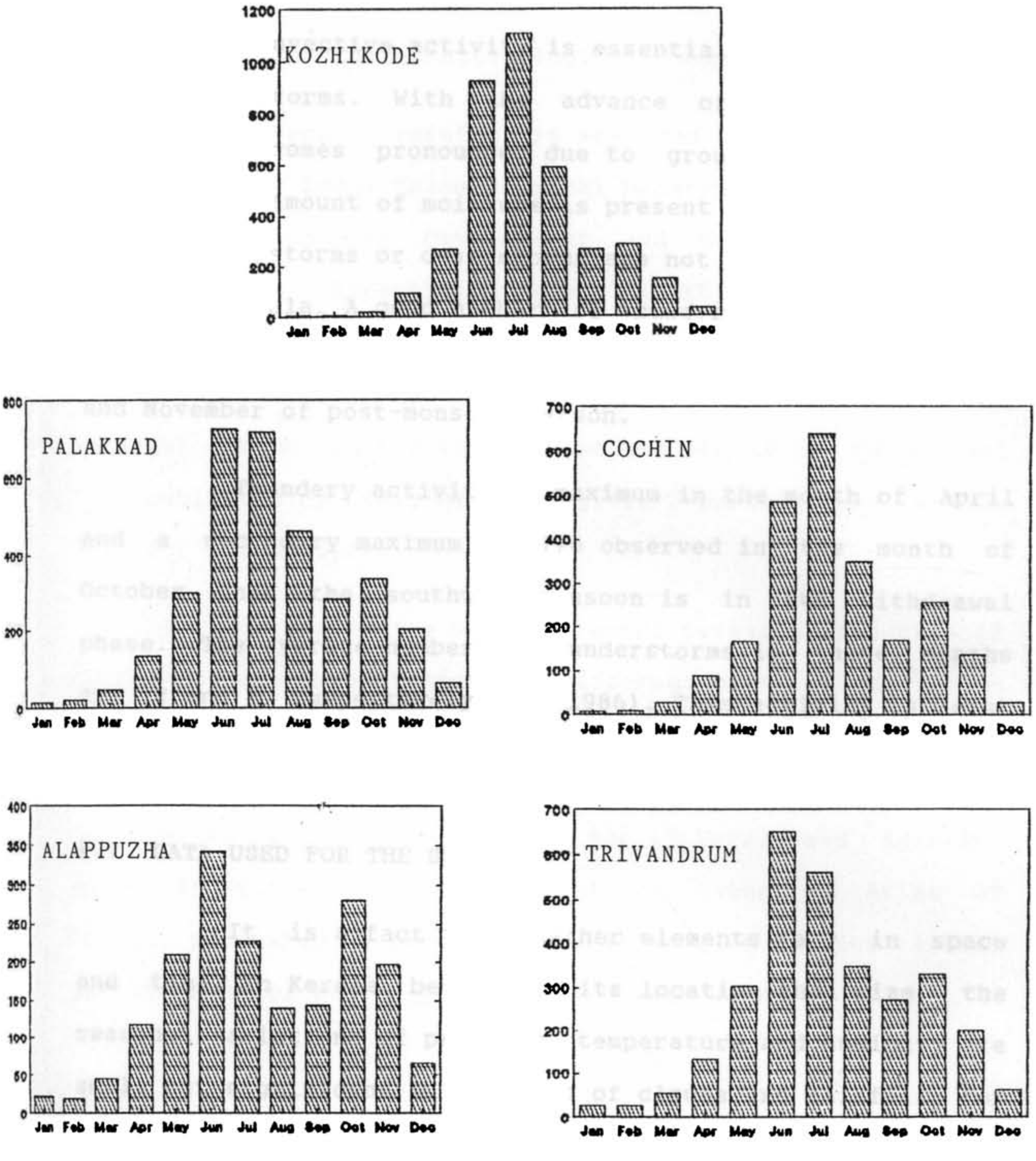


Fig. 1.14 Normal monthly rainfall (mm)

1.6.8. Thunderstorms :

Convective activity is essential for the occurrence of thunderstorms. With the advance of summer, thundery activity becomes pronounced due to ground heating. Since sufficient amount of moisture is present in the atmosphere, dry thunderstorms or dust storms are not normally found to occur in Kerala. A good number of thunderstorms occur in the pre-monsoon months (March - May) and in the months October and November of post-monsoon season.

Thundery activity is maximum in the month of April and a secondary maximum is also observed in the month of October when the southwest monsoon is in its withdrawal phase. The average number of thunderstorms in these months are 12 and 8, respectively (IMD 1986). This activity is least in the months of December, January and February.

1.7 DATA USED FOR THE STUDY

It is a fact that weather elements vary in space and time. In Kerala, because of its location and size, the seasonal variations of pressure, temperature and humidity are small but significant in the case of clouds and rainfall. For micro-level studies all meteorological parameters are important. The information pertaining to these parameters help for planning and executing various developmental projects in the State with a view to have the maximum advantage of favorable meteorological conditions.

In Kerala, rainfall is measured at several stations maintained by India Meteorological Department (IMD), Centre for Water Resources Development and Management (CWRDM), Kerala State Electricity Board (KSEB), Public Works Department (PWD), Agriculture Department, Revenue Department, Private Estates, etc. Meteorological data of different agencies which have been compiled and stored at CWRDM and data published by India Meteorological Department are mainly used for the analyses.

In connection with different research projects of CWRDM, 43 raingauge stations in different parts of the State have been installed and maintained by this student since 1980. Data from these stations are also used for the study. In order to prepare physiographic map of Kerala and identify exact locations of raingauge stations, Resources Atlas of Kerala, published by Centre for Earth Science Studies (1984) and GTS maps of Survey of India have been used.

CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

The geographical factors which strongly influence mountain climates are latitude, altitude, and topography. The influence of latitude on the climate of different mountain systems shows up in a variety of ways. First, solar and net radiation and temperature broadly decrease with increasing latitude and, as a result, the elevations of the tree line and the snow line decrease polewards, i.e., permanent snow and ice are represented on much lower mountains in high latitudes than in the tropics. Second, the latitude factor is apparent in the relative importance of seasonal and diurnal climatic rhythms. This is determined by the seasonal trend in the daily sun path at different latitudes. Seasonal changes of solar radiation, day-length and temperature are basically small in low latitudes, where as the diurnal amplitude of temperature is relatively large.

2.2 INTERNATIONAL STUDIES

The effect of altitude on climatic elements is having primary importance. The relationship between altitude and pressure was first demonstrated more than three centuries ago (Barry, 1981). It is the most precisely documented aspect of altitudinal influence on meteorological elements, although the mean condition is of little direct significance for weather phenomenon. Since temperatures at high altitudes are low, vapour pressures in mountain areas are also low. These decrease in temperature and vapour pressure are proportionately greater in the lower layers. For Mount Fuji, Japan, the vapour pressure averages 3.3 mb at 3776 m compared with 11 mb at 1000 m and 14.5 mb at Sea level (Fujimara, 1971).

The most important characteristics of wind velocity over mountains are related to their topographic, rather than their altitudinal effects. In middle and high latitudes it is normal to expect that on average there will be an increase of wind speed with height due to the characteristics of the global westerly wind belts (Reiter, 1963). Isolated peeks and exposed ridges experience high average and extreme speeds as a result of the limited frictional effect of the terrain on the motion of the free air. In the case of tropics, generally, the easterly trade winds weaken with height. In the winter season, on their poleward margins, they may give way to westerly winds associated with the extra - tropical westerly air circulation. Synoptically, this is most likely when polar troughs in the upper air penetrate into tropical latitudes. In southern Asia there is a marked seasonal changeover, from strong westerly flow over the Himalaya between about October and May, on average, to moderate easterly winds.

The interaction between topography and meteorological elements involves several basic characteristics of any relief feature. The overall dimensions and the orientation of a mountain range with respect to prevailing winds are important for large scale processes, relative relief and terrain shape are particularly important on a regional scale, while slope angle and aspect cause striking local differentiation of climates.

The effects that an orographic barrier produces on air motion depend first on the dimensional characteristics of the barrier - its height, length, width, and the spacing between successive ridges - and, second, on the properties of the airflow itself - the wind direction relative to the barrier, the vertical profiles of wind and of stability. Each of the three dimensions of a mountain barrier interacts with a particular atmospheric scale parameter (Smith, 1979). Hence, the vertical dimension of the mountain should be compared with the atmospheric depth, as measured by the 'density scale height', about 8.5 km.

The air arriving at a barrier must have sufficient kinetic energy in order to rise over it against the force of gravity (Stringer, 1972). The level of exhaustion of Kinetic energy for an air parcel rising from the surface, which is affected by friction is approximately 0.64 u/ S, where u =

surface speed of upwind, (m/sec) and $S = g (B - r)/T$ is the static stability, representing the net balance of buoyancy forces and gravity; B = the adiabatic lapse rate, and r = the environmental lapse rate (dT/dz) (Sheppard, 1956; Wilson, 1974).

Small scale topography and vegetation cover play a major role in modifying micro-climates in mountains, especially in the vicinity of the timber line. Studies in the Sub-Alpine in Switzerland, for example, show that ridges and gullies with a relief of 5-12 m can modify the wind speed by $\pm$ 60 per cent when the direction is perpendicular to the ridges (Barry, 1981). More important is the formation of vertical eddies in the form of a rotor, in the lee of obstacles. Gloyne (1955) shows that these extend horizontally downwind 10-15 times the height of the obstacle. For a vegetation barrier of 50 per cent density, the wind speed is reduced by 80 per cent up to 3-5 times the height of the vegetation downwind.

Cloud type in mountain areas is primarily determined by air mass characteristics and is therefore related to the regional climate conditions. The spatial distribution of convective upcurrents in mountain regions shows some pronounced effects of topography. There may be strong contrasts between shaded and sunny slopes. Fujita et al (1968) reported rapid cumulus build-up on the slope of Mt. Fuji between 0845 - 0915 hrs in July as the solar altitude increased from 47° to 53° and surface temperatures on the rocky slopes exceeded 30 °C. Surface temperatures on mid-latitude mountains during summer afternoons tend not to differ much from those in adjacent valleys since the change of net radiation with height is small (Scorer, 1955). Consequently potential temperatures are higher in the mountains. in Idaho, Maccready (1955) found an average potential temperature gradient on summer after noons of 2.9 k/km between 700 and 1700m, with maximum rates of 5.5k/km. Therefore, thermals start more readily over high ground, although because of the higher potential temperatures, cloud bases over these locations also tend to be higher. In such terrain, the height difference between the bases of cumuli over valleys and over hilltops is about half of the valley summit relative relief.

The influence of mountain barriers on precipitation distribution and amount has been a subject of long-standing debate and controversy. It is a problem that is compounded by the paucity of high-altitude stations and the additional difficulties of determining snowfall contributions to total precipitation especially at windy sites. As recognised by Salter (1918) from analysis of British data, the effect of altitude on the vertical distribution of precipitation in mountain areas is highly variable in different geographical locations. A convective pattern of vertical precipitation distribution is widely found in the tropics where the cloud base is typically about 500 - 700 m in coastal areas and 600 - 1000m inland. As noted by Barry (1981), these areas characteristically have a rainfall maximum between 1000 m and 1500 m. This pattern is especially pronounced in the trade - wind inversion belt where the air is very dry above the inversion. On Hawaii, for example, more than 550 cm falls at 700 m on the eastern slopes of Mauna Loa, whereas the summit (3298 m) receives only 44 cm. Similar trends are apparent on windward slopes of the coastal mountains of Central America (Hastenrath, 1967). Flohn (1974) states that, in the area of the inter-tropical convergence, precipitation amounts on mountains above 3000m are only 10-30 per cent of those in the maximum zone. Examples are Mt. Kenya and Mt. Cameroon.

The amount of orographic precipitation depends on three factors operating on quite different scales (Sawyer, 1956). They are (i) air mass characteristics and the synoptic - scale pressure pattern; (ii) local vertical motion due to the terrain; and (iii) micro-physical processes in the cloud and the evaporation of falling drops. Air mass characteristics of major importance are the stability and moisture content of the air, the pressure field determines the wind speed and direction. Douglas and Glasspoole (1947) found that heavy orographic precipitation is most likely in Britain when winds are strong and perpendicular to an extensive mountain range, the air is already moist and cloudy, and the lapse rate is near neutral, facilitating the release of conditional instability through uplift.

The most complete global survey of vertical precipitation profiles has been carried out by Lauscher (1976) using data for 1300 long-term stations grouped into three major categories: below 1 km (1029 stations), 1-2 km (222) and 2-3km (43) for 10° latitude - 20° longitude sectors between 35° S and 55° N from 130° E westward to 110° W. He distinguishes five general types as shown in Fig. 2.1. There are 'tropical' (T) with a clear maximum at about 1.0 - 1.5 km; 'equatorial' (E) where there is a general decrease with height above a maximum close to sea level; a 'transition' type (Tr) in the subtropics where there is either little height dependence, or conditions vary considerably locally; a 'mid-latitude' type (M) which shows a strong increase with height, and a 'polar' type (P) where higher totals tend to occur near sea level, at least in the vicinity of open water.

Several research investigations in Western Canada include studies of the distribution of precipitation in mountainous regions. The results of the study carried out by

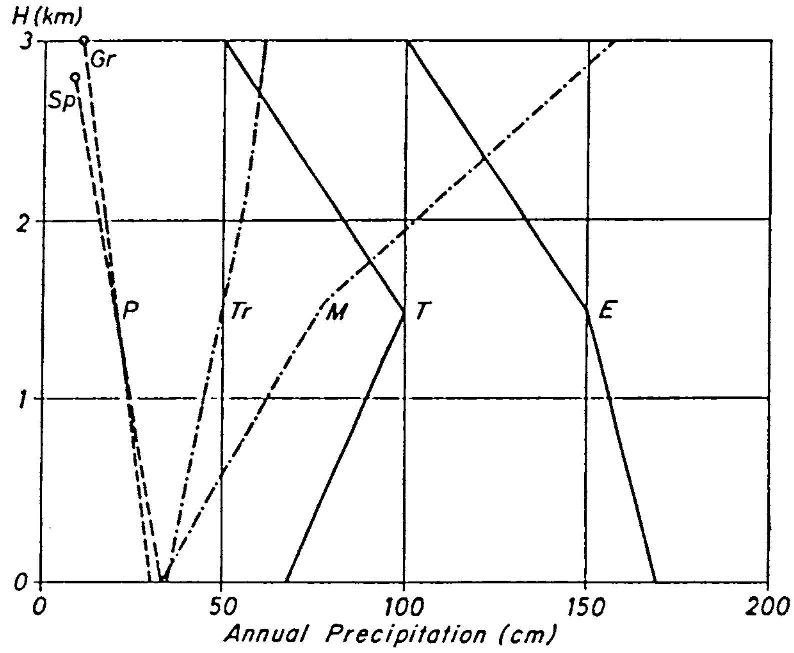


FIG.2.1 SCHEMATIC PROFILES OF MEAN ANNUAL PRECIPITATION VERSUS ALTITUDE IN EQUATORIAL CLIMATES (E), TROPICAL CLIMATES (T), MIDDLE LATITUDES (M), AND POLAR REGIONS (P). Sp DENOTES SPITZBERGEN; Gr GREENLAND; Tr IS A TRANSITIONAL PATTERN BETWEEN LATITUDES 30° AND 40° N.

(AFTER LAUSCHER, 1976)

Storr and Ferguson (1972) in the experimental basins located on the eastern slopes of the Rocky Mountains in Alberta are as follows. Five to ten years data were used for the study. Some tentative generalisation were possible from the precipitation patterns presented for the three Albert watersheds. It was noted that the variability of both rainfall and annual precipitation (including snow, hail, sleet, dew forest, etc.) was much greater at Maonmot Creek than in Streeter or Deer Creek. Spreen (1947) has shown that precipitation amount and variability is a function of elevation, slope and aspect. Brown and Peek (1962) emphasised the importance of the catch efficiency of the gauges in any study of the precipitation variability.

Detailed studies of distribution over a number of small areas have been made in Project Pluvuis (Anderson, 1963, 1964) and in later Swedish studies (Sandsborg 1969, 1970) using raingauges installed in a level with the ground. The coefficient of variation was employed to describe differences across the area being investigated in a level with the ground. In another study by Sharon (1970) rainfall distribution across a small catchment in the Negev was assumed to be complicated by the effect of wind on the gauges that were employed.

Precipitation in the Scottish high lands has highly individual characteristics resulting from the location of Scotland and from its topography (Green, 1972). The mountains of Scotland are sufficiently high to induce a large orographic increase in precipitation, but at the same time they do not form a sufficient barrier significantly to divert traveling depressions, which therefore usually travel right across Scotland. The average annual rainfall clearly shows the strongest .pa correlation with eastward moving air-streams. The highest annual falls are in the mountainous areas close to the west coast.

During the years 1963- 66 an agro-climatic investigation was carried out by Skaar (1972) in the Sognefjord region, a mountainous area of Norway, approximately 11000 sq.km. Daily precipitation amount was measured at 145 stations in the period April to October and at 50 stations in Winter. The coastal districts are among the most precipitatous in Norway. During the study period the average annual precipitation at Brekke was 3354 mm. The valleys at the head of the eastern-most parts of the Fjord got only about 1/9 of this amount. The three years concerned included one wet year, one dry year and a year with near average precipitation amount.

The areal distribution of precipitation, daily maxima, in Gorski Kotar and Lika (Yugoslavia) has been studied by Plesko (1972) in relation to the prevailing air-streams in the atmospheric layer from the earth surface and up to the height of about 1500 m. The isohyetal charts of daily maxima have been elaborated for each of eight main wind directions. The estimates of daily maxima were found for various return periods and for selected stations as well as their maximum expected value. Terrain in Lika is mostly at 500-700 m above sea level and in Gorski Kotar 700-800 m above msl. The high land of Lika is mostly covered with fields, and Gorski Kotar has a very developed orography and a lot of woods. The mountain ridge Dinaride (1758 m - the highest top) play an important role in the precipitation regime of these regions making a barrier to the Adriatic Sea. Towards the east Lika is also surrounded by mountains (800-900 m), while mountainous country of Gorski Kotar gradually lowers eastward. Gorski Kotar belongs to the most rainy regions in Yugoslavia, approximately 2500-3000 mm. In Gorski Kotar area, the up-slope rising of the air in mountains is maintained by southerly air-streams and even intensified by the general lifting up of the air in cyclones. Southerly air streams bring considerable daily rainfall maxima to Lika as well, still 3-4 times less than in Gorski Kotar, because the most of the precipitation falls down on the seaward side.

Patterns of orographic precipitation in the western United States are subject to considerable variation. Multivariate correlation analyses were used by Eugene (1972) to determine whether meteorological parameters might be used to predict the distribution patterns of winter precipitation without the need for storm typing. Twelve hour precipitation values for stations in the northern Utah having large range of elevation were correlated with meteorological parameters derived from concurrent radiosonde observations. The meteorological parameters were sufficient to define general precipitation patterns for winter orographic precipitation.

Miller (1972) made an investigation on the precipitation - frequency regime on the mountainous western portion of the United States. These investigations have attempted to depict the variations of the precipitation - frequency regime with the variations in physiographic factors for return period between 2 and 100 years and durations of 6 and 24 hours. Relationships between precipitation - frequency data at stations and topographic and climatic parameters, such as elevation, exposure and normal annual precipitation, were developed to aid in understanding these variations. These relationships were used in the preparation of generalised isopluvial charts. In some portions of the mountainous western United States, snow contributes significantly to the series of extreme precipitation amounts. In these regions, an additional set of maps have been prepared which depict the precipitation - frequency regime for May to October season, when practically all heavy precipitation is in the form of rain.

With the inception of the Indian Meteorological Department in 1875, systematic recording of daily rainfall was initiated in the Indo-Pak sub-continent. Prior to 1961, the normal and other isohyetal maps drawn on the basis of available data were found unsatisfactory for the hilly areas. Following the signing of the Indus Basin Treaty 1960, special hydro-meteorological studies were taken up by the Pakistan Meteorological Department for the implementation of the Water Resources Projects connected with the Indus Basin Development Plan. By 1961, though the network of raingauges had fairly improved, the undeveloped and inaccessible areas, particularly the mountainous areas of the Northern region were still inadequately or completely ungauged. Consequently in the studies conducted by Florence C. Khurshid Alam (1972) since 1961, the technique of analysis ensuring homogeneity and accuracy of data were employed. The primary draw back of lack of basic data was considerably eliminated by developing Elevation - Barrier - Precipitation relationship, depicting the effect of topography of the area on the resultant precipitation. These varied with the season as well as with different project areas. The topographically adjusted normal isohyetal maps thus developed were found to provide reliable results in the computation of the probable maximum precipitation studies. These studies also provided objective basis for improving the precipitation gauge network in the mountainous areas of Pakistan (Fig. 2.2)

An analysis of precipitation in Taiwan mountainous area was done by Pan (1972). The island receives very little snowfalls even in mountain peaks exceeding 3000 meters in height, which is similar to Kerala Condition. The annual precipitation of Taiwan is attributable mainly to monsoons and typhoons averaged to 2340mm. Due to rugged topography and the north east ... oriented Central Mountain Range, the orographic effect has a great influence on the distribution of precipitation in mountain areas caused by monsoons, and additional precipitation results on the mountain areas caused by tertiary circulations.

Cheang (1993) has studied inter annual variations of the monsoon utilising homogeneous rainfall records of 41 years (1951 - 1991) from Malaysia and upper air data of stations in Asia, Australia and Western Pacific. He has tried to find out the influence of ENSO (El Nino Southern Oscillation) on Malaysian annual rainfall. No linear trend has been found in the annual rainfall of 16 stations in

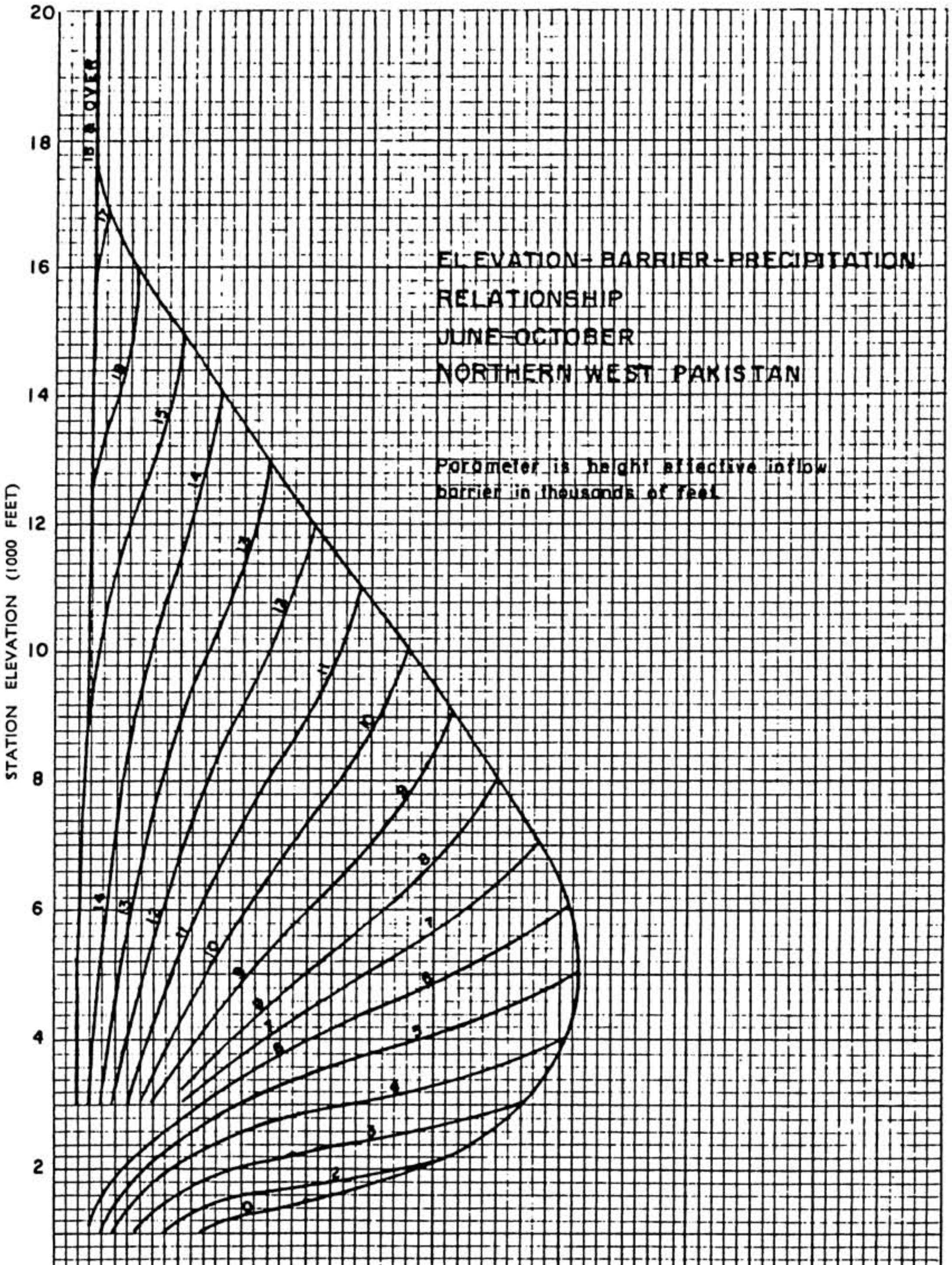


FIG.2.2 ELEVATION - BARRIER - PRECIPITATION RELATIONSHIP (JUNE - OCTOBER) IN NORTHERN WEST PAKISTAN (AFTER FLORENCE & KHURSHID ALAM, 1972)

Malaysia. Most El Nino years are associated with below median and La Nina years with above median rainfall at most stations in Malaysia. ENSO has greater influence over East Malaysia than peninsular Malaysia.

One of the important physical processes contributing to climatic variability is the interaction between the land surface and the atmosphere. The land surface exert a pronounced effect on the variability of the atmosphere. The potential importance of such interactions for climatic variability has been examined by Delworth and Manabe (1993) through the use of numerical modeling studies. It has been shown that interactions between soil wetness and the atmosphere can both increase the total variability of the atmosphere and lengthen the time scales of near surface atmospheric fluctuations.

Verma (1993) correlated the monsoon rainfall values with the gridded surface air temperature over northern hemisphere land at various time lags of months to identify teleconnections of monsoon with the northern hemisphere surface air temperature anomalies.

As per the study, two regions in the higher latitudinal belt of 40 °N - 70 °N over North America and Eurasia show positive correlations with temperatures during northern winter. The region located over northwest India and adjoining Pakistan show maximum positive correlation during the pre-monsoon months of April and May. These relationships suggest that cooler northern hemisphere during the proceeding seasons of winter/spring over certain key regions are generally associated with below normal summer monsoon rainfall over India and vice versa which could be useful for predictors for long - range forecasting of monsoon.

Muthuchami and Ravikumar (1992) examined the activity of monsoon and the intensity of SHET (Southern Hemispheric Equatorial Trough) using selected INSAT - IB pictures from 1984 to 1989, during the monsoon period. It has been pointed out that when the system in the N.H. reaches its peak intensity, clouds start appearing in S.H. near equator, which shows that the intensity of the synoptic systems in the north Indian Ocean is seen to be inversely related to the activity of SHET.

2.3 STUDIES CONDUCTED IN INDIA

In India, systematic and scientific studies on variation of precipitation with elevation are limited mainly because of lack of sufficient information on the amount of precipitation at higher elevation. This is due to non-availability of automated recording precipitation gauges and problem associated with measurement of precipitation at such higher elevation on a routine basis.

Nearly 35% of the geographical area in India is mountainous. Of these nearly 58% is accounted for by the mighty Himalayas, extending from north-west to east. Besides, the Khasi and Jayantiya hills in the northeast, the Vindhya and Satpura hills in central India, the Western Ghats running all along the west coast from Maharashtra to Kerala and the broken hill ranges of Eastern Ghats largely determine and guide the Country's rainfall pattern during the summer as well as winter. Isolated hill ranges like, the Aravalis and Nilgiris also influences the rainfall occurrence in those areas. Important mountain ranges in India are presented in Fig. 2.3.

Dhar et al (1978) carried out a study of the heavy rainfall stations in India. For the purpose of the study, stations with mean annual rainfall of 500 cm were considered as heavy rainfall stations. In Table 2.1, stations receiving more than 500 cm of annual rainfall together with their elevation and mean annual rainfall are presented.

From the Table 2.1, it may be seen that 10 of the heavy rainfall stations lie in the Western Ghats and the rest are located in the hills of northeast India. There are,

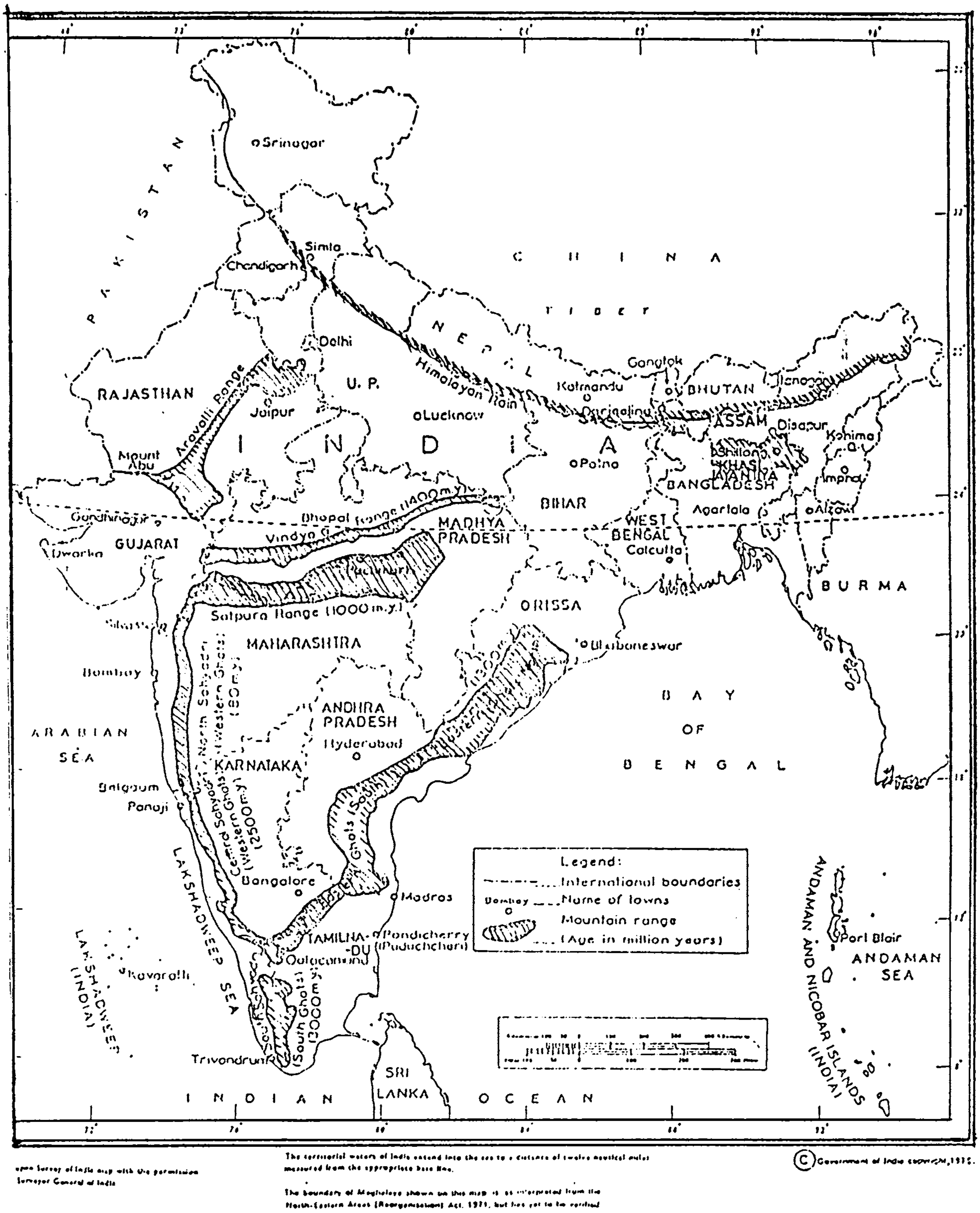


FIG. 2.3 IMPORTANT MOUNTAIN RANGES IN INDIA

Table 2.1: **Heavy Rainfall Stations in India**

Station	State	Mean annual rainfall (cm)	Period of Record
Agumbe	Karnataka	847	1952-1970
Amboli	Maharashtra	747	1934-1951
Bhagamandala	Karnataka	596	1907-1970
Buxa	West Bengal	532	1891-1968
Cherrapunji	Meghalaya	1102	1902-1975
Denning	Arunachal Pradesh	528	1929-1949
Gaganbawda	Maharashtra	596	1901-1974
Mahabaleswar	Maharashtra	630	1891-1976
Makut	Karnataka	517	1933-1974
Matheran	Maharashtra	534	1892-1974
Mawsynram	Meghalaya	1221	1941-1969
Neriamangalam	Kerala	504	1940-1973
Peermade	Kerala	500	1901-1970
Pulingoth	Karnataka	588	1933-1967

however, none in the Himalayan region. There are some stations in the Darjeeling hills with short period means over 500 cm, which are not included in Table 2.1. During the onset of the southwest monsoon, the moisture laden monsoon winds first approach the Western Ghats and the Khasi Jayantiya hills and precipitate most of the moisture over these regions. By the time they approach the Himalayan regions much of the moisture is lost and, therefore, the less rainfall in these areas. In the case of highest one day rainfall, while Cherrapunji, Jowai and Mawsynram had 103.6, 101.9 and 99.0 cm respectively, Dharampur a plain station on the west coast in Gujarat received 98.7 cm.

Dhar and Bhattacharya (1976) made a study on the variation of precipitation with elevation in the Central Himalayas. A relationship between precipitation and elevation was obtained for the Central Himalayas using 15 to 20 years data of more than 50 stations. Variation of rainfall with the elevation showed that there are two zones of maximum precipitation. One near the foot of the Himalayas and other at an elevation of 2.0 to 2.4 km. For higher elevations beyond 2.4 km the precipitation decreases sharply as one moves across the region.

Nagara (1981) carried out an analysis of a real rainfall in the Khatmandu Valley. The Khatmandu Valley lies in the hilly region of Nepal where a number of mountain ranges extend generally west to east parallel to the greater Himalayan range. The most prominent peaks rising from the valley are Shoopuri (2689 m) in the north and Phulchowki (3132 m) in the south. Based on the data for the period 1971-

76 for a few stations in the valley, the variation of precipitation with elevation has been studied. The seasonal and annual rainfall together with the elevation are given in Table 2.2.

Table 2.2 : **Seasonal and Annual Rainfall (mm) in the Khatmandu Valley**

Station	Elevation (m)	Nov-Feb (mm)	Mar-May (mm)	June-Sep (mm)	Oct (mm)	Annual (mm)
Bhaktapur	1350	48.5	222.8	1231.4	86.2	1588.9
Godavari	1400	50.0	219.3	1717.5	88.5	2075.3
Indian Embassy	1324	44.2	220.3	1249.3	67.8	1581.6
Kokani	2064	45.5	295.6	2428.4	139.4	2908.9
Khumaltar	1350	44.3	173.0	974.3	65.4	1257.0
Nagarkot	2150	54.9	266.0	1950.4	124.6	2395.9
Saankhu	1463	50.8	231.6	1652.8	109.0	2044.2
Sundarijal	1576	53.9	280.9	1887.8	91.2	2313.8
Thankot	1630	57.6	297.9	1744.2	103.0	2202.7
Tokha	1790	50.5	303.4	2150.1	73.7	2577.7
Tribhuvan	1336	43.7	189.6	1155.0	65.1	1453.1

From Table 2.2, it may be seen that rainfall increases with elevation though not in a systematic way as revealed by the seasonal and annual rainfall values at Kokani, Nagarkot, Thankot and Tokha.

Upadhyaya and Bahadur (1982) carried out a study of the variation of precipitation in Himalayas. The Himalayas Mountain system was conceived to be constituted of three parallel longitudinal ranges. They are (i) the outer Himalayas on Shiwalik ranges with height from 1000-1300 m and width from 10 to 50 kms, (ii) the lesser or middle Himalayas with height ranging from 2000-3300 m and width between 60 to 80 kms and (iii) the greater Himalayas with average height of 6100 m and average width of about 200 km.

Data of rainfall from seven sub-regions in western Himalayas having homogeneous topographic aspects were considered for the study of the variation of precipitation with altitude. From the study it has been noticed that the precipitation gradient decreases or even becomes negative when considerable increase of wind speed occurs with increasing elevation which partly explains the decrease of precipitation after a certain elevation in the Himalays. This elevation was noticed to be generally around 2000 m. Based on the study, the authors concluded that the precipitation is influenced by increasing altitude in three ways.

i) The quantity of precipitation increases with altitude upto a certain level and decreases thereafter. The level of maximum varies greatly from place to place depending on local topography. It was generally observed to be between altitudes of 1500 to 2500 m.

ii) Average variability of precipitation generally increases with elevation.

iii) At higher altitudes, the period of maximum precipitation is generally earlier than that on foot hills.

Divya (1991) carried out a study on climatic changes with regard to increase in green house gases. The analysis of mean annual temperature for India during the period 1901 - 1982 has indicated that about 0.4 °C warming has occurred during recent 8 decades. The study indicates that there is no significant trend for precipitation over India.

With an objective to understand the influence of surface marine meteorological parameters in relation to the extreme monsoon activity over the Indian sub - continent leading to flood/drought, a detailed analysis of the sea level pressure over the southern hemisphere and various surface meteorological parameters over the Indian seas has been carried out by Mohanty and Ramesh (1993). The study indicates that the sea surface temperature changes over the south eastern pacific (El Nino/La NIna) have only a moderate impact (not exceeding 50% reliability) on the Indian summer monsoon activity. On the other hand the sea level pressure anomaly (SOI) over Australia and the south Pacific has a reasonably high degree of significance (more than 70%) with the Indian monsoon activity. Over the Indian seas, the parameters which are mainly associated with the connective activity such as cloud cover, relative humidity and the surface wind were found to have a strong association with the extreme monsoon activity (flood/drought) over India.

Summer monsoon over India shows variability on many time scales. Variability in the time scale of 5 to 10 days is of considerable importance for medium range forecasting. The study of De and Lele (1992) presents a detailed account of the variation in this time scale of the two important parameters, viz., the rainfall distribution over the Country and the cloudiness in the southern hemispheric equatorial trough. The spatial monthly mean temperature distribution over a portion of peninsular India has been calculated as a function of elevation by Srinivasan and Ramanathan (1992). It has been stated that there is a considerable variation of lapse rate in the study region (peninsular Indian region between 14° N and 22° N and from 72° E to 82° E) in a year. High degree of instability is found in June while maximum stability is noted in December.

2.4 SUDIES WITH REFERENCE TO KERALA

On the meteorological map of India, Kerala has a prominent place. It is the gateway through which the great rain - bearing south-west monsoon current which sustains the economy and prosperity of India gains access to the sub-Continent year after year by the end of May or in early June, and through which the monsoon makes its lingering exit towards the end of the year after having dispersed its priceless bounty over the length and breadth of the country. Much studies have been carried out on the topics related to rainfall of Kerala, some of them are highlighted in this section.

Rainfall over Kerala during the southwest monsoon period is fairly steady with not much of variability. The reason may be the mechanism of rainfall is orographic in this season. Kerala does not suffer from too wide an inter-annual variation in the total seasonal rainfall amount, though large variations do occur in monthly rainfall figures. However, the total rainfall depends on the behaviour of the southwest monsoon. Some abnormal years have occurred as can be seen from Table 2.3 shown below (Menon and Rajan, 1989).

Table 2.3: **High and Low of Annual Rainfall Amounts (Annual normal - 301 cm)**

High		Low	
Year	Amount (cm)	Year	Amount (cm)
1924	410	1928	240
1933	406	1944, 1945	235
1946, 1959	360	1952	230
1961	418	1976	218
1975	355	1982	220

Averaged over the entire state, Kerala gets an annual rainfall of 301 cm spread over 126 rainy days. A day's rainfall is reckoned as the total amount of rain during 24 hrs ending at 0830 hour IST of the day and a day with 0.25 cm or more rain is counted as a rainy day. The distribution over the year is as illustrated in Table 2.4 (Menon and Rajan, 1989).

Climatologically the onset of the southwest monsoon over extreme south Kerala is Ist June. The onset, however, can take place earlier or later and in some years there is multiple onset when the initial onset takes place too early.

Table 2.4 : **Rainfall distribution of Kerala**

Month	Rainfall		No. of Rainy days	
	Amount (cm)	% of Annual total	No. of days	% of Annual total
June to Sept.	201	66	79	64
Oct. to Nov.	50	16	23	19
Dec. to Feb.	9	3	4	3
Mar. to May	41	14	20	15
Annual	301	-	126	-

Table 2.5 : **Frequency of occurrence of onset of SW Monsoon**

May						June					
Date	No.of occ.	Date	No.of occ.	Date	No.of occ.	Date	No.of occ.	Date	No.of occ.	Date	No.of occ.
11	2	18	1	25	2	1	8	8	2	15	1
12	0	19	2	26	2	2	3	9	1	16	0
13	0	20	1	27	3	3	2	10	1	17	0
14	1	21	2	28	2	4	4	11	1	18	1
15	2	22	2	29	5	5	5	12	1	19	0
16	1	23	1	30	5	6	5	13	0	20	0
17	3	24	1	31	5	7	5	14	2	21	0

Multiple onset means that there is a recession of the monsoon after the initial onset and another onset of the current that to take place before it gets established. Between 1901 and 1985, the earliest onset is 11th May in 1918 and 1955 while the most delayed onset date is 18th June in 1972 (Menon and Rajan, 1989). On 47 occasions out of 85 between 1901 and 1985, the onset has taken place between 29th May and 7th June. The highest number of occasions of onset is 8, on Ist June, as can be seen in Table 2.5 which shows the frequency of occurrence, date wise, of the onset of southwest monsoon over south Kerala during the years 1901-1985 (Menon and Rajan, 1989).

Ananthakrishnan et. al (1979), discussed in detail about the meteorology of Kerala. It is suggested that the most outstanding feature of the meteorology of Kerala is the seasonal reversal of the wind circulation which constitutes the summer and winter monsoons. This seasonal reversal is linked with the seasonal reversal of temperature and pressure gradients following the apparent north-south movement of the Sun in the course of a year. The seasonal progressions of temperature, pressure and winds at the surface and in the upper air are illustrated and the significant points high lighted. The variations of the thermal gradients in the horizontal and in the vertical are linked with the occurrence of the sub-tropical westerly jet stream over north India in winter and the tropical easterly jet stream over south India in the summer monsoon months. The rainfall of Kerala and its space - time distributions .pa are considered at same length. The importance of orography for the rainfall of Kerala is mentioned in the paper.

In the study by Ananthakrishnan et al (1979), diurnal variations of pressure, temperature, relative humidity, winds and rainfall are also discussed. It is reported that the coastal stations have a rainfall maximum in the early morning hours and a rainfall minimum towards noon and early afternoon. Attention is drawn to some special features of the meteorology of Kerala such as the effects produced by the Palghat Gap on rainfall and airflow, squalls associated with the southwest monsoon rainfall at the coastal stations, the easterly jet stream of summer monsoon season and quasi - biennial oscillations at equatorial latitudes shown by the lower stratospheric zonal winds of Trivandrum.

The rainfall time series of 75 rain recording stations over Kerala for the 80 year period 1901 to 1980 have been statistically examined by Soman et al (1988) for long-term trends. Application of Mann - Kendall rank statistic test to the time series of annual and seasonal totals as well as extreme rainfall of 1, 2,..., 10 day durations revealed a significant decreasing trend in the rainfall over the eastern high lands and adjacent areas to the west. This finding is supported by the fact that the mean rainfall for the second half of the period is 10 to 20% lower than for the first half over the same area.

According to Soman et al.(1988), such changes in rainfall may have association with environmental modifications due to human interventions with natural ecosystems, although the physical mechanisms of the effect of vegetation loss on the climatic condition of a region are not well understood. The decrease in rainfall is maximum over the highlands of the state, where the forest cover is more and most of the hydel projects are situated. Construction of hydel projects, expansion of human settlements, extension of agriculture and plantations towards the east have resulted in appreciable deforestation over the highlands in recent decades. To what extent these activities have contributed towards the observed decrease in rainfall remains to be understood.

Utilising daily mean rainfall from dense rain gauge networks, the dates of onset of the southwest monsoon over south and north Kerala have been derived by Ananthakrishnan and Soman (1988) on the basis of objective criteria for the years 1901 to 1980. These dates have been compared with the onset dates as per records of the India Meteorological Department. Statistics of the onset dates are presented. The mean daily rainfall series for south and north Kerala enable formulation of objective criteria for fixing monsoon onset dates in individual years. From the dates thus arrived at, the mean onset dates for south and north Kerala are found to be 30 May and I June respectively for the period 1901 - 1980 with a standard deviation of about 9 days (Table 2.6).

Table 2.6 : **Mean Onset Days of SW Monsoon for South and North Kerala (Ananthakrishnan and Soman, 1988)**

	1901 - 1940			1941 - 1980		
Item	S.K.	N.K.	IMD	S.K.	N.K.	IMD
Mean date	I June	3 June	4 June	28 May	30 May	31 May
Std. Dev. (days)	7.5	7.9	7.0	9.6	10.1	7.9
May onset (No. of years)	15	11	9	25	18	25
June onset (No. of years)	25	29	31	15	22	15

S.K. : South Kerala; N.K. North Kerala;

The mean onset date for 1901 - 1940 is later than for 1941 - 1980 by 4 days. Super-posed epoch analysis of the mean daily rainfall reveals a sharp and spectacular increase heralding the monsoon onset. The statement often made that the Pre-monsoon thunderstorm rain over Kerala progressively increases and merges with the monsoon rains resulting in a gradual transition is found not valid. It was also noticed that the spell which heralds the onset of the monsoon had a mean duration of about 15 days and the associated daily mean rainfall was 26mm.

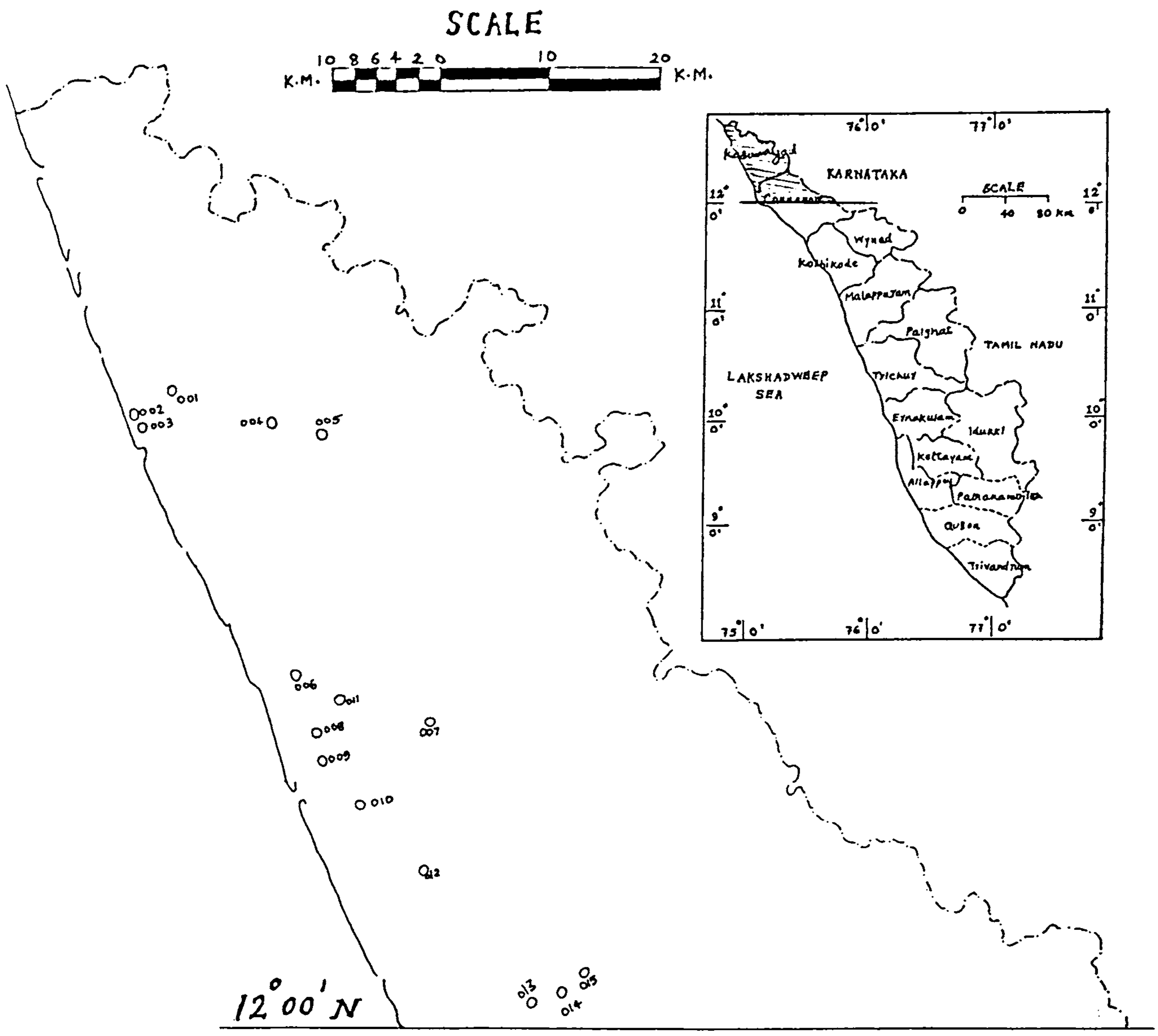
CHAPTER 3

RAINGAUGE STATIONS IN KERALA

3.1 GENERAL

Rainfall measurement is one of the most important meteorological observations and is of vital importance to agencies and departments involved in irrigation and drainage, hydropower generation, agriculture, forestry, public health and water supply, fisheries, etc. The accuracy requirements may vary from department to department and agency to agency. The accuracy requirements of developmental agencies may be much different from those of research organisations.

It has been reported that there are about 450 rainfall stations in Kerala (CWRDM 1983). The region-wise location of the rainfall stations are shown in Figs 3.1 to 3.5. These stations are maintained by India Meteorological Department and other Departments of Government of India, Kerala Revenue Department, Public Works Department, Kerala State Electricity Board, Departments of Agriculture and Forest, Kerala Agricultural University, Centre for Water Resources Development and Management (CWRDM) and other research organisations as well as a number of private agencies.



001 KASARAGOD SSF
002 KASARAGOD TO
003 KUDLU CPCRI
004 PADIATHADKA
005 PARAPPA
006 HOSDURG TO
007 KAKKADAVU
008 NILESWAR
009 NILESWAR CCRS
010 PILICODE
011 PULLUR SSF
012 PAYYANNUR
013 TALIPARAMBA ARS
014 TALIPARAMBA PRS
015 TALIPARAMBA TO

FIG. 3.1 RAINGAUGE STATIONS NORTH OF 12°00'N IN KERALA

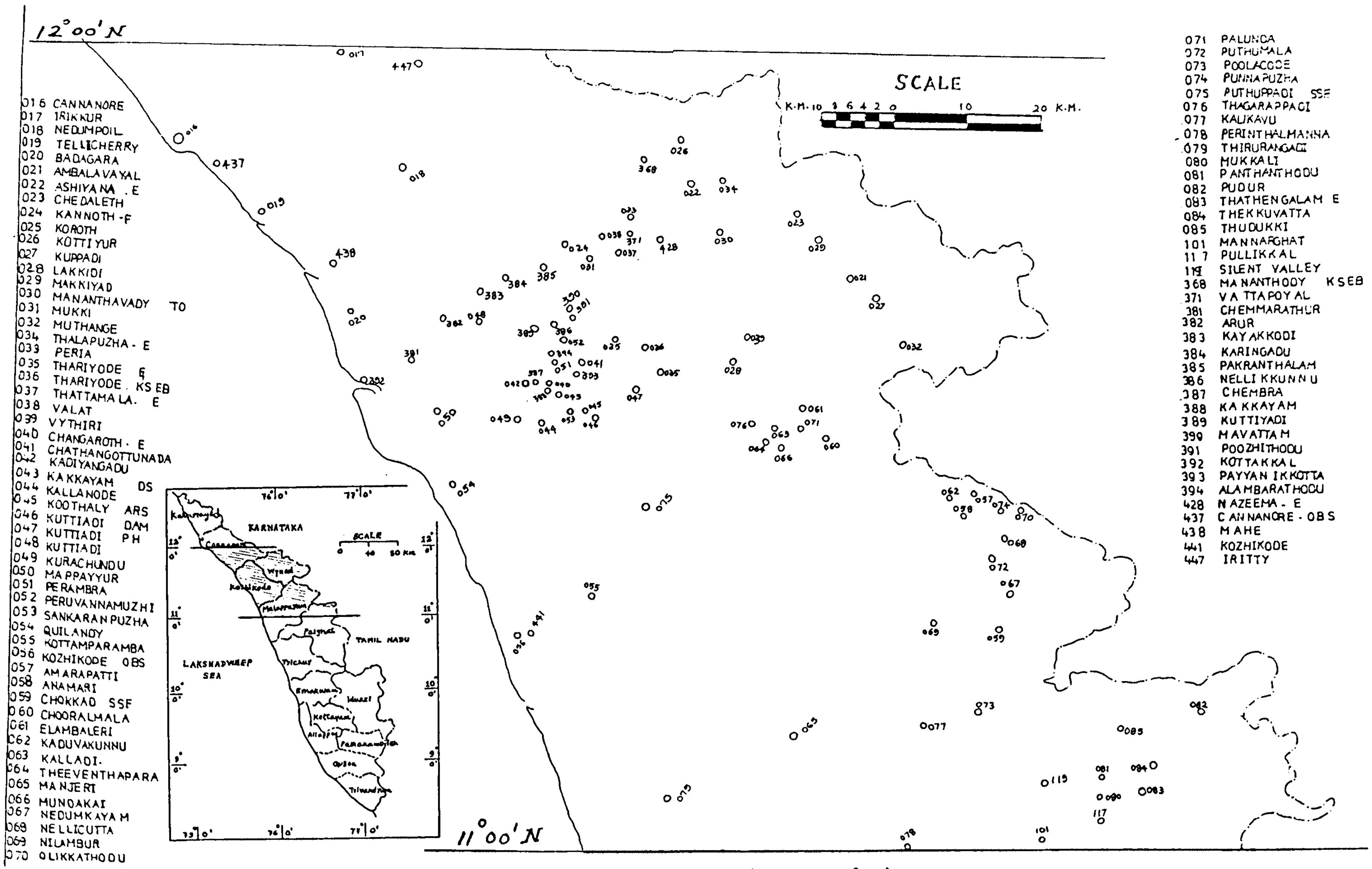


FIG.3.2 RAINGAUGE STATIONS IN BETWEEN 11°00'N AND 12°00'N IN KERALA

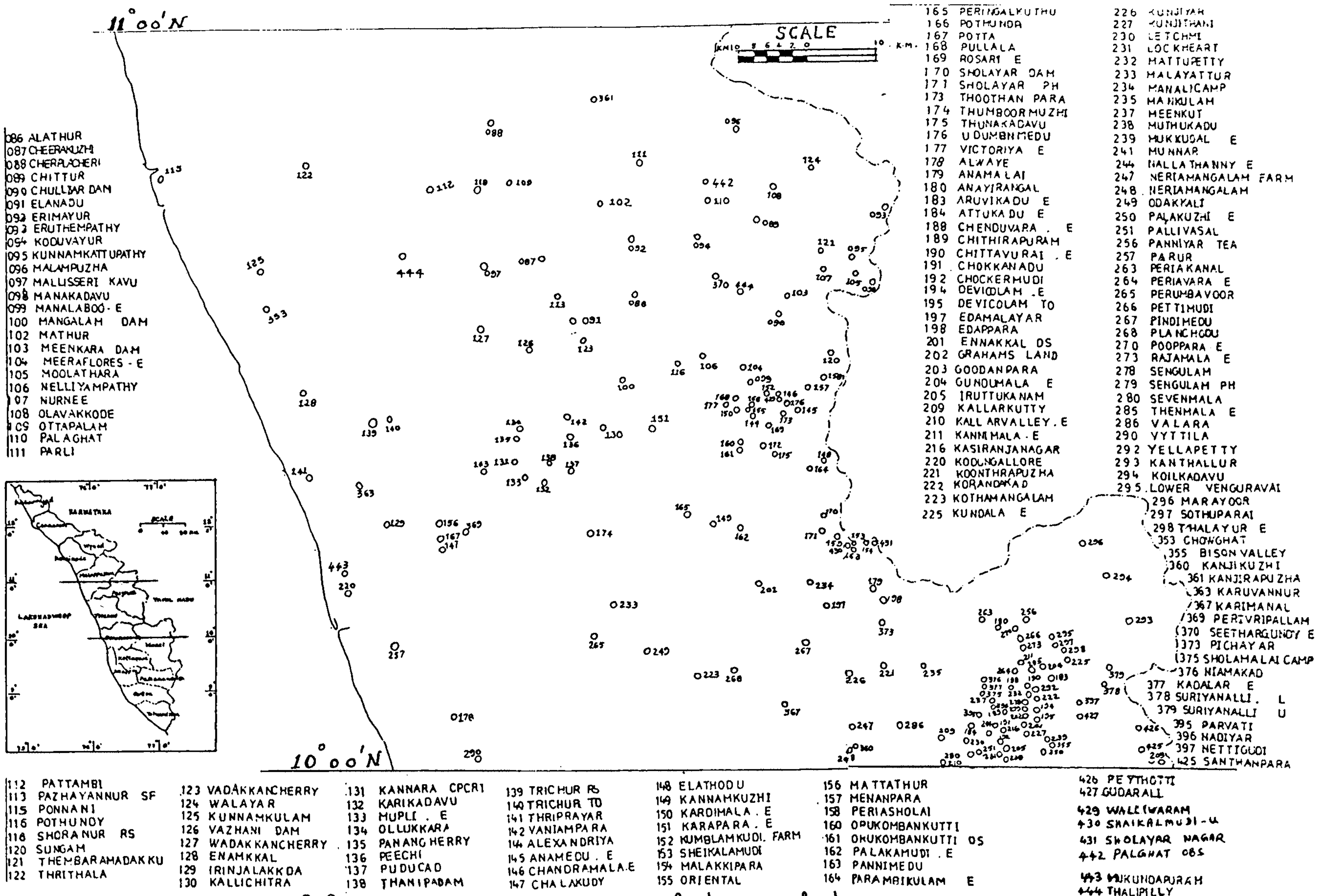
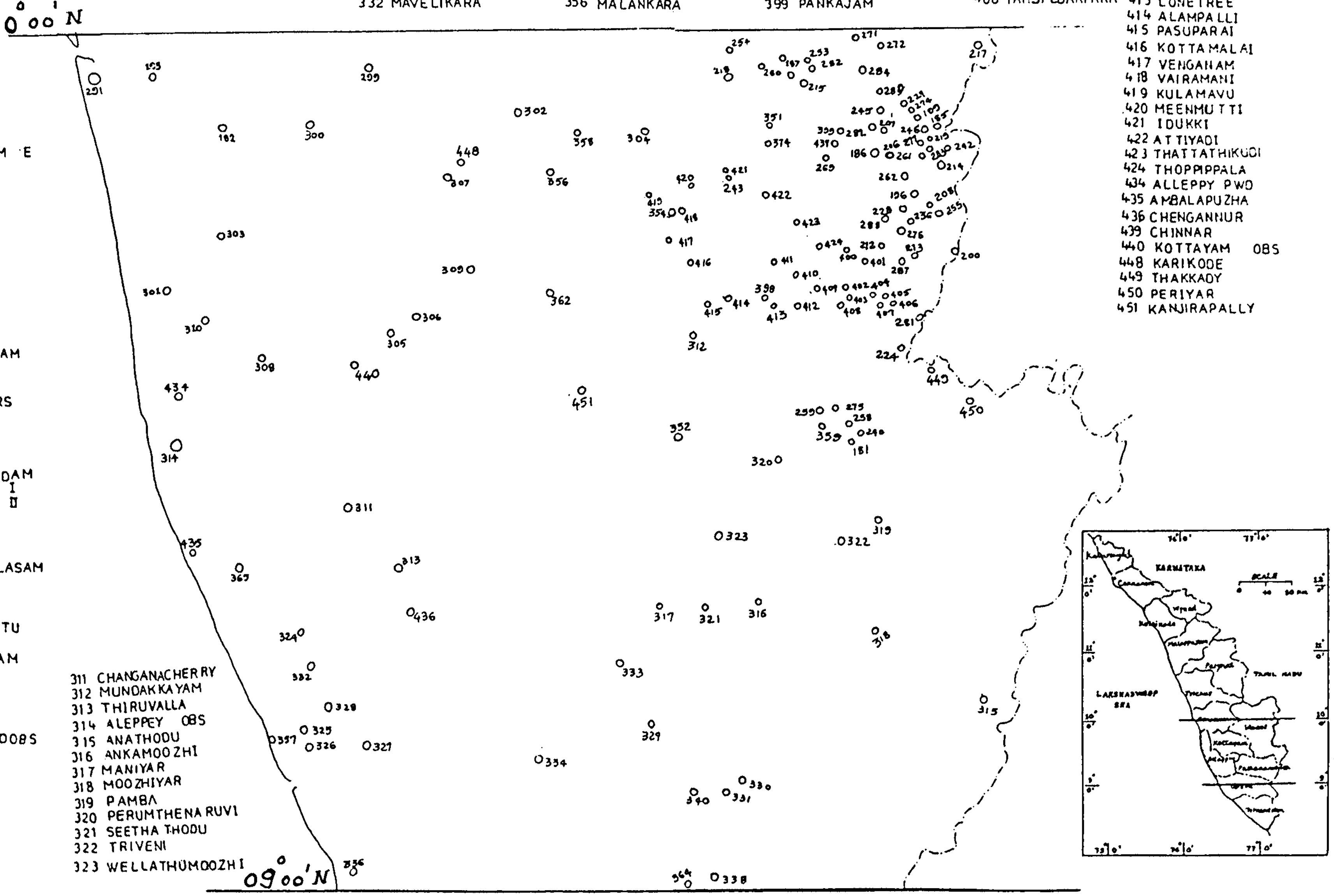


FIG. 3.3 RAINGAUGE STATIONS IN BETWEEN 10°00'N AND 11°00'N IN KERALA



181 ARNAKAL E
182 AROOKUTTY
185 CHATHURENGAPARA
186 CHAMPAKAPPARA
187 CHEMMANAR
193 COCHIN
196 EATTITHOPPU
199 ELAPPARA
200 ENAMKUTTY
206 KALARIKKAL
207 KALKOONTHAL
208 KALLAR CAMP SHED
212 KAMAKSHI E
213 KAMAKSHI VILASAM E
214 KAMBAMETTU
215 KARIMALA E
217 KATTOTHI
218 KEERITHODU
219 KILAVIKULAM
224 KUMILY
228 KUPPACHAMPADY
229 LAKSHMIVILASAM
235 MANNAKODY
240 MUNJAMULLAY
242 MUNTHIRAMEDU
243 MURUKADY E
245 NATARAJAVILASAM
246 NAVARIPPARA
252 PAMPADUMPARA E
253 PAMPADUMPARA RS
254 PANAMKUTTI
255 PANIKARKUDI
258 PEERMADU
259 PEERMADU TO
260 PERINJANKUTTY DAM
261 PERINJANKUTTY I
262 PERINJANKUTTY II
269 PONMUDI DAM
271 RAJAKAD
272 RAJAKUMARI E
274 RAMAKRISHNA VILASAM
275 RANICOIL
276 RETTAYAR
277 SHANTHARUVI
281 SHELLARCOILMETTU
282 SINGARAPARA
283 SRIKRISHNAVILASAM
284 SMJ GANDHIPARA
287 VANDANMETTU
288 VAZHAVARA
289 VENKAL PARA
291 WELLINGTON ISLANDOBS
299 MUVATTUPUZHA
300 PIRAVAM
301 SHERTALAI
302 THODUPUZHA
303 VAIKOM TB
304 VELLORE
305 KOTTAYAM BSR
306 KOTTAYAM RRI
307 KOZHA
308 KUMARAKAM
309 PALAI
310 THANNEERMUKKAM

311 CHANGANACHERRY
312 MUNDAKKAYAM
313 THIRUVALLA
314 ALEPPEY OBS
315 ANATHODU
316 ANKAMOOZHI
317 MANIYAR
318 MOOZHIYAR
319 PAMBA
320 PERUMTHENA RUVI
321 SEETHA THODU
322 TRIVENI
323 WELLATHUMOOZHI

324 HARIPADU
325 KAYAMKULAM CPCRI
326 KAYAMKULAM K
327 KAYAMKULAM RRI
328 KAYAMKULAM ST
329 KONNI DFO
330 KONNI E
331 KONNI SCRS
332 MAVELIKARA

333 PATHANAMTHITTA
334 ADOOR
336 KARUNAGAPPALLY
338 PUNALOOR
340 RAJAGIRI
351 MILADUMPARA
352 MUNDAKAYAM E
354 MAVADI
356 MALANKARA

357 KAYAMKULAM
358 MANIYARAMAKUDY
359 MT DN MUNJAMULAY
362 ERATTUPETTA
364 PUNALUR KIP
365 MANCOMP
374 UPPUTHODU
398 PULLIKKANAM
399 PANKAJAM

400 KATTAPPANA
401 NANDAGOPAKVILASAM
402 KANAVAKUZHI
403 CHATHANODAI
404 ELAVANAM
405 MANGLADEVI
406 CHITTAMPARA
407 KATTACHEURIAN
408 TAHSILDARPARA

409 MATTUKOTTA
410 AYYAPPANCOIL
411 MUTHANPADI
412 POOKULAM
413 LONETREE
414 ALAMPALLI
415 PASUPARAI
416 KOTTAMALAI
417 VENGANAM
418 VAIRAMANI
419 KULAMAVU
420 MEENMUTTI
421 IDUKKI
422 ATTIYADI
423 THATTATHIKUDI
424 THOPPIPPALA
434 ALLEPPY PWD
435 AMBALAPUZHA
436 CHENGANNUR
439 CHINNAR
440 KOTTAYAM OBS
448 KARIKODE
449 THAKKADY
450 PERIYAR
451 KANJIRAPALLY

FIG.3.4 RAINGAUGE STATIONS IN BETWEEN 09°00'N AND 10°00'N IN KERALA

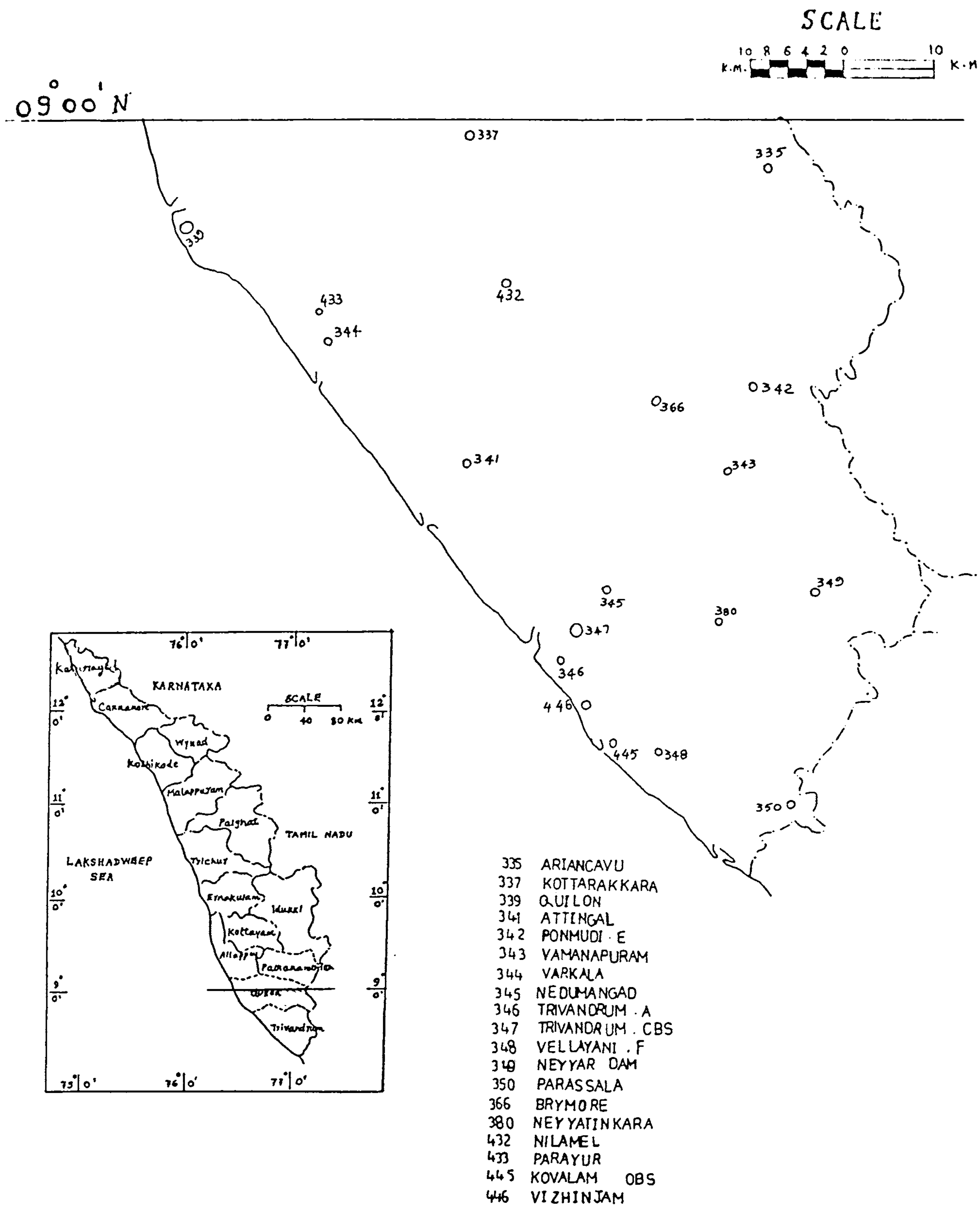


FIG. 3.5 RAINGAUGE STATIONS SOUTH OF 09°00' N IN KERALA

3.2 EVALUATION OF RAINFALL STATIONS

During 1984-85, the Centre for Water Resources Development and Management took up a project namely 'Evaluation of Rainfall Stations in Kerala State'. The main objective of the project was to collect the details of existing rainfall stations such as location, date of installation, authority, type of rainguage, observation details, exposure, foundation particulars, state of fencing, etc., and to suggest necessary modifications with regard to installation, maintenance, observation and recording of rainfall data. It is worth to mention some of the salient results of the project in this chapter.

As a part of the evaluation work, 330 non-recording rainfall stations distributed in the State were inspected. The inspected stations form about 83% of the total stations in the State identified at the time of the Project work. In connection with the work all the 330 stations mentioned above, have been visited.

3.3 SALIENT RESULTS

Out of the 330 non-recording rainfall stations inspected, 103 stations have been found to be good, 90 to be satisfactory, 91 to be unsatisfactory and 46 to be defunct or dismantled. Of the 181 stations, 134 gauges were to be replaced and the remaining 47 stations to be modified. Symons gauges were used in many stations which have to be replaced considering the recommendations of IMD (1981). Fig 3.6 illustrates the general condition of rainfall stations inspected and Fig 3.7 gives the information on raingauge stations maintained by different agencies and the general condition of the stations.

The major problems/defects encountered pertain to (i) measure glass, (ii) exposure/enclosure (iii) foundation, (iv) fence and (v) funnel/tube/receiver. In the case of some stations, the gauges were found to be not in accordance with the IMD standard specifications. In some stations proper records were not maintained; in some others time of observation did not tally with that of IMD specification. Many an observer require training in carrying out their duties. The major shortcomings of different rainfall stations inspected with regard to measuring glass, exposure/enclosure, funnel/tube/receiver, foundation and fence are furnished in Fig 3.8. Photographs of some of the good and bad stations of different agencies are shown in Figs 3.9 and 3.10.

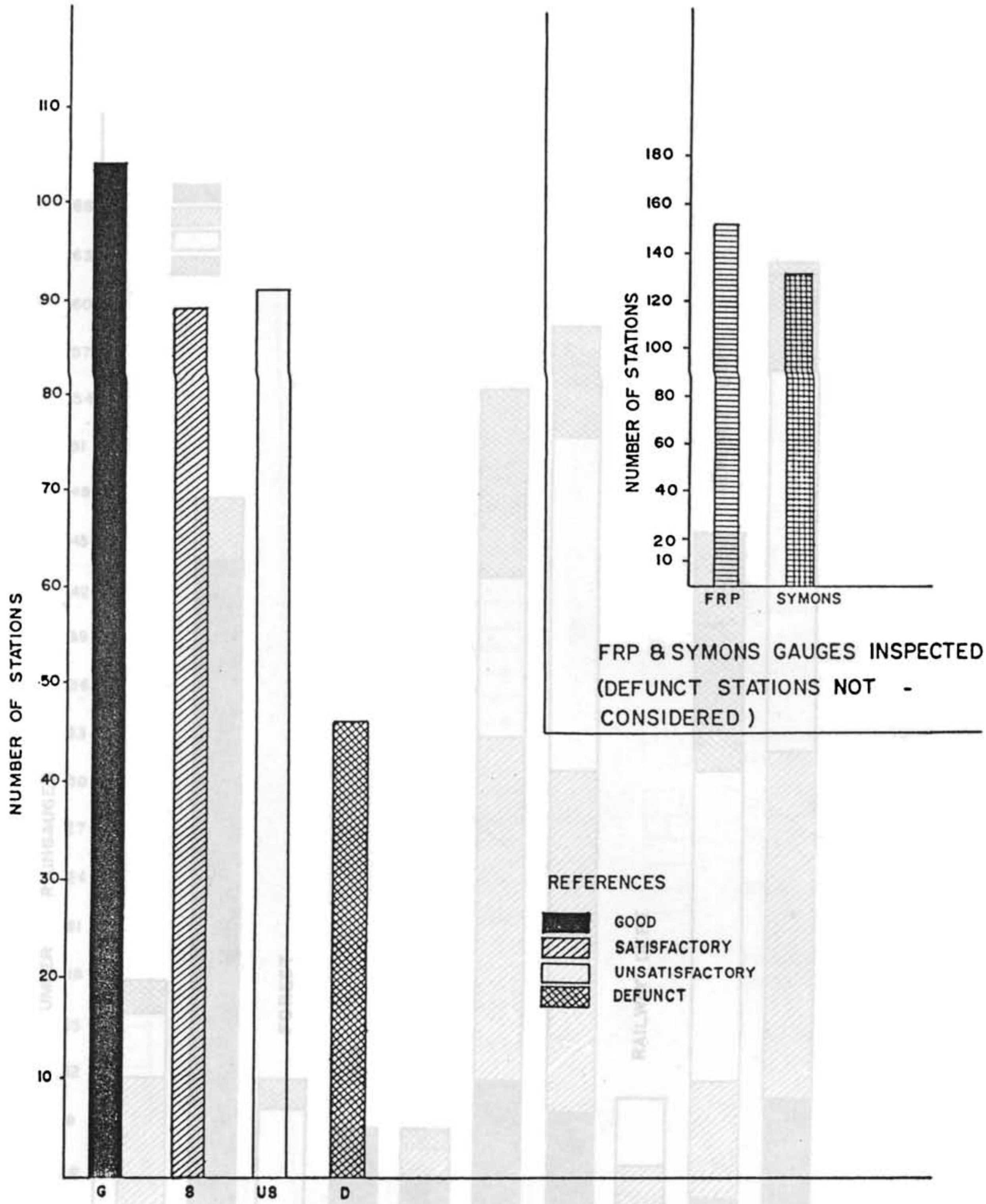


FIG 3.6 GENERAL CONDITION OF RAINFALL STATIONS INSPECTED

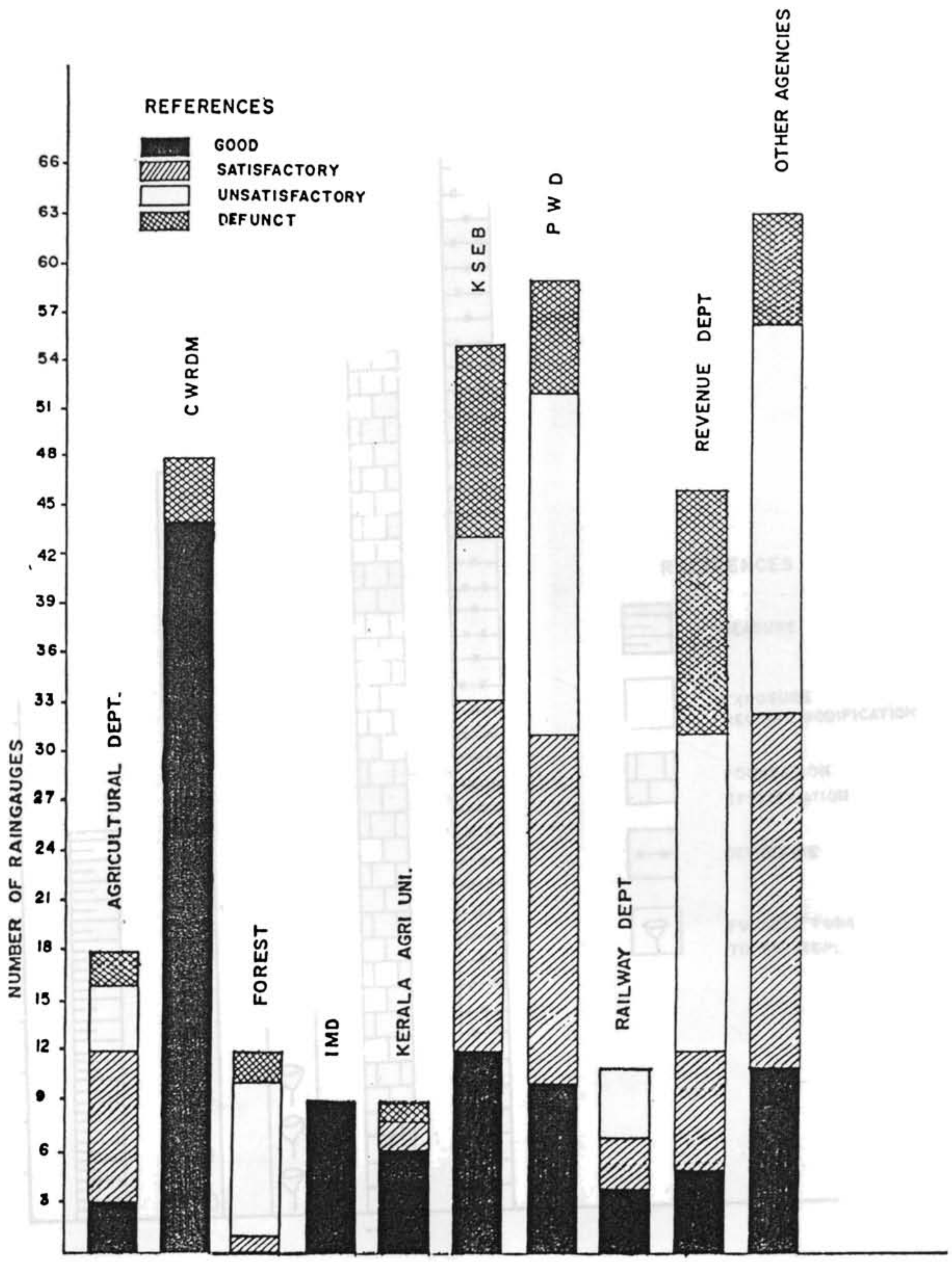


FIG 3.7 INSPECTED RAINGAUGES OF DIFFERENT AGENCIES WITH GENERAL CONDITIONS OF STATIONS

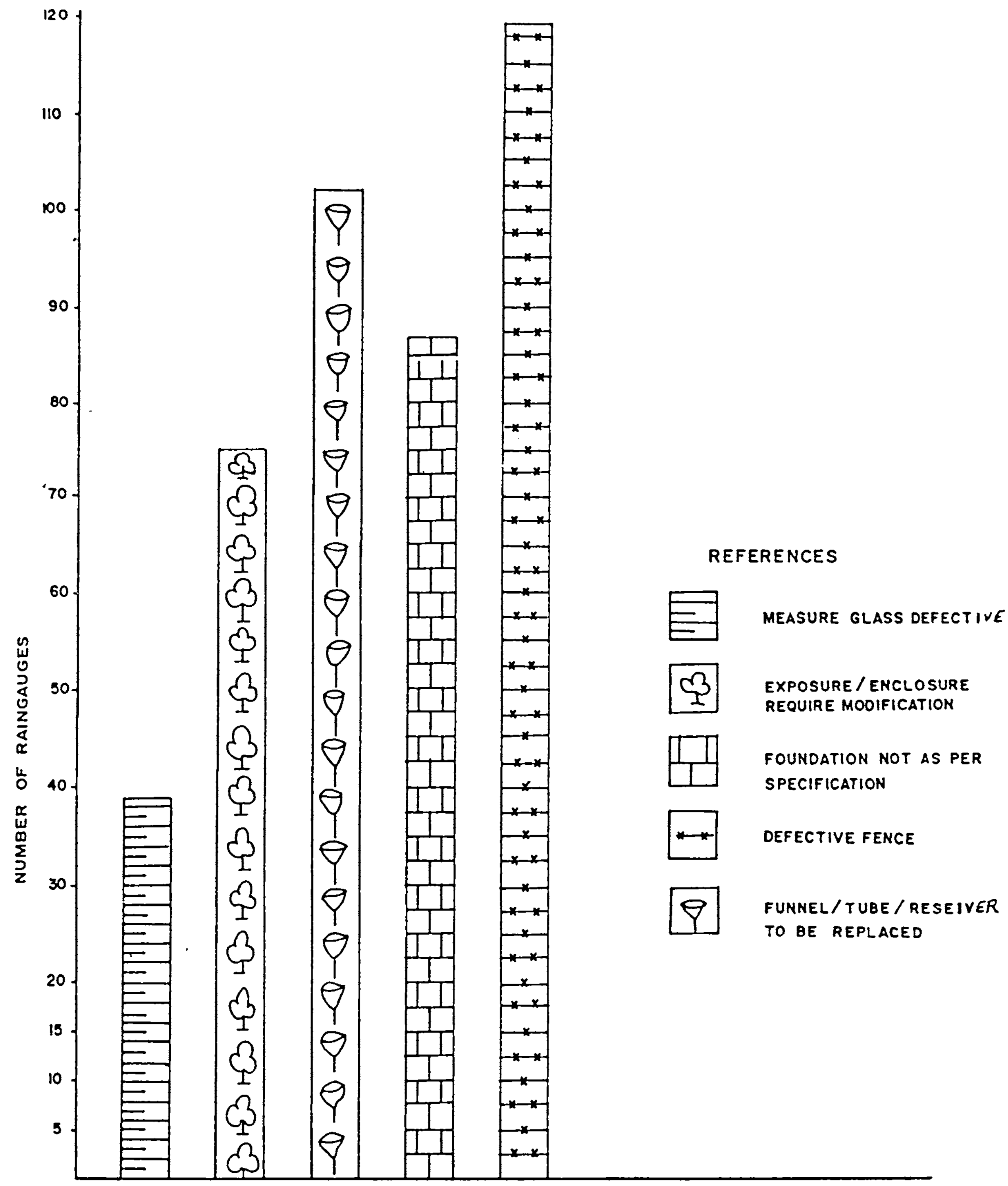


FIG 3.8 RAINFALL STATIONS (INSPECTED) - DETAILS REGARDING DIFFERENT SHORTCOMINGS

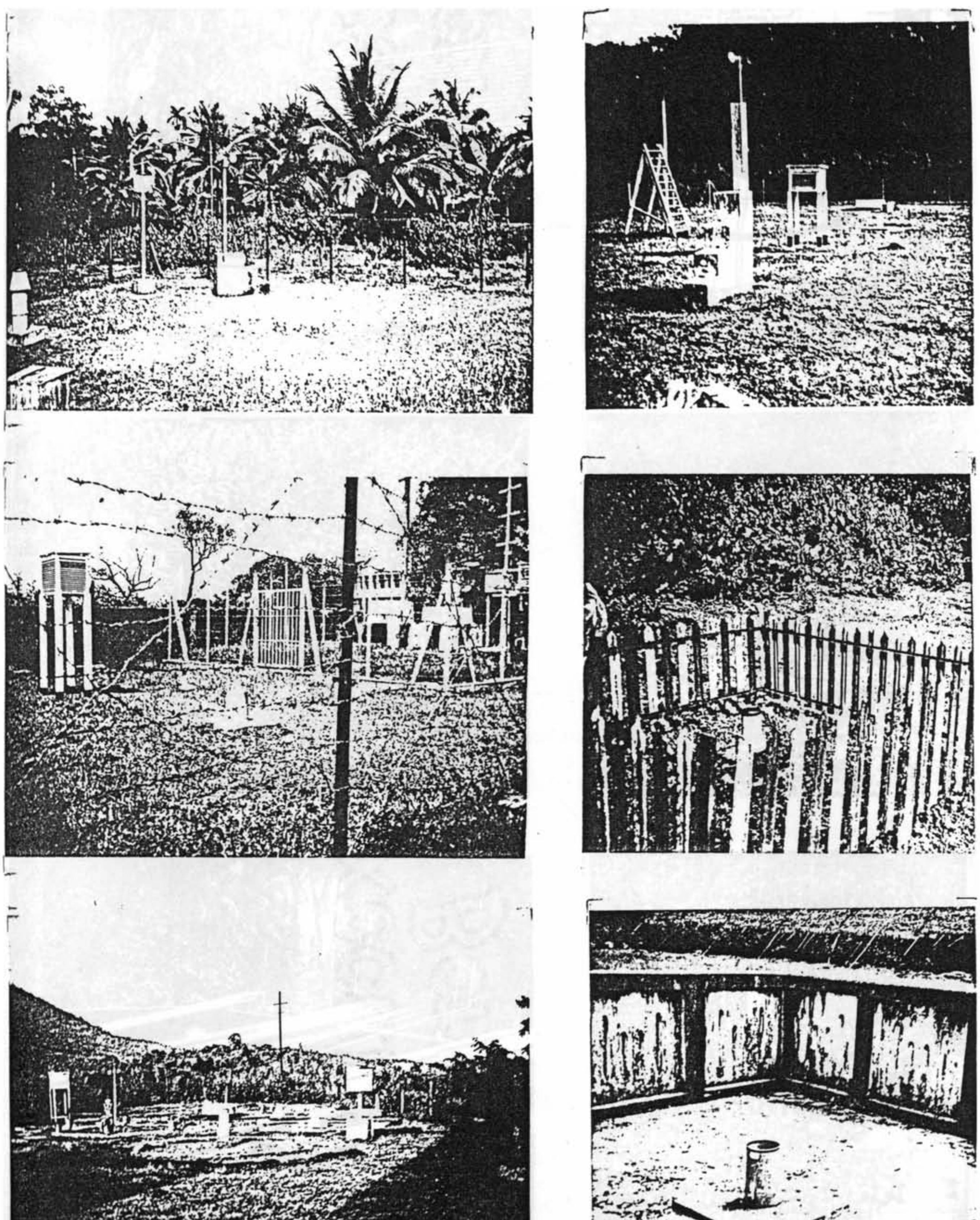


FIG.3,9 SOME OF THE GOOD STATIONS OF DIFFERENT AGENCIES

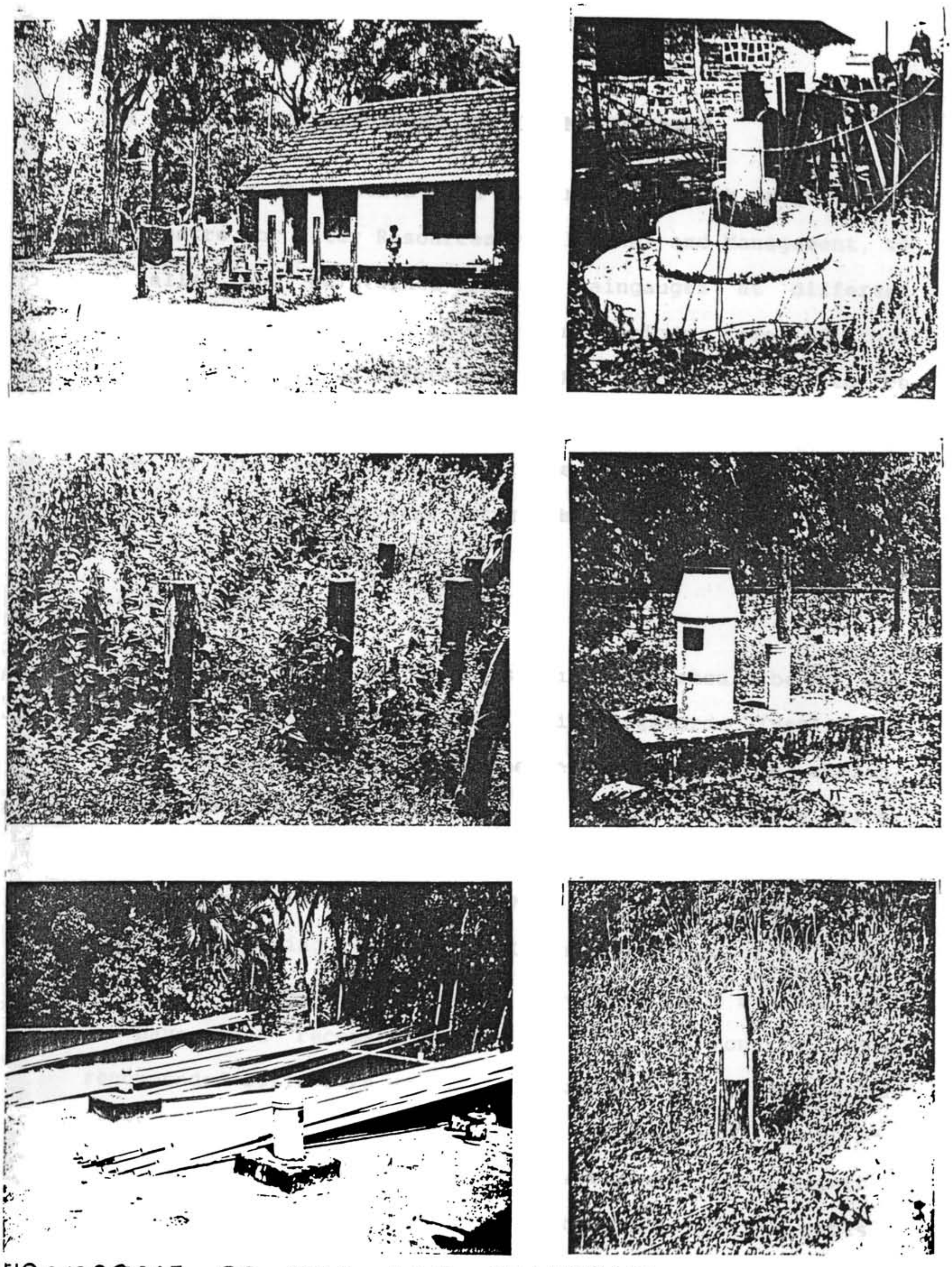


FIG.3.10 SOME OF THE BAD STATIONS OF DIFFERENT AGENCIES

3.4 INSTALLING RAINGAUGES AND ITS MAINTENANCE

In connection with different research projects of the Centre for Water Resources Development and Management, we installed and maintained about 50 raingauges at different places in the State during different periods, some of them are presently being maintained. The important points to be kept in mind while installing/maintaining a raingauge and some of the remarkable events experienced are briefly described in the following paragraphs.

3.4.1 Raingauges

The raingauge to be used in India should be as per the specifications given by the Indian Standards Institution (5225-1969). The capacity of the receiver should be chosen, keeping in view the heaviest rainfall that occurs in a 24-hr period in the surrounding region. Fibre-glass Reinforced Polystyrene (FRP) raingauges with a funnel area of 200 sq.cm and with measuring capacity of 100 mm and 200 mm or a funnel area of 100 sq.cm with measuring capacity of 400 mm and 1000 mm have been recommended for use in the country. The recommended collectors having mouth area of 100 sq.cm and 200 sq.cm will have rim diameters of 112.9 mm and 159.6 mm, respectively. The base and the collector are locked together by a set of two locking rings fixed firmly to the two parts.

3.4.2 Installation Site

The quantity of rain collected in a raingauge depends to some extend upon the exposure of the gauge, so the selection of the site is important. The site should be on level ground not on a slope or terrace and never on a wall or roof. A raingauge should on no account be placed so that the ground falls away steeply on the side facing the prevailing wind. The distance to the gauge from each and every object should be preferably four times the height of the nearest object but never less than twice the height of the object, above the rim of the gauge.

In Kerala, some times, the researchers/planners may find it difficult to get an open spot for installing a raingauge in the proposed study area. In that case, if the concerned party is interested in reliable and good data and giving importance to the data, some trees and bushes of poor quality have to be cut and removed from the spot. The trees and bushes so cut should be as minimum as possible. It should also be noted that the bushes and trees are not growing near the gauge after installing the same, since the soil and weather in most places in the State are suitable for fast growing of bushes and trees.

The location selected for installing a raingauge should be accessible to the observer of the gauge. Suppose the site selected is, say 5 km away from the residence/office of the observer, and there are no road connection to the site, the chances of the observer going by walk daily to the spot is meagre. He may go for one or two days to the spot for taking the measurements and guess for remaining days. Especially, during heavy rains of monsoon periods the difficulty of the observer to walk a long distance amidst the bushes will be more. If anybody desire to install a raingauge in an isolated place, for example in the middle of a forest, then all facilities should be provided to the observer for residing near the gauge and taking the observations daily or a long period automatic data collection system should be installed in such places.

While selecting the location, it should also be foreseen that the miscreants activities would be less if the raingauge is installed in the proposed site. To reduce the mischief of scoundrels, an awareness has to be created among the local people regarding the importance of data and its purpose. If the purpose and sincerity are convinced, some local broad-minded people will cooperate with the venture and these people may handle the local miscreants.

In connection with a research project, a raingauge was installed in a school compound. Later it was noticed that whenever there was students' strike or agitation, some of the students would come to the raingauge and shout slogans and throw stones to the gauge, as they knew the gauge is a government property. Some years back the mentality of a few ill bred students was to destroy government property when they were on strike or agitation. This sort of probable happenings also should be foreseen before installing a gauge.

3.4.3 Installation of the Gauge

The gauge should be fixed on a masonry or concrete foundation (60 cm x 60 cm x 60 cm) sunk into the ground. Into this foundation the base of the gauge is cemented so that the rim of the gauge is exactly 30 cm above the ground and perfectly in level. This is just high enough to prevent excessive in- splashing yet not high enough for the gauge itself to cause undue turbulence. If the height is more, rain water collected will be less owing to the probable wind eddies. The rim should be perfectly horizontal to ensure effective area of the collecting funnel in receiving rain water (WMO, 1983).

3.4.4 Protection of Gauge

In order to protect the raingauge from stray cattle and miscreants, it is desirable to have a fence around the gauge. It is advantageous, perhaps, to adopt barbed wire or similar suitable material. The fence suggested by IMD is 1.2 m high, the distance between the ground and the first strand, and the first strand and the second may vary between 18-20 cm; the other strands may be equally spaced. The height of the fence above the rim of the gauge should not be, in any case more than half the distance. The gate of the fence may be locked with a padlock for safety. Some times miscreants may tamper the gauge and steal away the contents of the gauge. In such instances the matter should be dealt very cleverly. Once the collecting Jar of the raingauge of a station was taken away by an unknown thief. When the missing was reported by the observer, the next day the matter was referred to the nearest Police station and along with some police personnels searched some of the nearby houses to trace out the missing jar and also warned the local people. That day it was not traced. But the next morning the jar was lying in the place where it was!

3.4.5 Measurement of Rainfall

The job of rainfall measurement may be given to the staff of the agency who has installed the raingauge or can be entrusted to a qualified local person on contract or job basis. The selection of the observer may be made such that he/she has got interest in data collection and research works. If the observer is selected on contract or job basis, prompt payment to the observer is essential so as to get sincere and reliable data from him/her. Sufficient training has to be given to the newly posted observer on data collection and its recording in the appropriate registers. Each station should be provided with an additional measuring glass. When the glass breaks and a spare is not available, the volume of rain water can be ascertained using a ml (cc) measuring jar. If such a provision is also not possible, the water should be carefully stored in closed bottles and labelled in order to enable measurement later. It should be clearly instructed to the observer that the rain water should not be measured using ordinary small ounze glass of medicines. If these sort of ounze glasses are used, then the chances of making mistakes while taking the measurements and calculating the values to m.m. or c.m. are more.

If the observer is asked to send the data by post daily, then a check at the receiving place is required to ensure that the data is sent in accordance with the date. Once an observer was given a set of post cards for one month, already putting the dates on the cards. By oversight the observer made a mistake of sending the data in the reverse order i.e., instead of Ist day of the month the observer recorded the data on the post card of the last day of the month and sent by post. By negligence the mistake was repeated for some more days. Since the mistake was noticed at the receiving point, immediate actions were taken to rectify the defects. Since the mistake was noticed in the same month itself, it was easy to rectify the same mistake; otherwise the data of the whole month would have been recorded wrongly.

3.4.6 Inspection of the Raingauge Station

After installing the rainguage, frequent inspections of the site are required by the concerned officers for noting down the defects of the gauge or surroundings, if any. This is necessary to ensure that observers are in station and they are taking the readings regularly as instructed. Lightning visits without prior intimation to the observer are also essential to examine the sincerity of the observer.

G5673

CHAPTER 4

EFFECTS OF MOUNTAIN BARRIERS ON RAINFALL OVER KERALA

4.1 GENERAL

Every year Kerala receives a good rainfall, having a mean annual value of nearly 3500 mm. The geographical condition, i.e., the hills and mountains of the Western Ghats at the eastern boundary, which have an average elevation of 1 km, provide orographic lifting of the moisture laden southwest monsoon current resulting in heavy precipitation over the western slopes of the Ghats as well as the midlands and lowlands of the State. About 73% of the total annual rainfall receives in the southwest monsoon period, locally known as 'Edavapathi Mazha'. The rainfall during the northeast monsoon season, 'Thulavarsha Kalam' and the hot weather period also contribute to the annual rainfall distribution over Kerala and adjoining areas to the north and east.

Floods and landslides are a common occurrence during the rainy seasons in Kerala. Heavy rains during southwest monsoon period (June-Sept.) and northeast monsoon period (Oct.-Nov.) result in increased risk of high floods. Rivers in Kerala are generally narrow and short, which flow down from the Western Ghats through steep gorges and are, therefore highly susceptible to flash floods which cause immense damage to the embankments, crops and cattle. Landslides give rise to blockages, snapping of communications and damage to the property.

4.2 ANNUAL RAINFALL

To get a clear resolution of the influence of orography on rainfall distribution, the entire Kerala region is divided into three regions, viz., northern Kerala (above 11° N), central Kerala (between 9° 30'N and 11° N) and southern Kerala (below 9° 30' N). Annual normal isohytes have been drawn on the relief map of northern, central and southern region of Kerala which are given in Figs. 4.1, 4.2 and 4.3, respectively.

From Fig 4.1, it is evident that there is a pocket of heavy rainfall lies in between 11° 30' - 11° 45' N Lat. and 75° 35' - 76° 05' E Long. mostly in Kozhikode and Cannanore Districts. In Table 4.1 the average/normal rainfall and number of rainy days at different stations of Kerala are given. In northern Kerala, the coastal stations are of the order of 3500 mm, while some of the mid-land stations exceed 4500 mm in a year. For example, the values of Kasaragod, Cannanore and Kozhikode are 3478 mm, 3274 mm and 3178 mm, respectively. The average annual rainfall of Vythiri, Karingad, Mavattom, Kuttiadi are 4435 mm, 4918 mm, 6073 mm, 4504 mm, respectively. From Fig. 4.1 it is clear that the maximum rainfall is not at the peak of mountain ranges but at the western slopes, much away from the peak. Orography plays an important role in the distribution of rainfall, as the

Table: 4.1 Average/Normal rainfall and rainy days at different stations

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Kasaragod	1231	7459	85	50	5.3	3.3	14.7	49.3	186.7	992.6	1042.2	598.2	253.7	205.5	99.6	26.7	3477.8
					0.3	0.2	0.6	2.5	7.2	24.9	27.3	23.9	14.9	9.8	4.6	1.1	117.3
Parappa	1229	7506	175	8	0.0	0.5	6.5	40.8	203.6	999.9	1152.4	664.5	256.4	184.6	113.1	24.2	3647.5
					0.0	0.1	0.3	3.1	7.6	25.8	28.0	24.6	15.1	7.4	4.8	1.2	119.8
Kakkadave	1215	7514	125	6	0.0	0.0	11.9	54.8	174.5	896.4	1108.3	588.6	365.2	167.5	116.1	16.0	3499.3
					0.0	0.0	0.4	2.6	6.9	23.2	27.9	22.4	16.8	8.2	5.0	1.3	114.7
Hosdurg	1218	7506	55	50	5.6	4.8	6.9	49.3	222.8	1024.1	1070.4	606.3	254.8	198.1	94.5	24.6	3562.2
					0.4	0.3	0.4	2.5	7.6	25.0	27.8	23.6	13.9	9.4	4.7	1.2	116.8
Nileswar	1214	7508	23	17	1.6	0.2	4.4	24.5	188.2	884.9	1097.6	742.8	278.2	188.4	102.9	16.9	3530.6
					0.1	0.1	0.3	2.2	6.3	23.8	25.7	22.4	14.6	9.3	5.2	0.7	110.7
Pilicode	1213	7510	85	17	0.0	1.5	14.2	32.5	215.1	946.2	1234.6	852.8	290.3	153.5	135.3	15.4	3891.4
					0.0	0.1	0.6	2.3	7.9	25.1	26.8	23.8	15.4	8.2	5.1	1.1	116.4
Payyannur	1206	7512	120	50	3.6	5.1	6.9	44.7	210.1	1016.5	1057.7	592.6	236.7	211.3	103.1	24.9	3513.2
					0.3	0.2	0.4	2.9	7.5	25.0	27.5	22.9	13.8	10.4	5.1	1.3	117.3
Taliparamba	1203	7521	110	50	4.6	3.1	6.9	51.1	186.2	976.1	1119.4	592.8	241.1	236.7	115.8	25.4	3559.2
					0.3	0.2	0.5	3.0	7.6	24.8	28.1	23.2	13.9	11.2	5.5	1.3	119.6
Irikkur	1158	7533	156	50	5.1	4.3	13.2	71.4	211.1	968.5	1237.0	724.9	286.5	288.3	143.8	24.1	3978.2
					0.5	0.3	0.8	3.9	8.6	24.8	28.1	24.6	15.4	13.5	6.8	1.6	128.9
Cannanore	1152	7522	18	50	3.8	5.3	8.9	49.3	212.6	924.1	989.1	509.3	228.6	216.1	109.5	17.8	3274.4
					0.3	0.2	0.6	3.0	8.2	24.4	27.0	21.3	13.2	10.3	5.2	1.0	114.7

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Tellicherry	1145	7530	100	50	6.9	5.3	9.9	66.8	235.2	916.4	980.4	509.8	221.0	221.7	106.7	23.4	3303.5
					0.6	0.3	0.7	3.2	8.8	24.1	26.9	21.1	12.7	10.2	5.6	1.3	115.5
Ambalavayal	1143	7613	974	15	3.4	4.7	11.8	79.3	142.5	601.3	1002.4	563.3	213.8	173.4	94.1	27.3	2917.3
					0.3	0.3	1.2	5.7	8.4	21.7	26.4	23.2	15.1	11.6	6.8	1.9	122.6
Badagara	1136	7535	45	50	7.6	6.3	15.0	77.7	261.6	955.0	1002.3	523.7	231.4	258.6	143.0	23.9	3506.1
					0.6	0.3	1.0	4.5	9.6	24.6	27.1	20.8	13.0	11.2	6.6	1.7	121.0
Chedaleth	1147	7608	800	42	4.5	6.8	19.3	82.1	128.7	629.4	1101.7	531.0	198.5	165.7	100.7	22.4	2990.8
					0.4	0.4	1.4	6.0	8.1	21.4	26.8	22.8	15.6	11.4	5.9	1.3	121.5
Mananthody	1148	7601	900	50	7.1	7.4	22.1	86.9	139.9	565.4	1011.9	544.1	192.8	166.1	75.2	15.5	2834.4
					0.5	0.5	1.7	6.5	8.2	21.2	27.2	23.0	14.3	11.2	5.4	1.2	120.9
Vythiri	1133	7602	945	50	9.9	9.4	24.6	105.4	195.1	1023.6	1499.4	778.5	322.6	297.9	137.7	31.0	4435.1
					0.8	0.7	2.3	8.2	10.3	24.1	27.9	24.0	16.8	14.4	8.0	2.3	139.8
Kadiyangad	1136	7546	28	9	13.9	3.6	18.3	61.9	121.1	988.3	707.6	703.2	346.8	261.9	118.2	32.8	3377.6
					0.4	0.3	1.3	6.2	9.4	24.8	27.1	24.2	15.8	13.4	7.1	2.2	132.2
Karingad	1143	7547	605	8	22.2	5.8	30.4	48.3	197.7	1270.3	1090.6	1075.4	448.0	490.8	165.8	72.9	4918.2
					0.5	0.4	1.1	5.8	9.8	24.6	27.4	24.2	14.8	12.6	6.8	3.4	131.4
Navattom	1140	7552	375	8	43.2	24.0	73.4	128.6	177.7	1564.1	1383.9	1330.3	580.2	428.4	254.1	85.3	6073.2
					0.6	0.5	1.2	6.1	10.2	25.7	27.8	24.0	15.3	13.4	7.3	3.9	136.0
Kottakkal	1133	7536	10	7	7.8	10.0	20.1	43.9	109.1	779.0	673.2	524.3	191.8	150.9	133.8	24.1	2632.0
					0.6	0.4	1.3	6.0	9.4	23.4	25.5	23.3	13.8	12.4	7.1	2.3	125.5

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Quilandy	1127	7542	58	50	8.9	4.1	16.0	69.3	257.3	892.3	949.7	512.6	224.0	256.8	138.7	27.2	3356.9
					0.6	0.3	0.9	3.9	9.3	24.7	26.4	21.0	12.4	10.9	6.6	1.7	118.7
Kozhikode	1115	7547	6	50	11.7	8.4	18.5	86.9	261.6	824.2	857.3	439.7	220.0	262.6	156.7	30.5	3178.1
					0.7	0.3	0.8	4.0	9.0	24.2	26.6	19.7	12.3	11.0	6.8	1.6	117.0
Kuttiadi	1140	7545	20	50	13.7	9.9	25.9	122.7	295.1	1027.4	1278.1	741.7	313.9	374.9	242.6	58.4	4504.3
					1.0	0.5	1.6	6.8	11.4	25.0	28.0	24.5	15.4	15.5	9.3	2.8	141.8
Manjeri	1107	7608	106	50	8.1	4.3	20.1	75.9	197.9	711.2	832.9	424.9	201.7	308.1	170.2	30.5	2985.8
					0.5	0.3	1.1	4.5	8.2	22.9	25.8	19.4	11.7	13.3	7.4	1.6	116.7
Nilambur	1117	7614	88	50	6.6	5.8	13.2	62.0	157.5	636.5	861.6	433.1	191.3	280.9	133.1	28.5	2810.1
					0.5	0.4	1.1	4.3	7.6	21.8	26.1	19.8	12.6	12.9	7.4	1.8	116.3
Thudikki	1109	7632	280	13	16.7	4.9	18.3	53.6	136.4	431.4	518.7	324.8	119.5	261.6	211.8	29.7	2127.4
					0.5	0.4	1.3	4.1	6.5	21.4	24.3	18.7	12.0	13.1	7.3	1.8	111.4
Thirur	1103	7555	84	50	5.3	6.1	14.2	72.1	242.1	760.7	765.5	390.1	208.5	253.2	159.0	37.3	2914.2
					0.5	0.4	1.1	4.0	9.0	24.2	25.6	19.4	12.6	11.8	7.4	1.8	117.8
Perinthal-manna	1058	7614	192	50	6.3	8.6	24.9	86.9	191.0	650.7	759.2	393.9	189.5	320.8	172.0	30.2	2834.0
					0.4	0.5	1.7	5.2	8.0	22.7	25.7	18.9	11.5	14.0	7.7	1.7	118.0
Alathur	1038	7633	65	45	12.5	9.1	29.2	79.0	148.3	473.5	616.7	373.6	148.3	206.8	129.8	27.4	2254.2
					0.5	0.5	1.8	4.6	7.1	20.3	24.2	17.8	9.8	10.9	6.4	1.4	105.3
Cherpla-sseri	1052	7619	35	50	7.1	9.1	28.7	97.8	179.6	607.3	709.4	377.7	180.6	297.9	156.7	28.2	2680.1
					0.4	0.4	1.6	4.9	7.7	21.9	25.3	18.5	10.8	13.7	7.3	1.3	113.8

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Chittur	1042	7644	300	50	10.7	9.4	22.1	61.0	106.2	337.8	498.3	272.0	131.3	182.9	127.3	35.1	1794.1
					0.5	0.5	0.8	3.0	4.6	17.6	22.5	15.9	9.7	9.6	6.2	1.6	92.5
Mannarghat	1059	7628	120	50	8.9	9.4	33.0	97.8	190.7	590.3	757.9	412.2	233.2	346.2	181.4	29.0	2890.0
					0.6	0.4	2.1	6.3	8.9	22.2	24.9	19.1	12.0	15.1	8.3	1.9	121.8
Ottapalam	1047	7623	34	50	8.9	9.9	26.7	85.6	177.6	585.7	686.6	399.0	170.9	267.7	148.6	29.5	2596.6
					0.5	0.6	1.5	4.6	7.7	22.0	25.3	18.6	11.7	12.7	7.0	1.5	113.7
Palakkad	1047	7639	95	50	10.9	10.9	23.1	60.2	132.3	428.5	605.3	333.8	154.7	209.5	115.8	30.2	2115.2
					0.4	0.6	1.3	3.5	5.9	19.6	24.1	17.4	10.9	11.6	6.2	1.5	103.0
Pattambi	1047	7617	25	29	8.2	8.9	25.8	92.6	181.5	596.2	702.4	389.1	174.6	279.8	152.3	28.7	2640.1
					0.5	0.6	1.6	4.4	7.6	22.3	25.7	19.0	12.1	12.5	7.1	1.6	115.0
Ponnani	1047	7555	20	50	7.4	7.6	24.1	96.5	266.5	753.1	715.8	383.0	202.9	286.8	184.9	28.2	2956.8
					0.5	0.5	1.3	5.0	10.6	24.3	25.0	18.5	11.8	12.6	7.6	1.7	119.4
Ollukkara	1032	7616	73	28	11.7	9.9	29.4	84.6	278.7	674.6	793.5	424.9	205.6	295.4	169.5	28.7	3005.5
					0.5	0.5	1.6	6.4	9.8	24.8	25.5	19.6	14.0	12.7	7.4	1.4	124.2
Trichur	1031	7613	102	50	6.6	5.8	24.4	76.2	238.3	791.7	751.8	450.9	257.1	311.9	155.5	26.2	3096.4
					0.4	0.5	1.4	4.4	10.0	24.5	26.4	19.9	13.6	13.1	7.1	1.4	122.7
Chavakkad	1034	7603	26	50	9.7	8.6	27.7	105.4	299.2	784.6	731.5	408.9	240.8	297.7	187.5	33.5	3135.1
					0.4	0.6	1.4	5.2	11.3	24.9	25.1	18.9	12.3	12.5	7.4	1.4	121.4
Mukunda-puram	1015	7610	39	44	11.4	10.4	33.0	90.4	302.0	849.4	761.0	451.1	257.3	336.8	164.6	29.0	3296.4
					0.5	0.6	1.7	4.4	11.2	25.0	25.3	20.3	13.6	13.3	7.7	1.5	125.1

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Kodungallur	1013	7612	55	50	7.9	11.4	35.1	100.3	313.7	816.6	712.2	446.3	264.9	306.3	171.7	38.1	3224.5
					0.5	0.7	2.0	5.4	12.4	25.0	25.2	20.8	14.6	13.4	8.7	2.1	130.8
Aluva	1007	7621	10	50	12.7	12.5	29.0	97.3	281.7	794.5	730.5	473.4	287.3	280.9	188.0	40.6	3228.5
					0.7	0.8	2.1	6.0	10.4	25.6	25.5	21.9	14.8	13.6	8.9	2.4	132.7
Fort Cochin	0958	7614	3	50	23.4	25.4	52.3	113.5	301.7	731.3	614.2	379.7	244.1	326.1	186.9	48.0	3046.6
					1.1	1.4	3.0	6.3	12.4	24.9	24.5	19.3	14.2	13.8	8.8	2.6	132.3
Ernakulam	0959	7617	10	50	14.2	20.3	40.4	107.2	282.5	744.7	633.2	413.8	267.2	335.3	153.9	49.0	3061.7
					1.0	1.1	2.6	6.5	11.7	25.1	24.6	20.7	14.2	14.4	9.0	2.7	133.6
Karikode	0950	7640	160	50	27.9	31.5	76.7	188.5	323.1	760.0	791.5	567.7	317.7	413.5	250.9	57.4	3806.4
					1.4	1.5	4.9	10.9	15.2	25.6	27.2	24.0	16.5	18.0	11.6	3.2	160.0
Parur	1009	7613	45	50	9.7	10.4	22.1	72.1	244.9	672.3	626.6	376.9	229.1	251.2	151.6	32.0	2698.9
					0.4	0.6	1.3	3.9	9.4	23.4	23.0	17.5	12.2	11.3	7.4	1.5	111.9
Perumbavur	1007	7629	48	50	14.7	14.2	41.7	130.8	272.8	772.4	794.5	524.0	298.7	351.3	216.1	47.2	3478.4
					0.7	0.8	2.7	7.1	10.9	25.4	26.3	22.6	15.5	14.8	9.5	2.8	139.1
Neriaman-galam	1003	7647	45	44	15.8	34.2	96.8	168.3	359.7	902.5	993.1	764.6	343.9	477.8	348.1	70.7	4575.5
					1.0	1.3	2.9	9.3	14.7	25.8	27.1	23.9	16.7	12.5	11.4	3.6	150.2
Muvattu-puzha	0958	7635	40	50	18.0	16.0	50.5	141.0	285.5	716.8	755.7	533.7	297.2	353.1	229.1	60.5	3457.1
					1.0	1.0	3.2	8.5	12.3	24.0	26.3	22.4	15.9	16.5	11.0	3.4	145.5
Marayur	1006	7709	870	50	54.6	8.9	22.3	70.6	95.5	135.1	185.4	128.8	106.4	221.5	219.5	100.3	1348.9
					3.1	1.0	1.5	5.1	7.0	9.8	12.4	10.1	8.3	12.9	12.3	6.1	89.6

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Munnar	1006	7704	1150	50	18.5	21.6	36.8	121.7	239.3	782.1	1122.7	705.1	341.4	248.9	137.4	40.4	3815.9
					1.5	1.8	2.9	9.4	12.6	24.7	27.4	24.4	17.5	15.3	9.7	3.4	150.6
Devikulam	1004	7706	1650	50	20.3	23.9	48.3	124.5	211.8	528.6	712.2	441.2	281.9	303.3	170.2	51.3	2917.5
					1.8	2.0	3.9	9.5	12.3	23.4	25.6	21.2	17.4	17.7	11.4	4.0	150.2
Vandanmettu	0943	7708	900	50	22.3	18.2	45.7	120.8	198.4	426.7	529.3	317.9	187.4	237.5	148.1	47.9	2300.2
					1.6	1.4	2.7	7.7	9.3	21.8	23.4	18.7	16.2	15.4	11.1	4.1	133.4
Vaikom	0945	7624	2	50	22.9	23.1	49.3	91.4	287.5	723.4	634.0	409.7	268.5	308.6	193.8	47.0	3059.2
					1.4	1.2	2.7	5.7	11.5	23.8	23.3	18.9	14.3	13.5	9.3	2.8	128.4
Palai	0936	7645	274	50	34.3	38.3	123.2	253.7	347.7	729.2	739.1	508.5	325.1	444.0	340.9	101.3	3985.3
					1.6	1.9	6.4	12.3	14.1	25.0	25.5	22.0	15.8	17.3	13.0	4.8	159.7
Ettumanur	0940	7634	823	50	26.7	14.2	60.5	145.0	280.9	694.7	690.5	437.6	273.8	293.4	185.2	60.5	3123.0
					1.4	1.0	3.6	8.2	11.4	24.3	24.4	20.8	13.9	14.5	9.8	3.1	136.4
Kumily	0935	7710	1100	43	51.6	25.7	37.6	92.5	111.3	280.7	333.0	175.3	116.8	212.3	190.7	93.2	1720.7
					2.6	1.4	2.3	6.0	5.9	16.5	18.8	12.7	8.8	12.8	10.3	4.7	102.8
Kottayam	0935	7632	30	50	30.2	26.4	55.4	134.1	303.0	717.8	642.1	419.6	299.7	357.9	200.9	74.4	3261.5
					1.6	1.5	3.3	8.0	11.7	24.0	24.2	20.4	14.1	14.9	9.8	3.4	136.9
Pirmed	0934	7659	950	43	19.3	43.2	58.9	130.3	300.0	996.9	1072.6	656.1	434.3	462.3	233.7	63.7	4471.3
					1.2	1.9	4.0	8.1	12.1	25.8	26.7	23.5	17.8	17.6	11.1	3.1	152.9
Kanjirapally	0934	7647	400	46	33.0	55.6	160.3	279.7	404.6	731.3	715.3	523.5	326.1	515.6	326.9	84.6	4156.5
					1.9	2.4	7.5	13.8	15.2	24.4	24.4	22.1	15.1	18.1	13.2	4.3	162.4

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Santhanpara	0958	7713	1097	43	43.2	38.1	54.9	118.6	131.6	256.3	279.4	173.2	128.0	334.0	224.0	79.8	1861.1
					2.4	2.8	3.5	7.7	8.0	16.1	17.4	12.1	9.2	16.4	11.8	5.3	112.7
Allappuzha	0933	7625	2	35	28.7	52.6	64.9	139.2	292.6	694.3	612.5	392.1	275.5	300.4	258.7	64.6	3176.1
					1.8	2.6	3.8	6.5	11.3	23.6	23.9	19.0	14.8	15.2	12.0	4.1	138.6
Arukutty	0952	7620	35	46	26.7	18.3	40.4	135.1	311.7	760.2	657.3	421.1	278.1	333.0	188.5	52.3	3222.7
					1.2	1.4	2.8	6.7	11.7	24.7	24.2	19.6	14.6	14.3	9.0	2.7	132.9
Chertala	0942	7620	10	50	24.6	26.4	54.1	113.3	275.3	674.1	567.9	344.2	256.8	295.7	190.3	51.3	2874.0
					1.2	1.4	2.9	6.3	11.9	24.1	23.4	18.5	14.0	14.5	10.5	3.2	131.9
Changana-cherry	0927	7633	45	50	25.4	23.9	63.7	157.5	320.8	683.3	565.1	386.1	285.5	383.0	220.7	73.7	3188.7
					1.6	1.5	3.8	9.2	13.0	24.3	23.2	18.7	14.9	16.1	11.3	3.9	141.5
Ambalapuzha	0923	7622	16	50	25.4	32.0	61.0	122.9	297.4	628.1	489.7	294.6	239.8	328.7	225.0	71.6	2816.2
					1.6	1.7	3.4	6.7	12.1	23.2	22.4	16.8	13.5	15.1	11.0	4.3	131.8
Thiruvalla	0923	7633	50	50	32.8	23.4	60.2	137.9	311.9	631.7	570.0	393.2	278.9	364.7	223.5	64.8	3093.0
					1.9	1.4	3.9	9.0	13.2	24.0	23.9	20.5	15.4	16.3	11.9	3.9	145.3
Chengannur	0919	7637	45	50	32.3	23.9	68.8	151.6	289.8	627.6	550.4	385.6	286.0	336.3	237.5	70.6	3060.4
					1.8	1.3	4.1	8.8	12.3	23.6	23.3	19.9	15.2	15.6	12.0	4.0	142.4
Haripad	0917	7627	12	50	27.4	23.9	53.6	113.0	275.6	639.6	507.0	329.7	253.5	339.9	216.1	67.3	2846.6
					1.5	1.4	3.2	6.3	12.5	22.9	21.5	17.1	13.8	15.1	10.7	3.8	129.8
Mavelikkara	0915	7632	10	50	28.7	20.1	61.5	138.7	311.9	702.3	574.8	381.5	286.0	376.7	229.1	75.4	3186.7
					1.6	1.4	3.6	7.5	12.3	24.6	23.3	19.4	15.5	16.0	12.1	3.9	141.2

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Kayamkulam	0911	7630	5	74	24.3	22.7	52.5	124.6	287.3	611.7	484.0	309.8	252.4	321.3	205.7	60.7	2756.0
					1.5	1.4	3.1	6.9	12.3	22.8	21.7	16.6	13.4	15.0	10.6	3.8	129.1
Pathanam-thitta	0916	7646	30	46	35.3	48.0	114.3	217.9	315.0	576.3	534.7	398.8	275.3	412.0	299.5	78.5	3305.6
					1.9	2.4	6.1	10.8	12.9	22.4	22.6	18.4	13.7	15.8	12.0	3.7	142.7
Konni	0913	7651	175	50	31.7	53.3	136.7	242.3	335.3	604.8	600.5	429.8	283.5	412.5	274.6	58.2	3463.2
					1.8	2.8	7.7	12.8	14.7	23.7	23.6	20.7	14.3	17.8	12.5	3.8	156.2
Adoor	0909	7644	121	50	22.3	33.3	96.0	188.2	268.0	567.2	494.0	349.8	247.1	351.8	254.0	63.3	2935.0
					1.6	2.0	5.1	10.2	11.8	22.6	22.7	18.8	14.0	16.1	12.3	3.8	141.0
Kottara-kkara	0901	7646	18	50	17.5	26.2	71.9	152.4	259.1	534.9	430.3	308.9	228.6	342.4	229.9	60.7	2662.8
					1.3	1.7	4.3	9.2	11.5	22.5	22.3	18.2	13.5	15.4	10.5	3.3	133.7
Aryankavu	0859	7710	240	74	44.6	30.4	76.7	92.1	158.5	492.6	429.6	273.1	211.2	341.9	264.7	87.5	2502.9
					1.8	1.9	4.1	6.7	8.7	21.6	21.3	17.5	12.2	16.4	12.2	4.1	128.5
Quilon	0853	7636	8	46	17.8	22.6	50.0	140.2	267.2	530.6	377.9	246.4	195.3	293.9	209.0	47.2	2398.1
					1.3	1.4	3.2	7.4	11.7	21.8	20.0	14.7	12.2	13.5	10.0	3.0	120.2
Paravur	0847	7640	40	46	12.7	17.5	45.7	110.2	219.5	448.8	323.9	215.1	167.6	282.2	194.8	43.2	2081.2
					1.0	1.0	2.6	6.4	9.7	19.2	17.0	11.8	9.2	12.0	8.3	2.2	100.4
Varkala	0843	7642	75	33	15.3	16.8	52.5	114.9	220.5	452.4	373.3	224.7	175.1	261.2	191.7	50.8	2149.2
					1.0	1.2	2.8	6.2	10.0	19.9	17.2	12.1	10.6	12.5	8.4	2.4	104.4
Attingal	0842	7649	75	50	20.6	17.5	38.6	106.4	218.9	421.4	277.6	189.7	138.9	289.8	177.8	58.4	1955.6
					1.2	1.0	2.5	6.3	9.6	19.0	16.9	11.3	8.4	12.2	8.9	3.1	100.4

Table: 4.1 (contd.)

Station	Lat.* (N)	Long.* (E)	Alt (m)	Data Length	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Nedumangad	0836	7700	100	50	27.2	22.1	65.5	172.5	227.8	408.7	227.6	190.5	181.4	342.4	246.6	78.5	2240.8
					1.9	1.4	3.5	9.3	9.9	18.2	16.2	11.6	9.9	14.2	11.3	4.6	112.0
Neyyattin-	0823	7705	50	50	31.0	17.3	39.6	101.9	182.4	292.9	187.2	117.1	124.7	256.0	230.9	72.9	1653.9
kara					1.9	0.9	2.4	6.1	8.2	15.4	12.9	8.2	7.6	11.9	10.8	4.3	90.6
Parasala	0820	7709	65	46	18.3	16.5	45.2	97.5	169.4	270.8	143.0	101.3	103.1	250.2	200.1	63.7	1479.1
					1.5	1.3	2.8	5.9	7.9	13.9	11.0	7.8	6.7	11.8	10.1	3.6	84.3
Trivandrum	0829	7657	64	50	22.9	20.8	38.6	105.7	207.8	356.4	223.0	145.5	137.9	273.3	205.5	74.7	1812.1
					2.0	1.3	2.7	6.4	9.5	18.1	15.6	10.8	9.1	12.3	10.3	4.1	102.2

* First two digits represent degrees and the next two digits represents minutes.

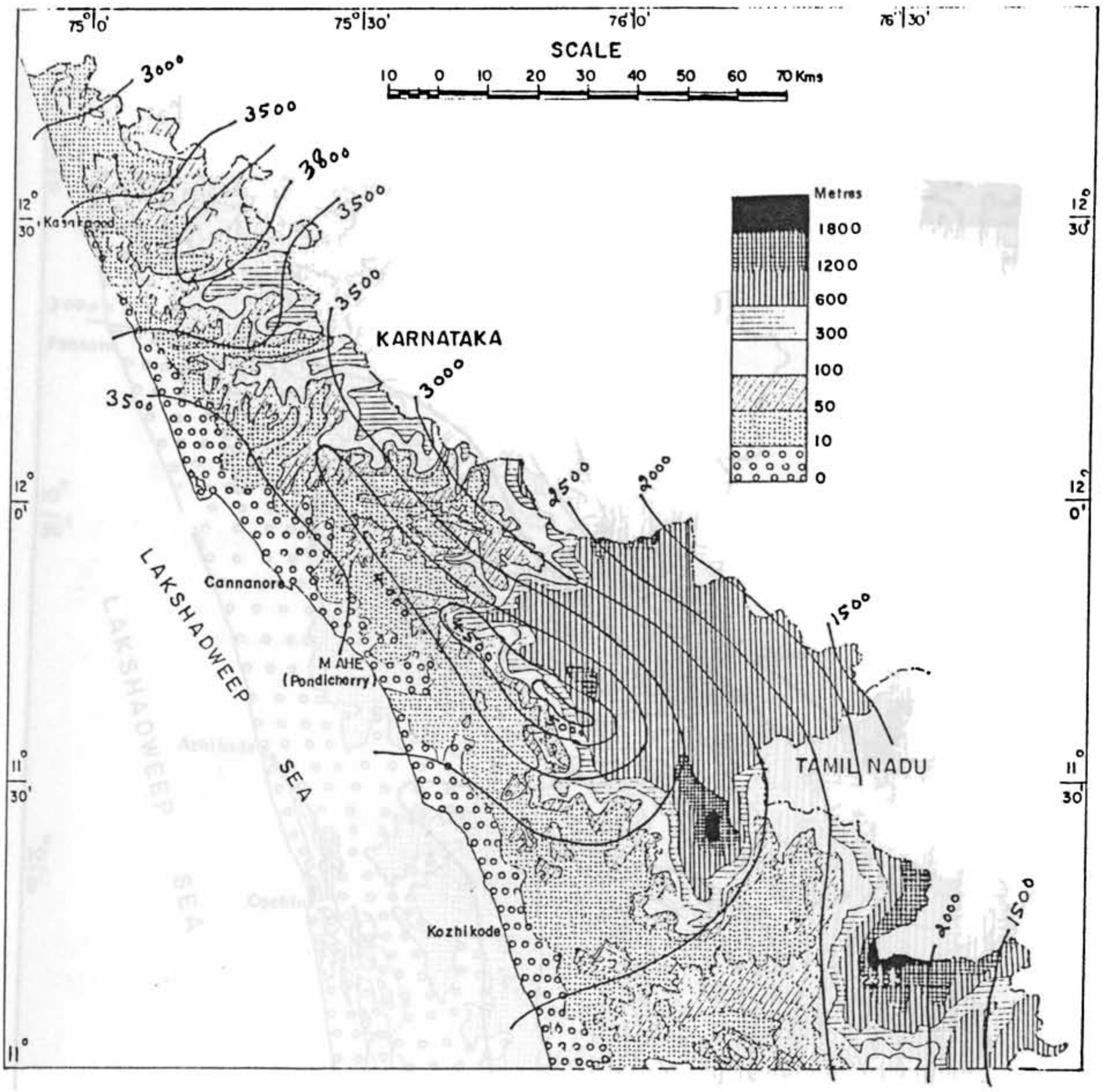


FIG. 4.1 ISOHYETS (m.m.) - ANNUAL NORMAL - ON THE RELIEF MAP OF NORTHERN KERALA

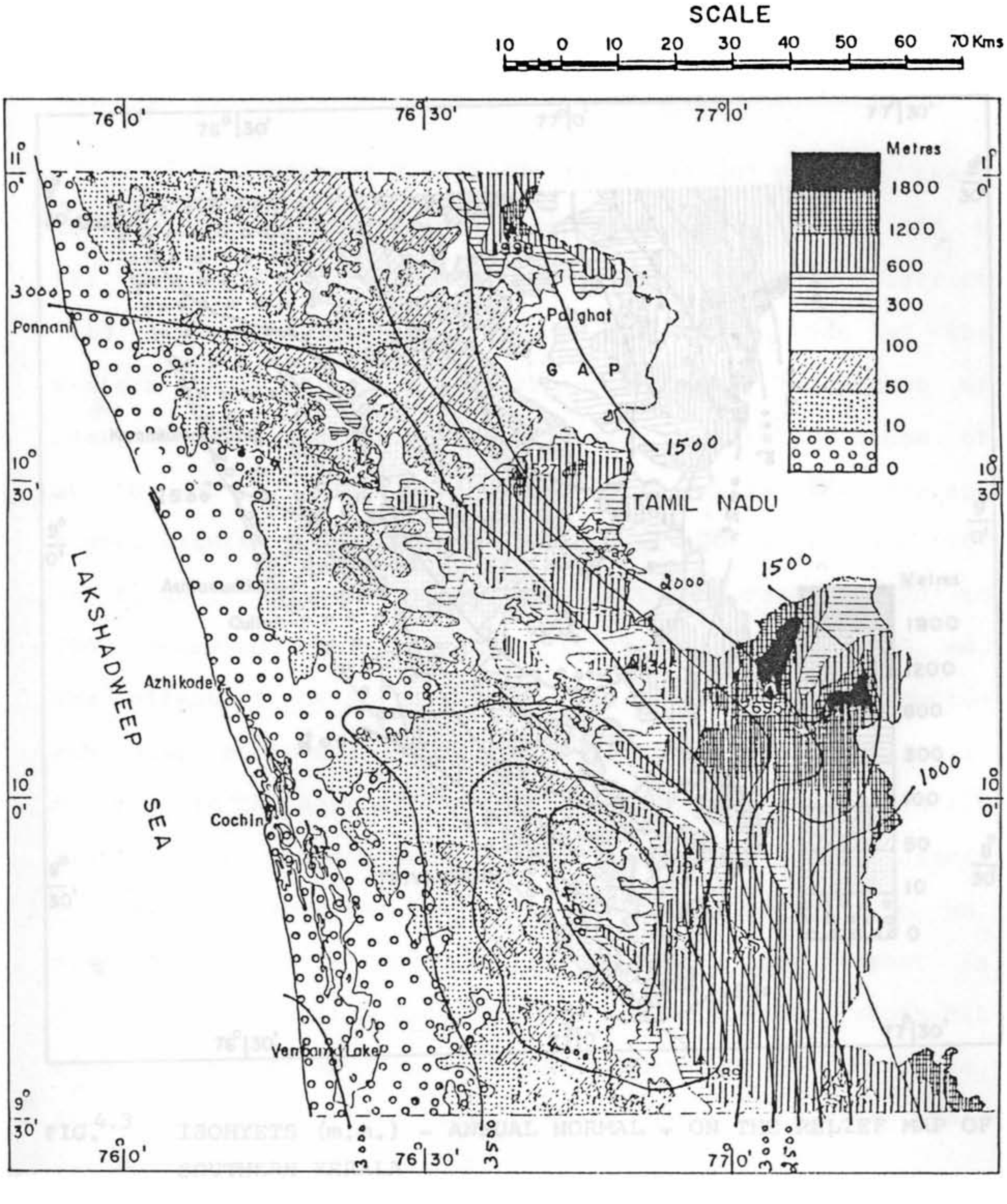


FIG. 4.2 ISOHYETS (m.m.) - ANNUAL NORMAL - ON THE RELIEF MAP OF CENTRAL KERALA

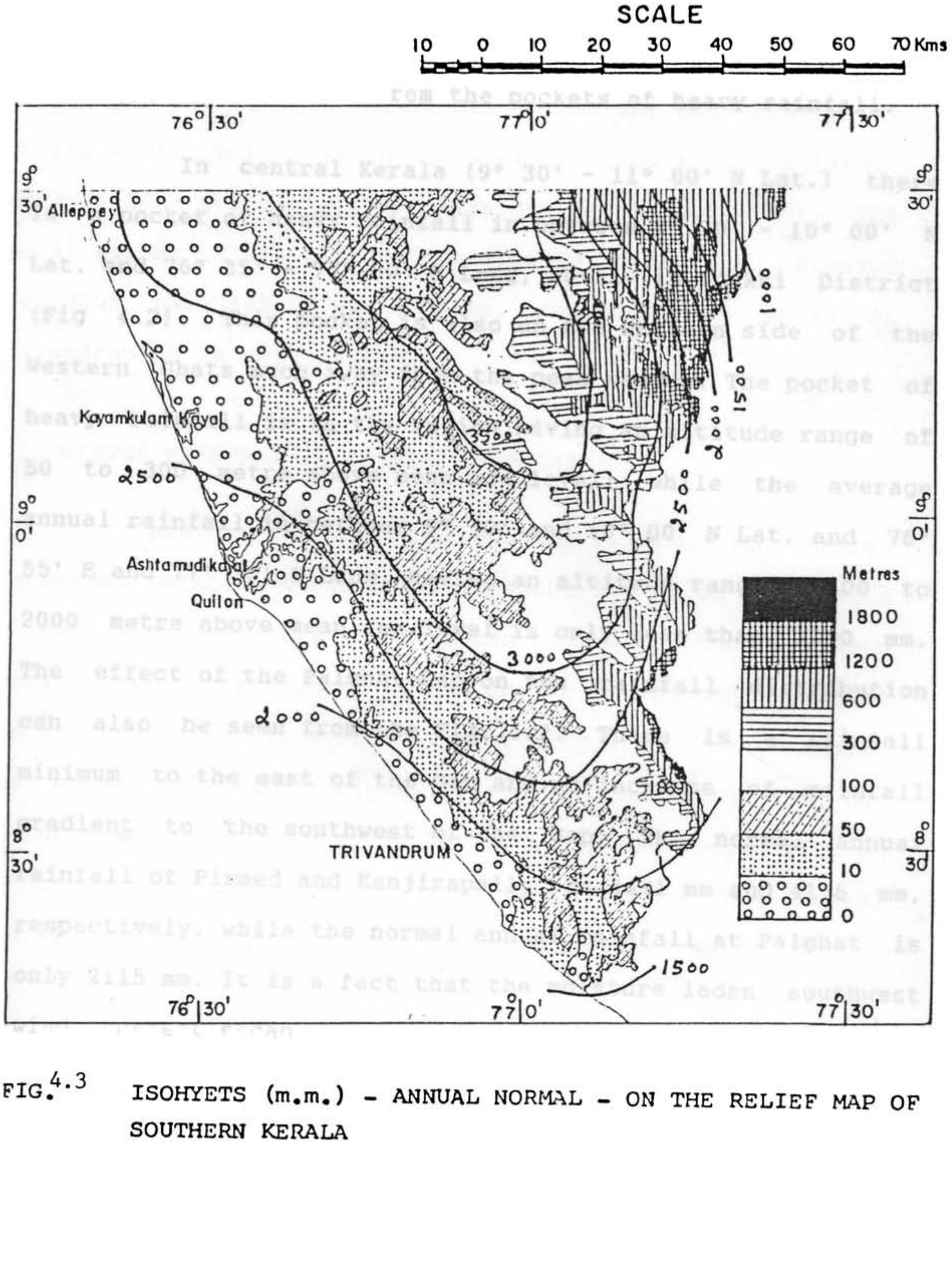


FIG.4.3 ISOHYETS (m.m.) - ANNUAL NORMAL - ON THE RELIEF MAP OF SOUTHERN KERALA

isohytes are parallel to the Western Ghats with a steep decrease to both sides from the pockets of heavy rainfall.

In central Kerala (9° 30' - 11° 00' N Lat.) there is a pocket of heavy rainfall in between 9° 30' - 10° 00' N Lat. and 76° 35' - 77° 00' E Long, mostly in Idukki District (Fig 4.2). This pocket is also on the western side of the Western Ghats much away from the peak ranges. The pocket of heavy rainfall is in the region having an altitude range of 50 to 300 metre above mean sea level; while the average annual rainfall in between 9° 30' and 10° 00' N Lat. and 76° 55' E and 77° 30' E Long. having an altitude range of 600 to 2000 metre above mean sea level is only less than 2000 mm. The effect of the Palghat Gap on the rainfall distribution can also be seen from the Fig. 4.2. There is a rainfall minimum to the east of the Gap and an increase of rainfall gradient to the southwest of the Gap. The normal annual rainfall of Pirmed and Kanjirapally are 4471 mm and 4156 mm, respectively, while the normal annual rainfall at Palghat is only 2115 mm. It is a fact that the moisture laden southwest wind current escapes through the Palghat Gap and therefore, this region is getting less rainfall compared to the other regions in central Kerala.

In southern Kerala (south of 9° 30' N Lat.), the annual normal rainfall is noted in the range of 1500 mm to

3500 mm (Fig.4.3). The maximum rainfall is in between 09° 00' - 09° 30' N Lat. and 76° 30' - 77° 05' E Long. In this region also the maximum values are not at the peak ranges of Western Ghats, but it is in the western slope at the altitude range of 50 - 600 metre above mean sea level (a.m.s.l.). The annual normal rainfall of Pathanamthitta, Konni and Punalur are 3305 mm, 3463 mm and 3159 mm, respectively; while at Trivandrum it is only 1812 mm.

4.3 WINTER RAINFALL (DECEMBER - FEBRUARY)

This is the period of minimum rainfall in Kerala. The normal rainfall decreases from about 200 mm in the south of Kerala to less than 10 mm in the north. In the northern Kerala itself the highest values are in Kozhikode District and to some extend in Wynad District (Fig.4.4). For example, the normal (50 years) rainfall values of Kasaragod for the months December - February is 35.3 mm. For Cannanore station it is only 26.9 mm. At Kozhikode and Vythiri the normal winter rainfall are 50.6 mm and 50.3 mm, respectively.

In central Kerala, the winter rainfall varies from about 50 mm to 150 mm (Fig.4.5). It is evident that the winter northeast winds play a major role for getting a good amount of rainfall in Ernakulam, Idukki and Kottayam Districts during this period. The normal winter rainfall for Trichur, Cochin, Alwaye and Kumily are 38.6 mm, 96.8 mm, 65.8

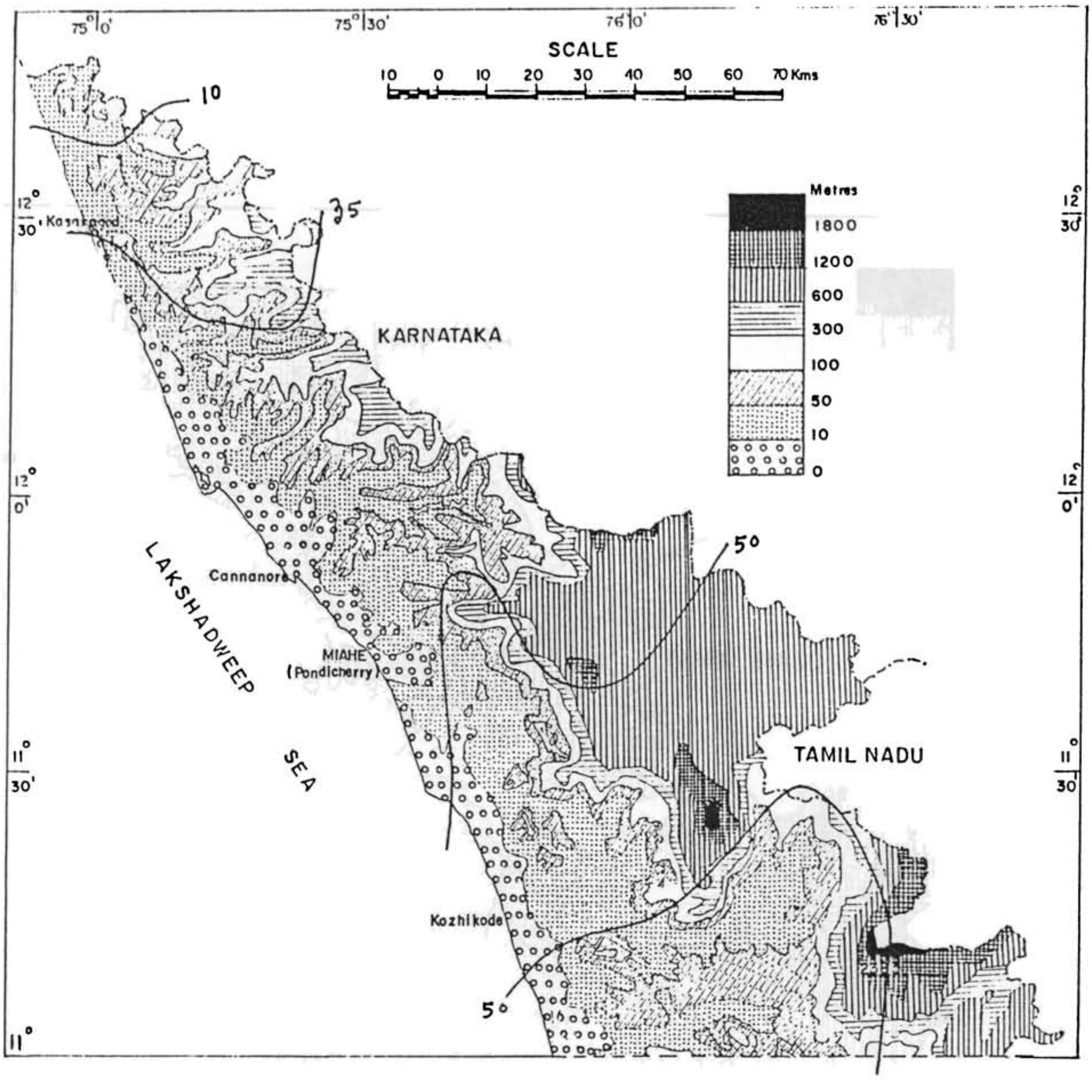


FIG. 4.4 ISOHYETS (m.m.) - DEC. - FEB. PERIOD NORMAL - ON THE RELIEF MAP OF NORTHERN KERALA

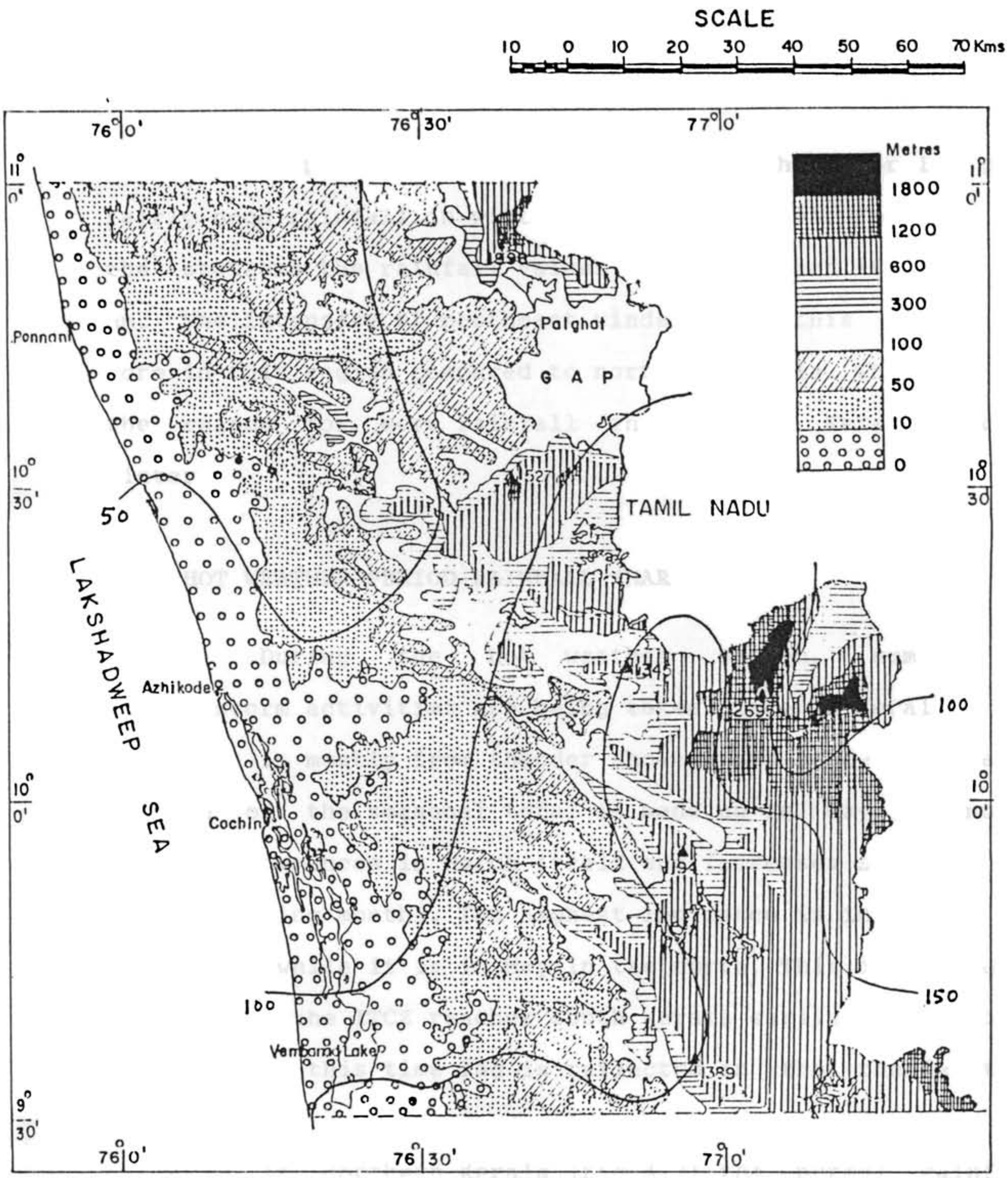


FIG. 4.5 ISOHYETS (m.m.) - DEC. - FEB. PERIOD NORMAL - ON THE RELIEF MAP OF CENTRAL KERALA

mm and 170.5 mm, respectively. At Kottayam the amount is 131.0 mm.

Compared to northern Kerala, southern Kerala gets fairly good rainfall in winter season (Fig.4.6). For most of the stations the rainfall values are in between 100 and 150 mm. The intensity of northeast winds during this period is more in this region compared to northern Kerala. That may be the reason for more rainfall in southern Kerala during winter.

4.4 HOT WEATHER PERIOD RAINFALL (MARCH-MAY)

During the hot weather season, number of thunderstorm activities are being taken place in Kerala. The rainfall is mostly from thunder showers and hence the major portion of the seasonal total is made up in May. Thundery activity commences in March itself and increases steadily in the following months. The highest incidence is in April in the south, while it is in May in the north. This is obviously because of the ITCZ reaches south Kerala earlier than north Kerala and this time lag is reflected in the thunderstorm activity.

In northern Kerala (Fig.4.7) the normal rainfall values are in between 100 mm and 400 mm. It may be noticed that the highest values are not at the high lands, but in the

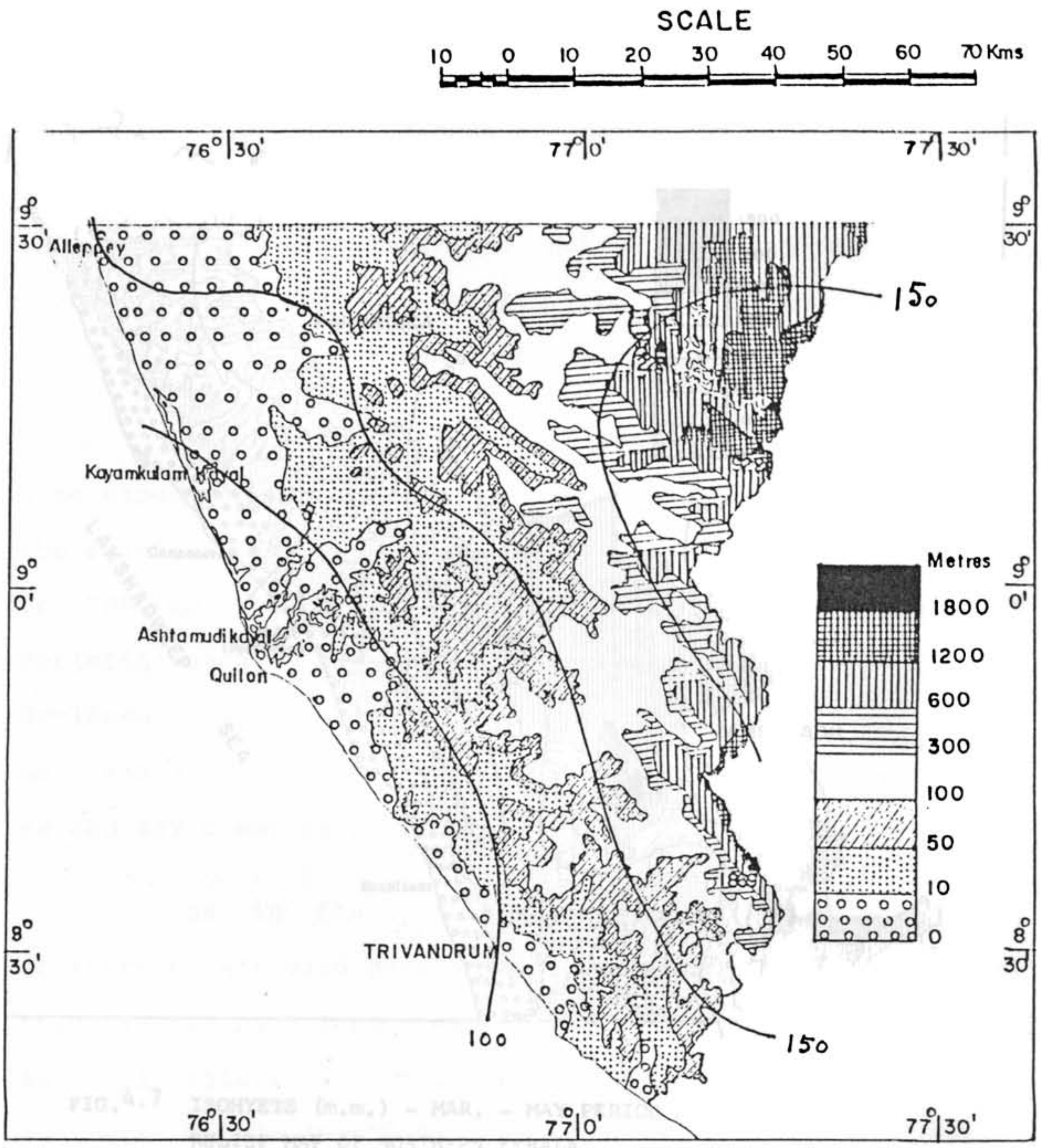


FIG. 4.6 ISOHYETS (m.m.) - DEC. - FEB. PERIOD NORMAL - ON THE RELIEF MAP OF SOUTHERN KERALA

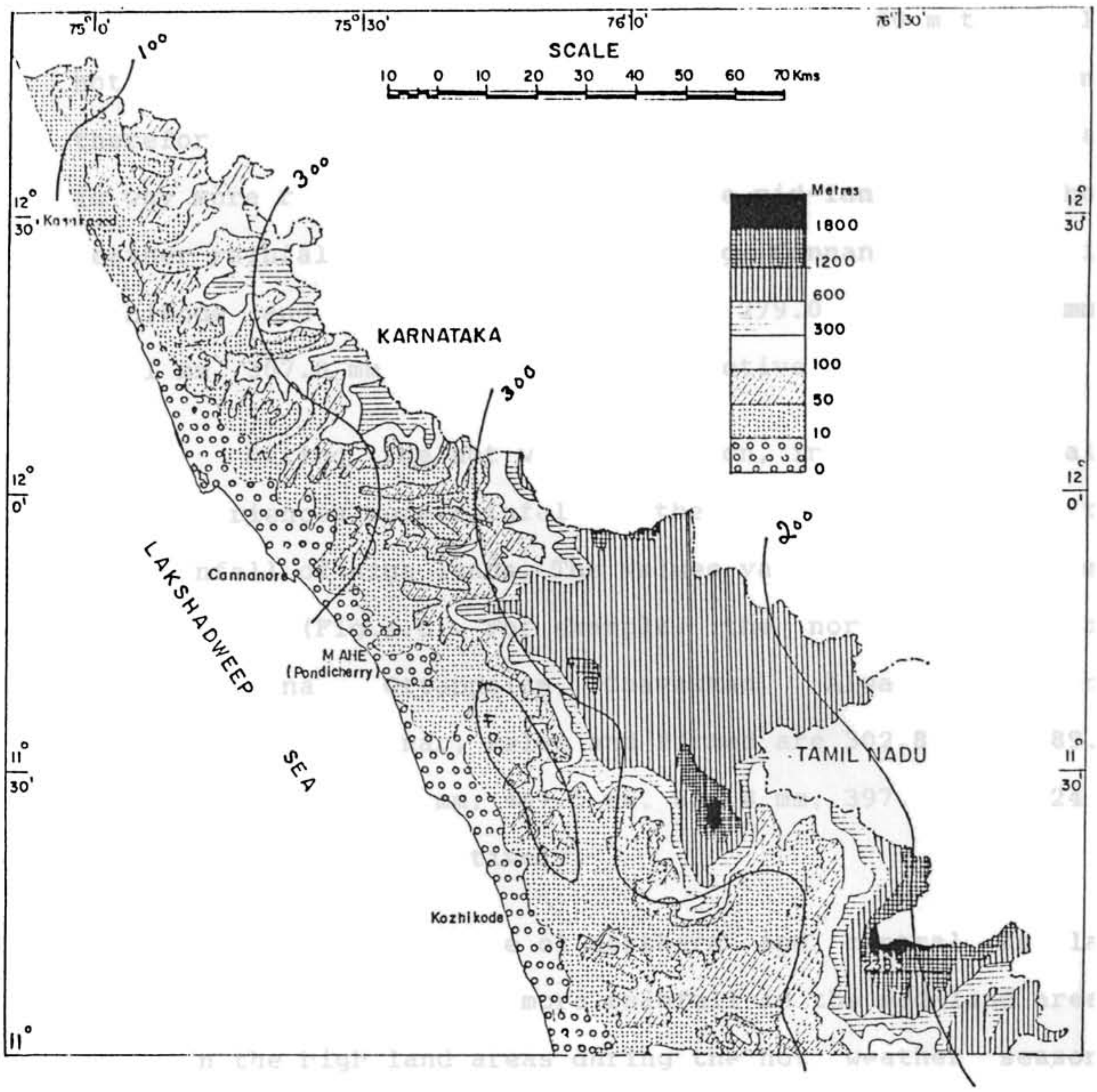


FIG.4.7 ISOHYETS (m.m.) - MAR. - MAY PERIOD NORMAL - ON THE RELIEF MAP OF NORTHERN KERALA

mid-lands having the altitude range of 10 to 100 metres. In hot weather season, mid-lands are hotter than high lands and therefore conventional clouds are more from this region. That is why more rainfall is obtained in the mid-lands. Normal hot weather rainfall for Kasaragod, Hosdurg, Cannanore, Vythiri, Kozhikode and Kuttiadi are 250.7 mm, 279.0 mm, 270.8 mm, 325.1 mm, 367.0 mm and 443.7 mm, respectively.

During the hot weather season, in central Kerala also experiences more rainfall in the mid-lands, compared to the rainfall of high lands. The values vary from about 200 mm to 700 mm (Fig.4.8). For example, the normal values of Perinthalmanna, Ottappalam, Chavakkad, Alwaye, Cochin, Neriamangalam, Munnar, Palai and Pirmed are 302.8 mm, 289.8 mm, 432.3 mm, 408.0 mm, 467.5 mm, 624.8 mm, 397.8 mm, 724.6 mm and 489.2 mm, respectively.

As in the case of northern and central Kerala, southern Kerala also gets more rainfall in the mid-land areas than in the high land areas during the hot weather season. Rainfall values vary from about 300 mm to about 700 mm in southern Kerala (Fig.4.9). The southern District of Kerala, Trivandrum get about 400 mm while the northern District, Kasaragod receive only less than 300 mm. The seasonal rainfall is about 15 to 20% of the annual for south Kerala and less than 10% for north Kerala. The southwest monsoon advances over south Kerala between 11th and 31st May in

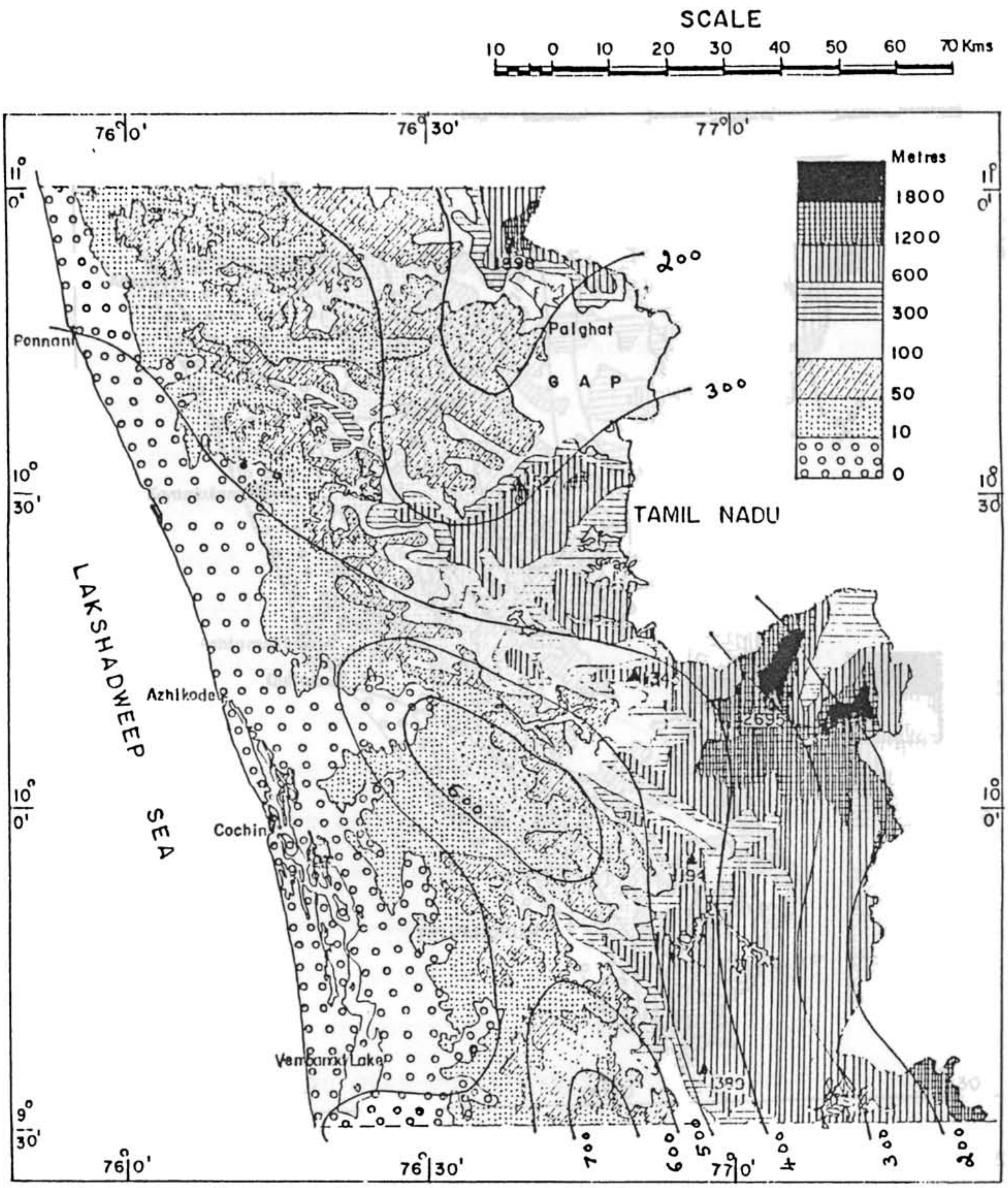


FIG. 4.8 ISOHYETS (m.m.) - MAR. - MAY PERIOD NORMAL - ON THE RELIEF MAP OF CENTRAL KERALA

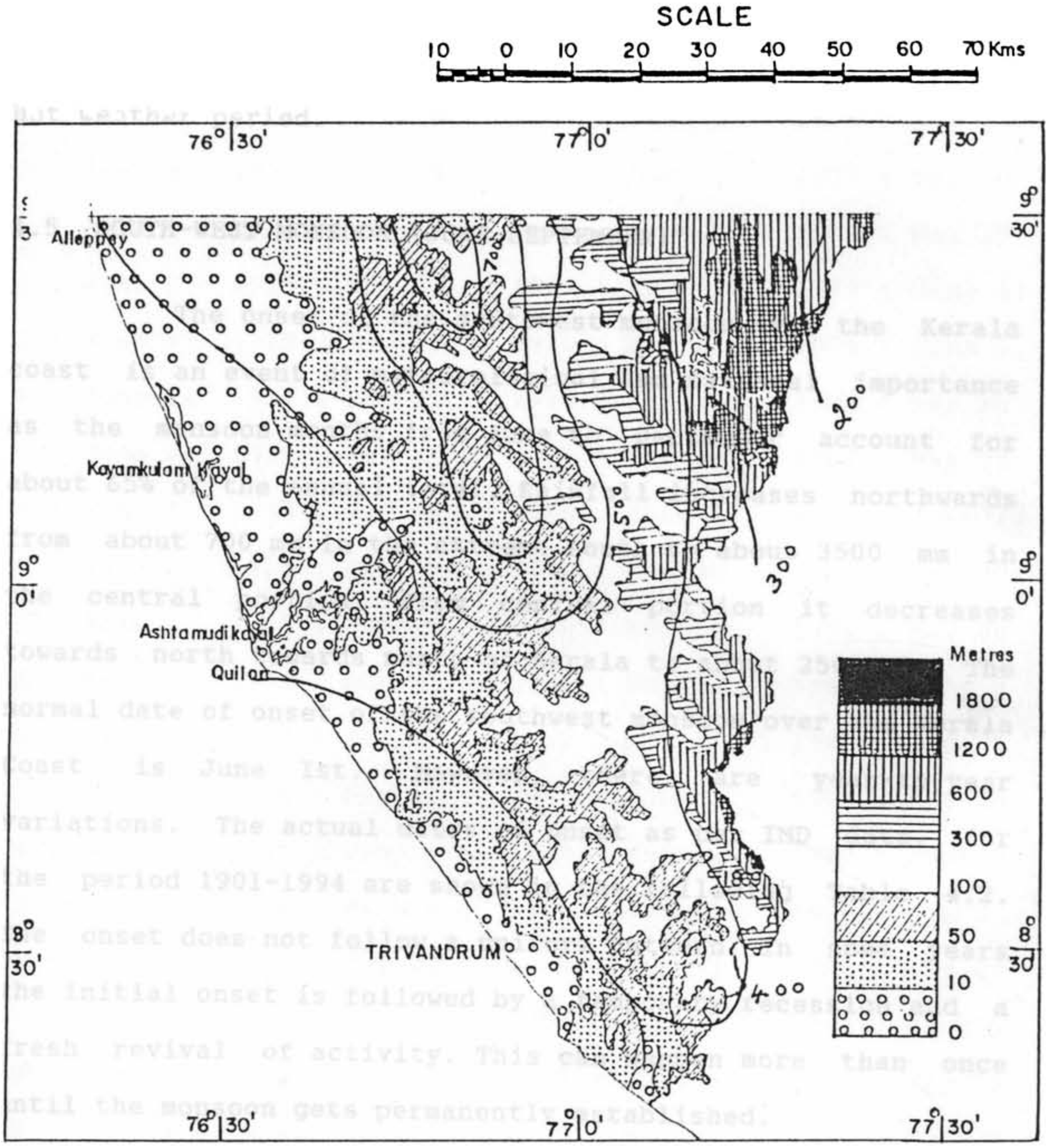


FIG. 4.9 ISOHYETS (m.m.) - MAR. - MAY PERIOD NORMAL - ON THE RELIEF MAP OF SOUTHERN KERALA

nearly 50% of the years. This is a contributory factor for the pronounced rainfall maximum over south Kerala during the hot weather period.

4.5 SOUTH-WEST MONSOON (JUNE-SEPTEMBER)

The onset of the southwest monsoon over the Kerala coast is an event of meteorological and national importance as the monsoon months from June to September account for about 65% of the annual total. Rainfall increases northwards from about 700 mm in the extreme south to about 3500 mm in the central portion. From central portion it decreases towards north towards north of Kerala to about 2500 mm. The normal date of onset of the southwest monsoon over the Kerala Coast is June Ist. However, there are year-to-year variations. The actual dates of onset as per IMD data, for the period 1901-1994 are shown in the following Table 4.2. The onset does not follow a uniform pattern. In some years the initial onset is followed by a temporary recession and a fresh revival of activity. This can happen more than once until the monsoon gets permanently established.

In north Kerala, the southwest monsoon contribute about 80% of the annual rainfall. In this region the rainfall values vary from 3500 mm in Kozhikode District to less than 2500 mm in Kasaragod District. As shown in the Fig. 4.10

Table 4.2 : Onset days of southwest monsoon over Kerala

Year	Date	Year	Date	Year	Date	Year	Date
1901	: June 5	1926	: June 6	1951	: June 1	1976	: May 31
1902	: June 4	1927	: May 19	1952	: May 21	1977	: May 30
1903	: June 5	1928	: June 1	1953	: June 7	1978	: May 28
1904	: June 2	1929	: May 30	1954	: May 22	1979	: June 11
1905	: June 7	1930	: June 3	1955	: May 11	1980	: June 1
1906	: June 14	1931	: May 29	1956	: May 16	1981	: May 30
1907	: June 1	1932	: May 15	1957	: May 30	1982	: May 30
1908	: June 7	1933	: May 18	1958	: June 14	1983	: June 12
1909	: June 2	1934	: June 7	1959	: May 20	1984	: May 30
1910	: June 4	1935	: June 6	1960	: May 14	1985	: May 28
1911	: May 25	1936	: May 21	1961	: May 19	1986	: June 4
1912	: June 5	1937	: May 27	1962	: May 15	1987	: June 1
1913	: May 25	1938	: May 27	1963	: June 5	1988	: May 26
1914	: May 29	1939	: June 6	1964	: June 7	1989	: June 3
1915	: June 15	1940	: June 6	1965	: June 6	1990	: May 25
1916	: May 22	1941	: May 23	1966	: June 3	1991	: May 29
1917	: May 29	1942	: May 17	1967	: June 8	1992	: June 5
1918	: May 11	1943	: June 1	1968	: June 8	1993	: May 28
1919	: May 29	1944	: May 30	1969	: May 17	1994	: May 28
1920	: June 4	1945	: June 2	1970	: May 26		
1921	: June 1	1946	: May 30	1971	: May 27		
1922	: June 1	1947	: June 3	1972	: June 15		
1923	: June 5	1948	: June 9	1973	: June 4		
1924	: June 1	1949	: May 24	1974	: May 26		
1925	: May 17	1950	: May 28	1975	: May 31		

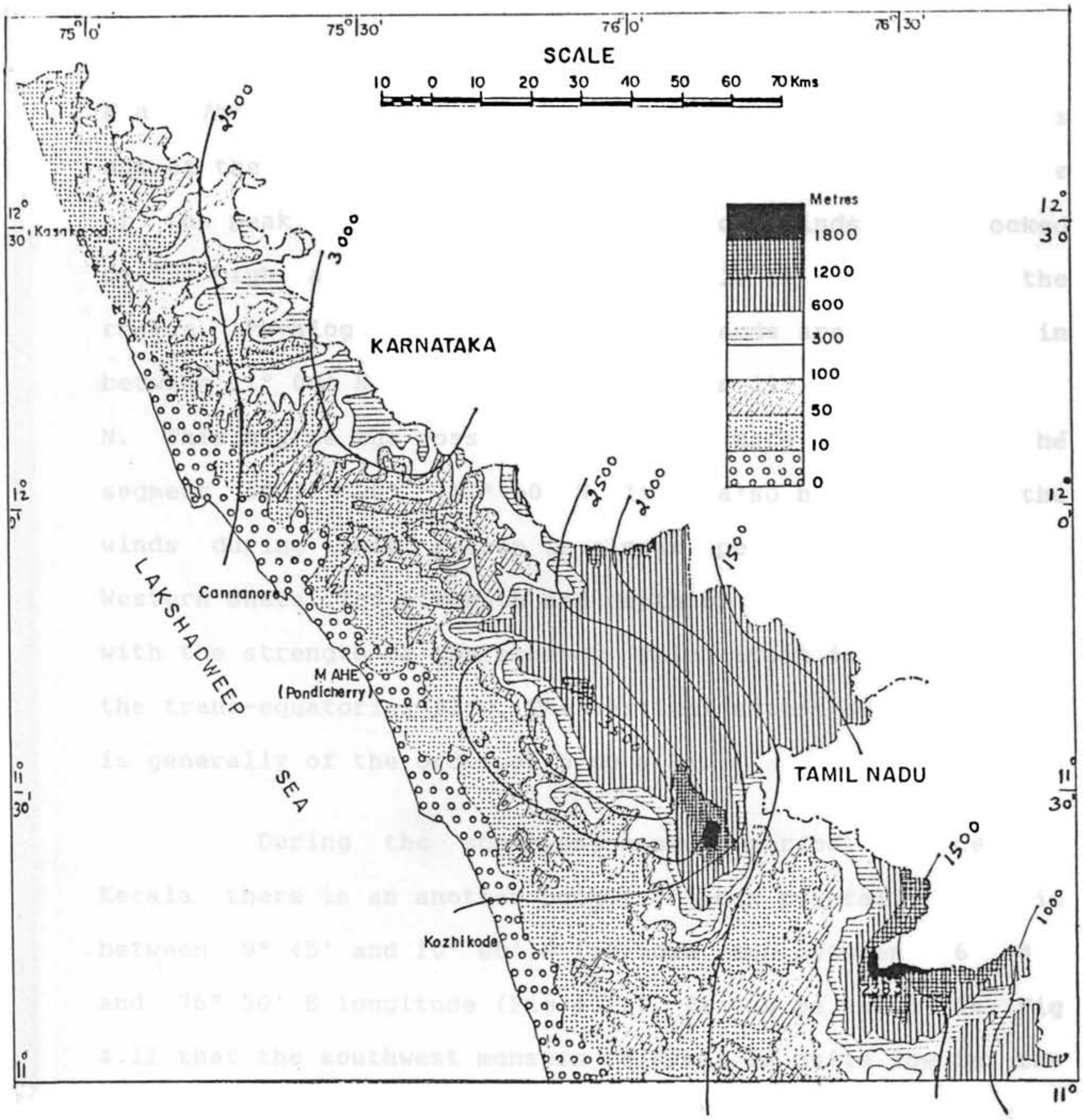


FIG. 4.10 ISOHYETS (m.m.) - JUN. - SEP. PERIOD NORMAL - ON THE RELIEF MAP OF NORTHERN KERALA

there is a pocket of peak value in between 11° 20' - 11° 40' N and 75° 45' - 76° 10' E. It can be seen that this pocket is not at the peak of high lands, but away towards western side of the peak. The strong southwest monsoon winds are blocked by the high lands and orographic rainfall is obtained in the region. Physiographically, more high-lands are situated in between 11° 00' N and 11° 50' N than in 11° 50' N - 12° 40' N. This may be the possible reason for more rainfall in the segment of 11° 00' - 11° 50' N. It is also noticed that the winds during this season is almost perpendicular to the Western Ghats. The strength and depth of the westerlies vary with the strength of the monsoon, which again is governed by the trans-equatorial flow. The vertical extent of the current is generally of the order of 5 to 6 km.

During the southwest monsoon period, in central Kerala there is an another pocket of peak rainfall lies in between 9° 45' and 10° 00' N latitude and between 76° 45' and 76° 50' E longitude (Fig 4.11). It can be noted in Fig 4.11 that the southwest monsoon rainfall is quite low in the Palghat Gap region. This is due to the escape of monsoon winds through this Gap to the Tamil Nadu region. There is no barrier to block the moisture laden winds in this region. But in the Idukki District, the high lands block almost all the southwest winds and thus a good amount of orographic rainfall is obtained in the region. As in the case of northern Kerala,

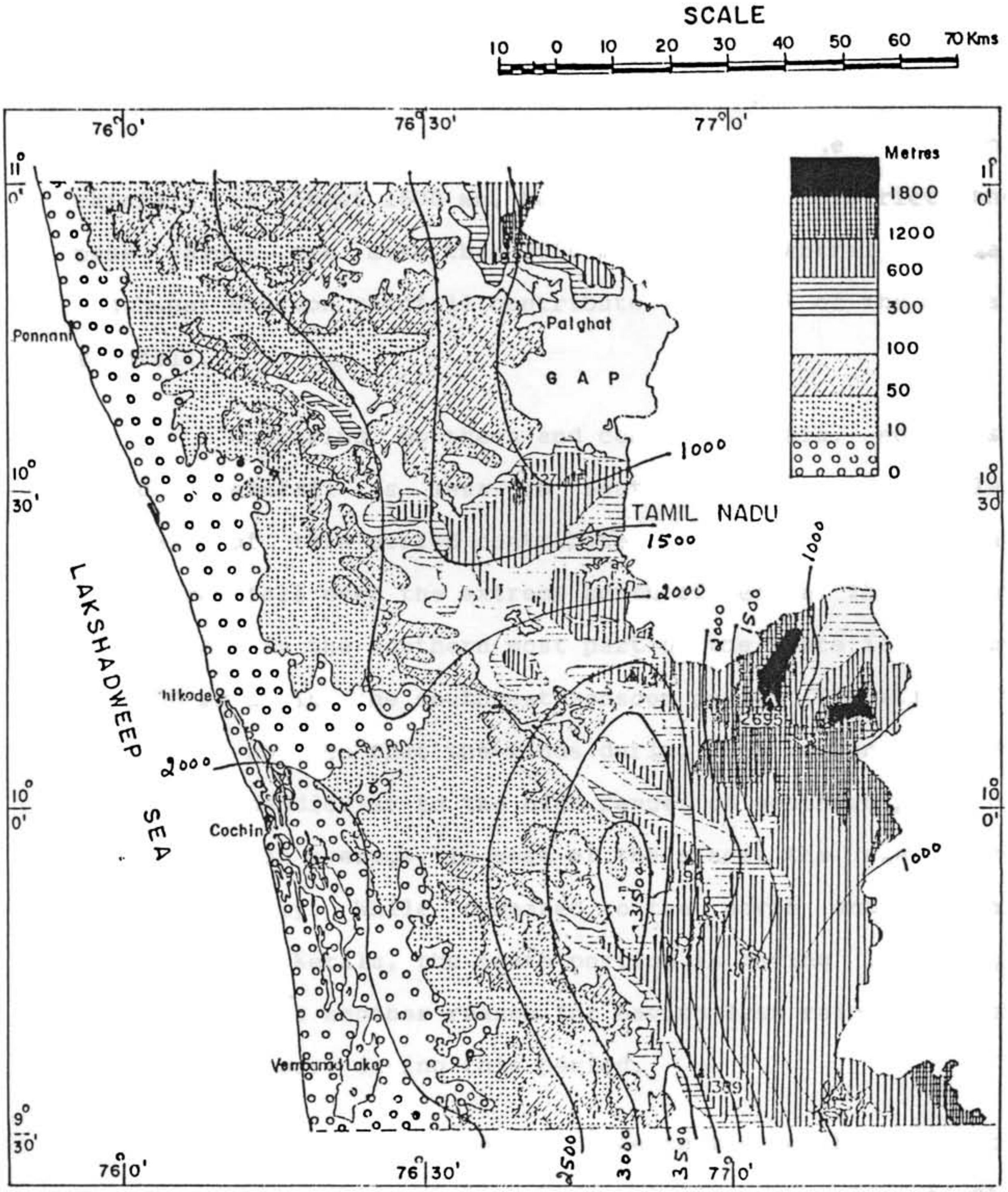


FIG.4.11 ISOHYETS (m.m.) - JUN. - SEP. PERIOD NORMAL - ON THE RELIEF MAP OF CENTRAL KERALA

the peak rainfall is not at the peak of high lands, but towards the western side of it. In central Kerala, the southwest monsoon wind currents are almost perpendicular to the western Ghats. In the Palghat Gap region, the value of rainfall is about 1500 mm, but in the Idukki District the peak values are more than 3500 mm. Over central Kerala, southwest monsoon rainfall contribute 70 to 75% of the annual rainfall.

Comparing northern and central Kerala, southwest monsoon rainfall is less in southern parts of Kerala. Rainfall of this period contribute only 40 to 50% of the annual rainfall over the extreme south of Kerala. The amount of rainfall in the southern most part of the State is as low as 1000 mm during the southwest monsoon period (Fig.4.12). It has been noticed that the winds during this season is not exactly perpendicular to the high ranges of southern part of Kerala. On an average, in most of the places the winds are north westerly. While compared to the north and central portions of Kerala, the south portion is having less high ranges. This is another reason for having less rainfall over the southern part during this period.

Rainfall is highest in June in the southern portion of the State while the northern portion experiences the highest rainfall in July. There is hardly any heavy rain occurrence in September. This is a contributing factor in

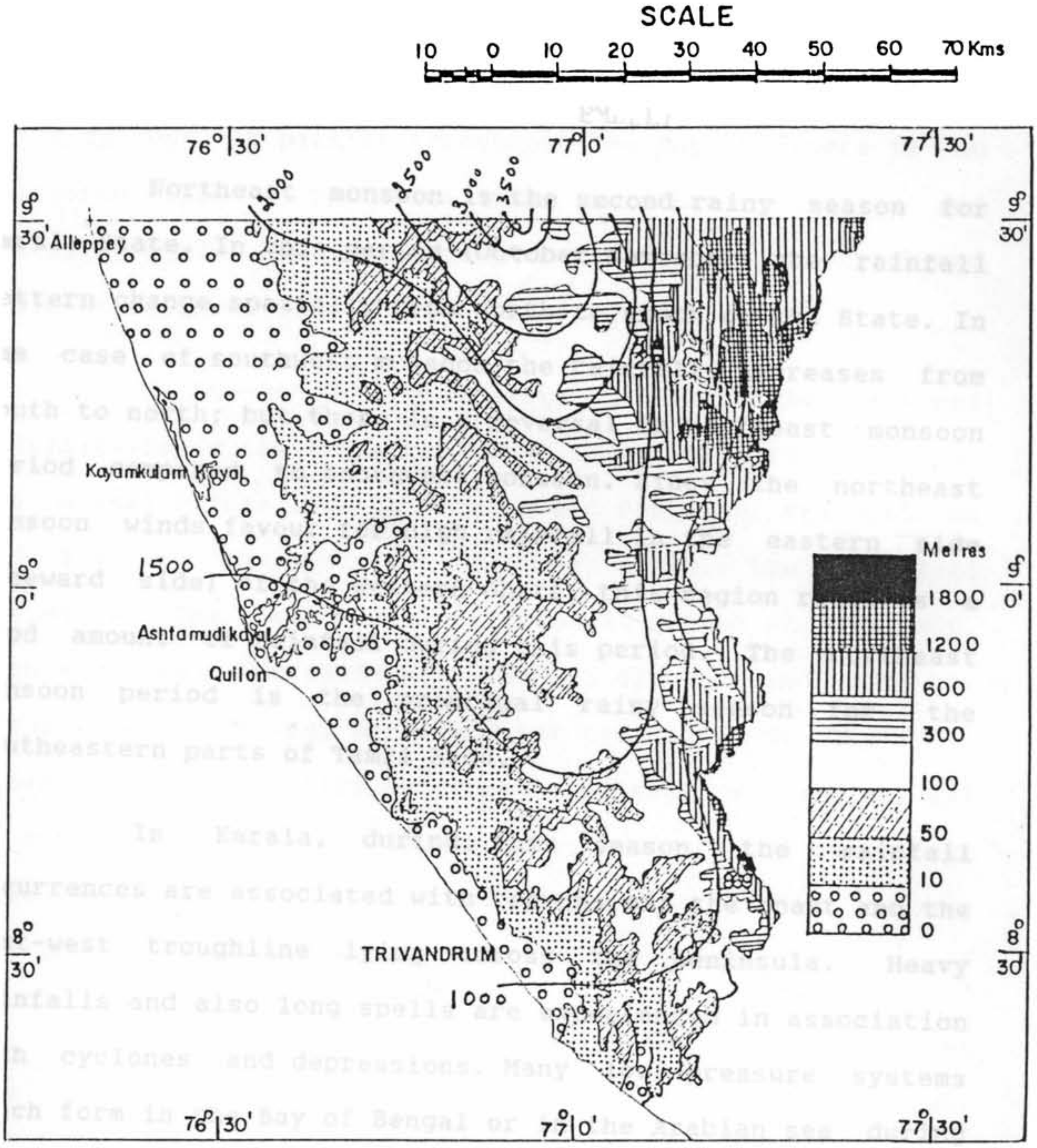


FIG. 4.12 ISOHYETS (m.m.) - JUN. - SEP. PERIOD NORMAL - ON THE RELIEF MAP OF SOUTHERN KERALA

producing the higher seasonal rainfall in south and north Kerala.

4.6 NORTH-EAST MONSOON (OCTOBER-NOVEMBER)

Northeast monsoon is the second rainy season for Kerala State. In this period (October-November) the rainfall pattern change spatially from north to south of the State. In the case of southwest monsoon the rainfall increases from south to north; but there is a reversal in northeast monsoon period compared to southwest monsoon. Since the northeast monsoon winds favour for high rainfall in the eastern side (leeward side) of the Western Ghats, this region receives a good amount of rainfall during this period. The northeast monsoon period is the principal rainy season for the southeastern parts of Tamil Nadu.

In Kerala, during this season, the rainfall occurrences are associated with troughs off the coast and the east-west troughline lying across the peninsula. Heavy rainfalls and also long spells are experienced in association with cyclones and depressions. Many low pressure systems which form in the Bay of Bengal or in the Arabian sea during this season become depressions or cyclones. Most of the destructive cyclones in Bay of Bengal occur in October-November period. In the beginning of the season, rainfall is confined mostly in the afternoon or in early night. As the season advances, the time of occurrence shifts, especially in the southern parts of the State, to late night or early morning. When the rainfalls are associated with a depression or a cyclone, it persist throughout the day and there is no preferred time of incidence. Rain incidence, duration and intensity would, however, depend upon the position, track and speed of movement of depression or cyclone.

In the northern-most parts of Kerala, the seasonal rainfall is of the order of 300 mm (Fig.4.13). For example, the normal rainfalls at Kasaragod and Payyannur are 305 mm and 314 mm, respectively. Further south, the rainfall increases. The normal seasonal rainfall values at Quilandy, Kozhikode and Kuttiadi are 396 mm, 419 mm and 618 mm, respectively. It may be noted that the altitude stations, Mananthavady and Vythiri get normal seasonal rainfall as 241 mm and 436 mm, respectively. From Fig. 4.13, it is also clear that the maximum values are not at the peak of high ranges; but towards the western side over the mid-lands.

In central Kerala, (Fig.4.14) the maximum values are also not found at the peak of high ranges. The normal values are of the order of 700 to 750 mm over the mid-lands located at the altitude range of 50 - 500 m above mean sea level. Compared to the other stations, Palghat region also get a good rainfall during this season, as moisture laden

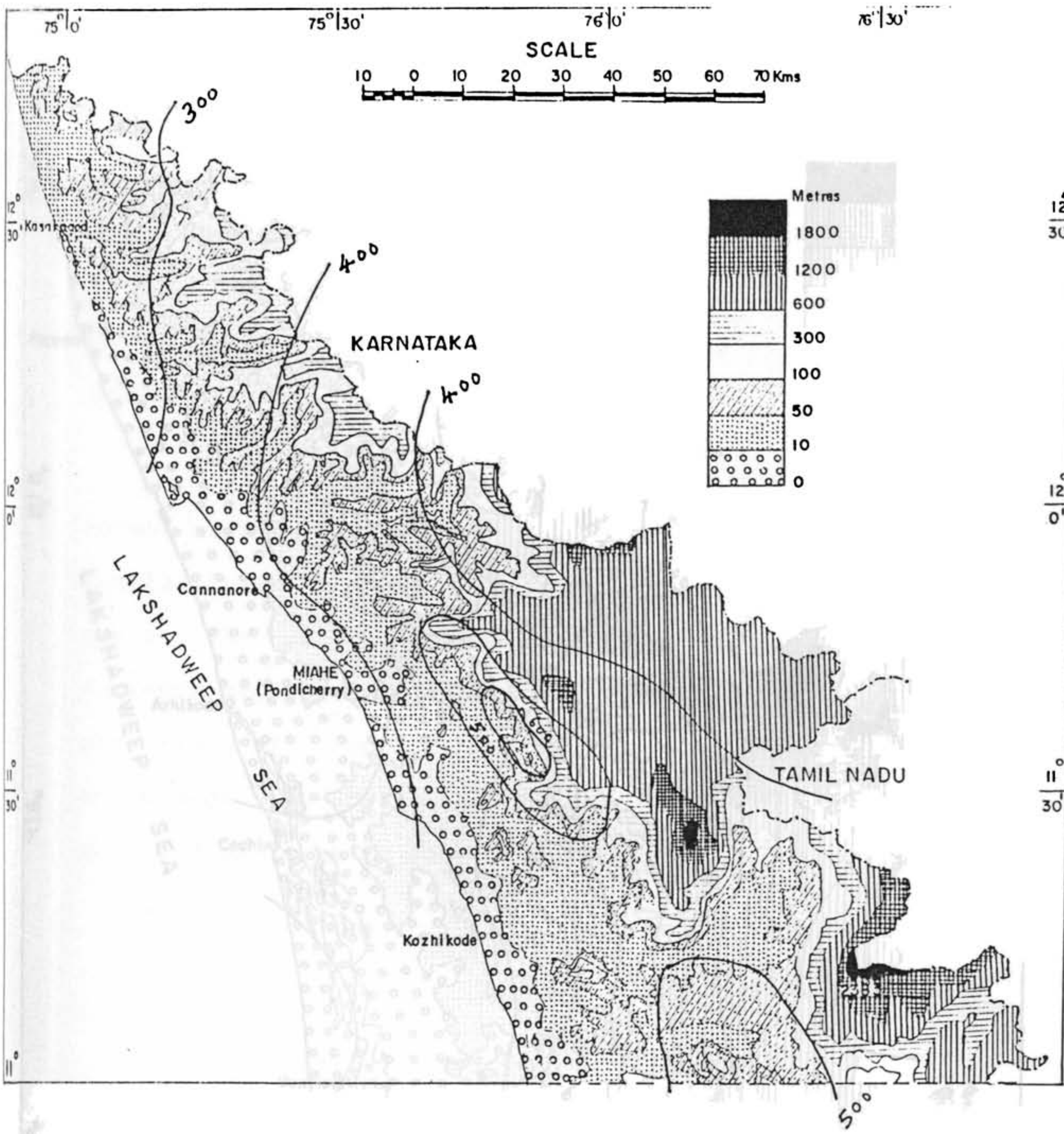


FIG. 4.13 ISOHYETS (m.m.) - OCT. - NOV. PERIOD NORMAL - ON THE RELIEF MAP OF NORTHERN KERALA

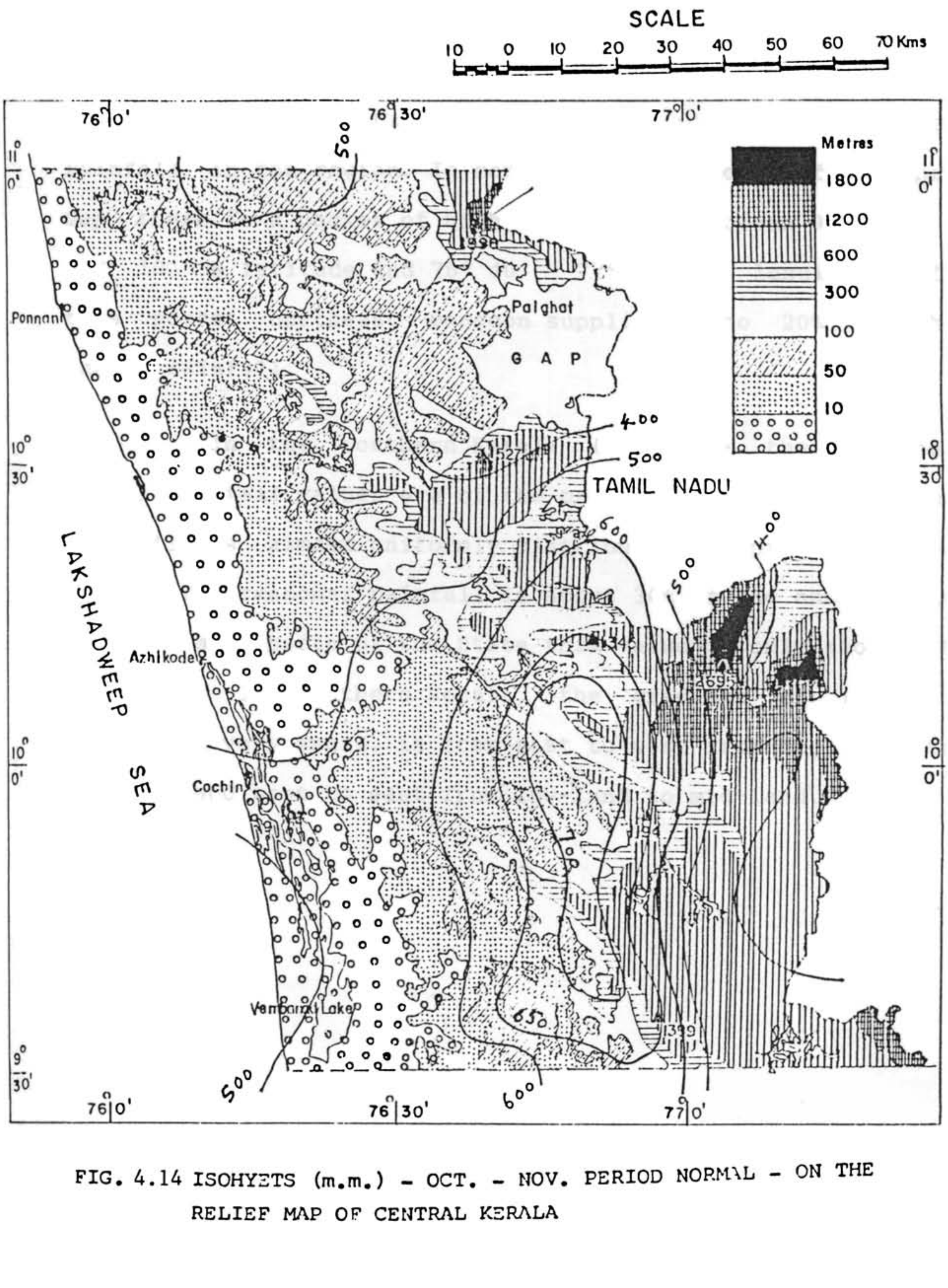


FIG. 4.14 ISOHYETS (m.m.) - OCT. - NOV. PERIOD NORMAL - ON THE RELIEF MAP OF CENTRAL KERALA

northeast winds penetrate through the Gap which causes a good rainfall in the region. In central Kerala, south of Palghat Gap there is a pocket of high rainfall in between 9° 30' - 10° 10' N latitude and 76° 40' - 77° 00' E longitude. In this pocket northeast monsoon supplies 15 to 20% of the annual rainfall.

In the southern Kerala (Fig.4.15) the seasonal normal rainfall values are of the order of 500 to 700 mm. The rainfall is almost uniformly distributed except at a few places. The seasonal rainfall is about 30% of the annual. At northern most parts of the State this value is only about 10 per cent. In southern Kerala, the gradient of isobars, eventhough very small, is from east to west from high-land to mid-land and west to east from low-land to mid-land.

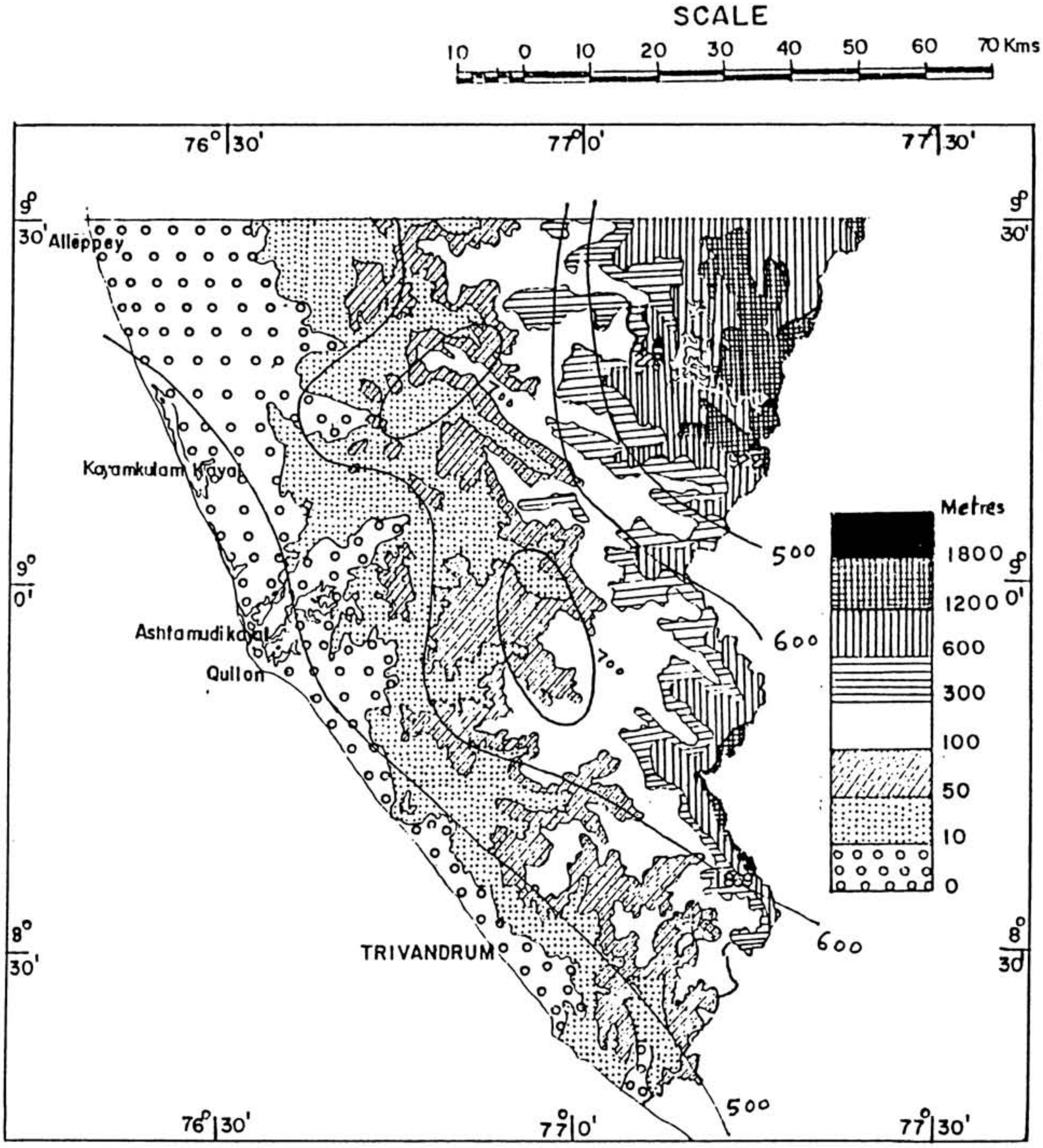


FIG. 4.15 ISOHYETS (m.m.) - OCT. - NOV. PERIOD NORMAL - ON THE RELIEF MAP OF SOUTHERN KERALA

CHAPTER 5

VARIATION OF RAINFALL WITH LATITUDE AND ALTITUDE

5.1 GENERAL

Kerala is an elongated coastal State lies in the south-western part of India. It lies between latitudes 8° N and 13° N comprising approximately 560 km in the north-south direction. Physiographically, Kerala extends from the lowlands adjoining the western sea bed, the landscape ascends steadily towards the east to the mid-lands and further on to the high lands sloping down from the Western Ghats. The mountain ranges which form a natural wall separating Kerala from the adjoining states, have an average elevation of about 1 km with peaks rising to over 2 km. The Anamalai and the Nilgiris are the tallest mountains in the Western Ghats skirting the west-coast of Indian peninsula. A remarkable feature is the Palghat Gap of about 25 km width between the Anamalai and the Nilgiris which is the only marked break in the mountain wall. The western slopes of the hills and mountains at the eastern border of Kerala receive copious rainfall during the monsoon season.

The nature of rainfall variations from south to north of Kerala associated with changes in latitude have been studied and are reported in the present chapter. For the purpose of the study, the variations in rainfall amount and the number of rainy days with latitude during annual as well as southwest and northeast monsoon periods were studied separately. Similarly, the variability of rainfall with stations located at different heights above mean sea level were also carried out to find the influence of altitude on the changes in rainfall pattern of the State.

5.2 DATA

Monthly mean rainfall data from 84 stations distributed in the entire State were utilised for the study. The stations are located latitude-wise from Parassala (8° 20' N) in the south to Kasargod (12° 31' N) in the north, and longitude-wise from the western-most station, Kasargode (74° 59' E) - which is also the northernmost station- to the eastern-most station, Marayur (77° 09'E). Table 4.1 lists the stations selected, their geographical location, altitude above mean sea level, number of years of data used, number of rainy days and the climatological monthly and annual rainfall data.

5.3 SPATIAL DISTRIBUTION OF ANNUAL RAINFALL

A three-dimensional representation of the latitude-longitude distribution of annual rainfall over Kerala State is depicted in Fig. 5.1. Annual rainfall showed two distinct peaks in the south-central as well as north-central regions. The southern peak is located in Idukki District and the northern peak is noted in Kozhikode

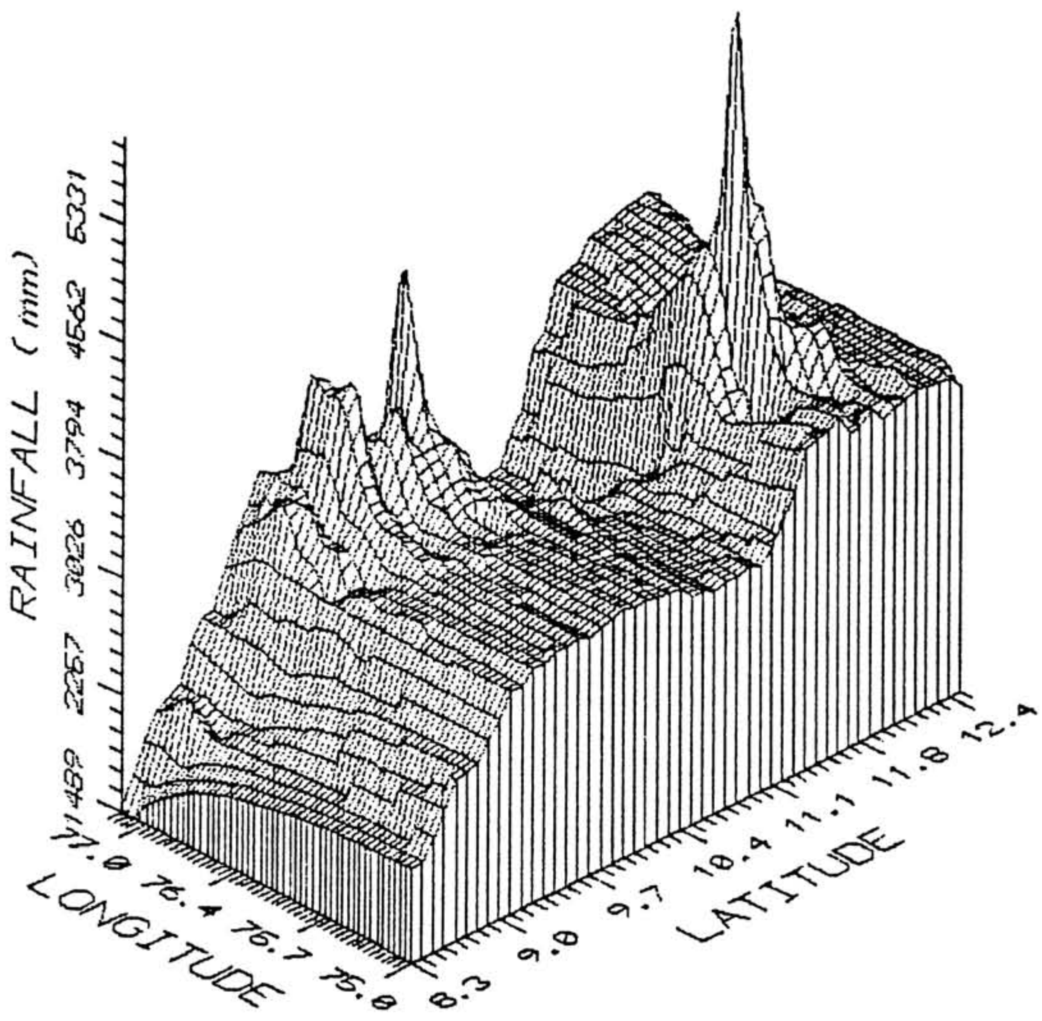


Fig. 5.1 Spatial distribution of annual rainfall

District. A region of low rainfall can be seen between the above two peaks is due to the low rainfall zone in the Palghat Gap located around 11° N.

5.4 LATITUDINAL VARIATION OF ANNUAL RAINFALL

Fig. 5.2. is a plot of the climatological mean annual rainfall with latitudes from 84 evenly distributed rainfall stations over Kerala, located from southernmost part to the northern latitude. The curve of best-fit of annual rainfall against latitude is obtained by using the 6-degree polynomial equations and are drawn as shown in Fig. 5.2.

From both Figs. 5.1 and 5.2, it can be seen that the annual rainfall over Kerala show an increase from southern-most latitude of Kerala to about 120 km northwards. Parassala, the southern-most rainfall station, located at latitude 8° 20' N, experiences the lowest annual mean rainfall of 1479 mm, which steadily increase to 3400 mm at about 9° 30' N. Between latitudes 9° 30' N and 10° 15' N, annual rainfall showed larger spatial variability. Three stations in this latitude belt showed annual rainfall well below 2000 mm. These stations are Santhanpara (1861 mm), Kumily (1721 mm) and Marayur (1349 mm). Even though the above stations are located at high altitude regions, annual rainfall is quite low comparing to other stations in the same latitude region. The main reason for a decrease in rainfall

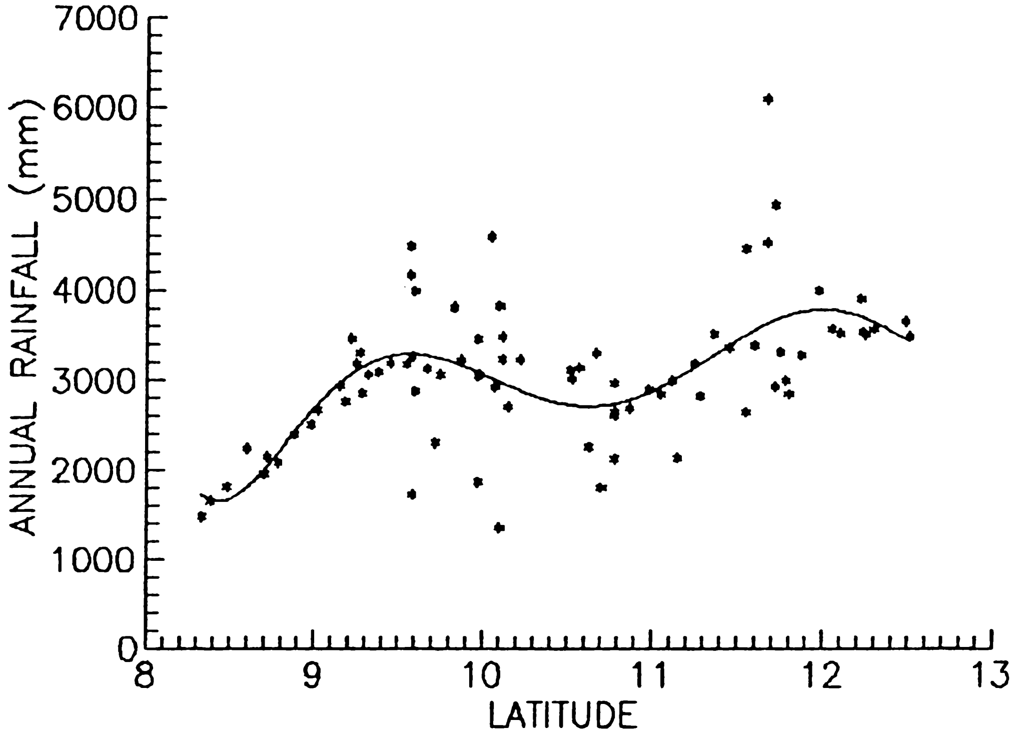


Fig. 5.2 Scatter diagram of annual rainfall versus latitude

in these stations are due to their location on the leeward side of the mountain, which reduces rainfall. On the other hand, stations which are located on the same latitude zone, namely Pirmed (4471 mm), Neriamangalam (4576 mm) and Kanjirapally (4157 mm) experiences very heavy rainfall, well above 4000 mm annually. The above high rainfall regions are not located at the same altitude levels. Neriamangalam is situated almost nearer to mean sea level, only at an altitude of 45 gpm from mean sea level. Kanjirappally is located at an elevation of 400 gpm and Pirmed is at 950 gpm. Higher amount of rainfall recorded at these stations are due to their position on the windward side of the mountain which favours condition for good rainfall.

After attaining the peak around 9° 30'N, the annual rainfall shows a decreasing trend with latitude to another 150 km northwards. The Palghat Gap plays a major role in reducing the rainfall at 11° N. An increasing trend in rainfall with large variability is again seen from 11° N to about 12° N. Heavy rainfall pockets of Kerala are situated around 12° N latitude region. Mavattom, is located at 11° 40' N, recorded the highest annual rainfall region of Kerala. In this station, an annual rainfall of 6073 mm with an average of 136 rainy days per year is reported. In addition, three more stations experiences annual rainfall well over 4000 mm in this latitude zone. They are Karingad (4918 mm), Vythiri

(4435 mm) and Kuttiadi (4504 mm). Northern portion of Kerala, beyond 12° N show a slight decrease in rainfall with lower variability.

In general, annual rainfall of Kerala shows an increase from 1479 mm in the extreme south latitude (8° 20' N) at Parassala to over 3500 mm in the northern-most latitude (12° 31' N) at Kasaragod. There are two heavy rainfall pockets seen over Kerala. One of the heavy rainfall zone is located in the southern half of the State, located between latitudes 9° and 10° N. Kanjirappally, Neriamangalam and Pirmed stations are located in this zone. Northern heavy rainfall pocket is situated in the district of Kozhikode, located near 12° N latitude. Heavy rainfall stations situated in this latitude region are Mavattom, Vythiri, Kuttiadi and Karingad.

The rainfall variation in the coastal zone of Kerala shows that the coastal belt from Cochin to Kozhikode receives an annual rainfall of around 3000 mm. The rainfall exhibits a sharp increase to the north of Kozhikode and a decrease to the south of Cochin along the coastal belt. There is a rapid decrease in rainfall is seen from Kayamkulam to the southern part of Kerala.

5.5 VARIATION OF THE NUMBER OF ANNUAL RAINY DAYS

Number of annual rainy days versus latitude is plotted in Fig. 5.3 and the best-fit curve is drawn using the 6-degree polynomial equations. There is a sharp increase in the number of rainy days with increase in latitude is noted in the southern part of Kerala, and attained the peak of 165 days near 9° 45' N latitude. Thereafter, the number of annual rainy days decrease with latitude. The annual number of rainy days attained the secondary minimum around 11° N, the region near the Palghat Gap, and then showed an increasing trend, reached the second maximum around 12° N. The rainy days decrease with latitude thereafter.

Lowest number of annual rainy days (84) reported at Parassala, the southernmost latitude station of Kerala. Another station Marayur, located near to the Tamil Nadu border and also on the leeward side of the Western Ghats, has lower number of rainy days in an year. On the other hand, highest number of annual rainy days are seen in the central Kerala, situated in Idukki District. The Kanjirapally station, located at latitude 9° 34' N, recorded 163 number of annual rainy days, and Karikode 9° 50' N, has 160 annual rainy days.

A comparison between Fig. 5.2 and Fig. 5.3 explain that the area of peak rainfall is not always associated with the region of highest number of rainy days. From Fig. 5.2 it

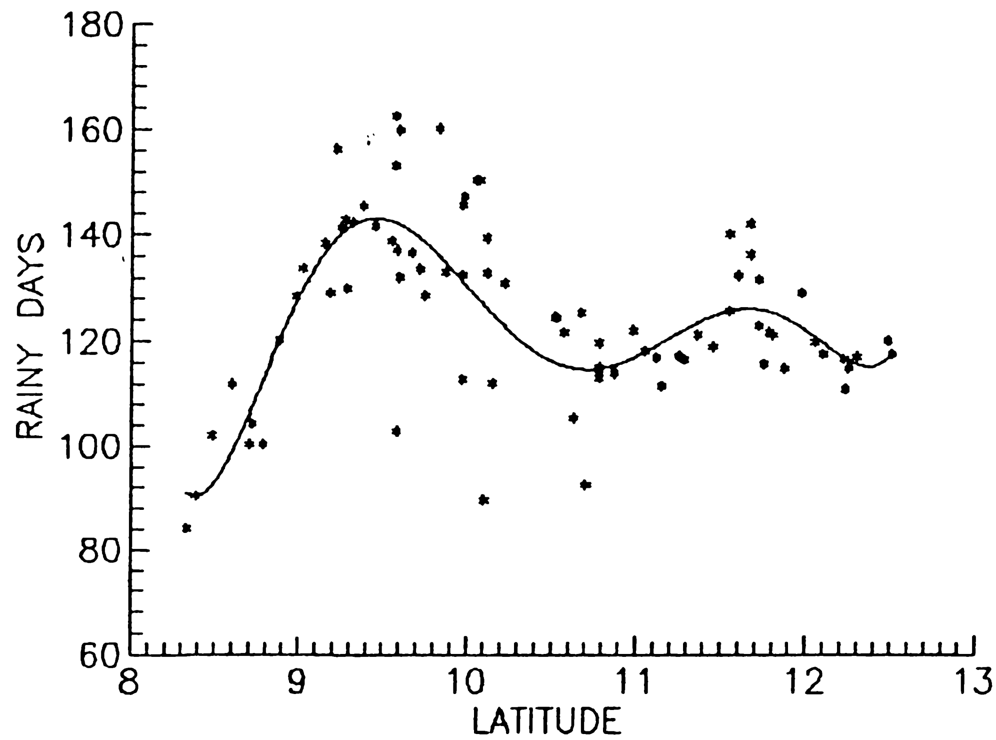


Fig. 5.3 Scatter diagram of annual number of rainy days against latitude

is evident that the highest annual rainfall region is located in northern Kerala, situated in Kozhikode District. Fig. 5.3 show that the maximum number of annual rainy days are located in the central Kerala, between 9° and 10° N latitude belt. The best-fit curve in both Figs 5.2 and 5.3 showed two peaks. The annual rainfall curve showed the maximum peak at higher latitude zone than the lower latitude, whereas the annual number of rainy days curve showed its highest peak in the central part of Kerala rather than in the northern latitudes. It is evident from these results that southern Kerala experiences more rainy days with lower intensity of rainfall. On the other hand, northern Kerala gets higher amount of rainfall with relatively less number of rainy days. The duration as well as the intensity of rainfall is quite large in the northern part of Kerala.

The study is further extended to find the influence of latitude on the two major rainy seasons of Kerala, viz., southwest monsoon season (June - September) and the northeast monsoon season (October - December), separately.

5.6 SPATIAL DISTRIBUTION OF SOUTHWEST MONSOON RAINFALL

Fig. 5.4 is the three dimensional representation of the latitude-longitude distribution of southwest monsoon rainfall over the entire State. It is evident from Fig. 5.4 that the rainfall during the southwest monsoon season have an

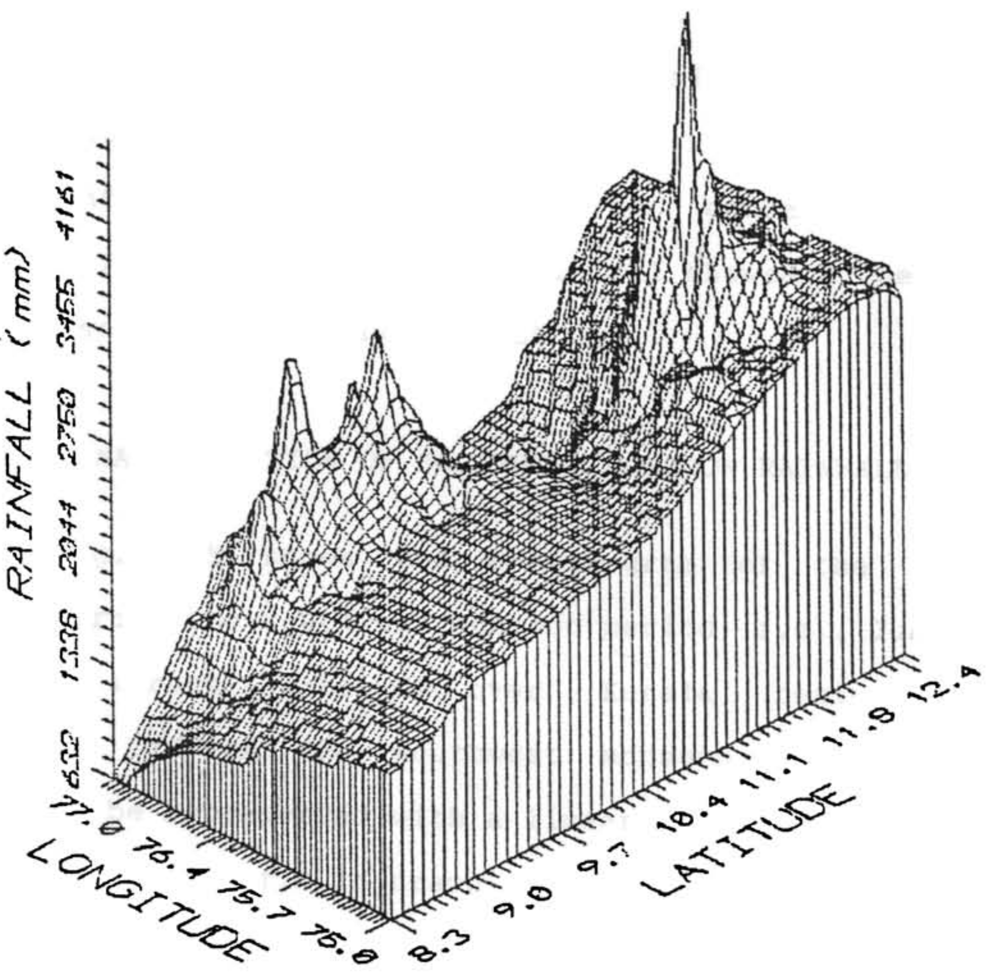


Fig. 5.4 3-Dimensional representation of SW monsoon rainfall over Kerala

increasing trend from the southern part of Kerala to the North. Southwest monsoon rainfall over Kerala region showed an increasing tendency with latitude. Superimposed on this increasing tendency, there are two distinct regions where the southwest monsoon rainfall peaks, one is situated in Idukki District and the other in Kozhikode District. Both these heavy rainfall pockets are seen in annual rainfall variations. In middle Kerala, the rainfall showed a decrease which is associated with the Palghat Gap.

5.7 LATITUDINAL VARIATION OF SOUTHWEST MONSOON RAINFALL

Fig. 5.5 shows the scattergram of the total rainfall during the southwest monsoon period, i.e., June to September, versus latitude over Kerala region. The relationship between the southwest monsoon rainfall and latitude can be represented with a linear regression equation and the line of best fit is drawn as illustrated in Fig. 5.5. A linear increase in the summer monsoon rainfall is noted from south to north of Kerala. Southwest monsoon rainfall is very less in the southern part of Kerala, of the order of 1000 mm during this season and increase four times of the order of 4000 mm in the northern latitude of the State. It is evident from the scattergram (Fig. 5.5) that relatively large variability in southwest monsoon rainfall is noted between 10° and 12° N, where the position and the orientation of the orography controls the rainfall activity. Northern Kerala

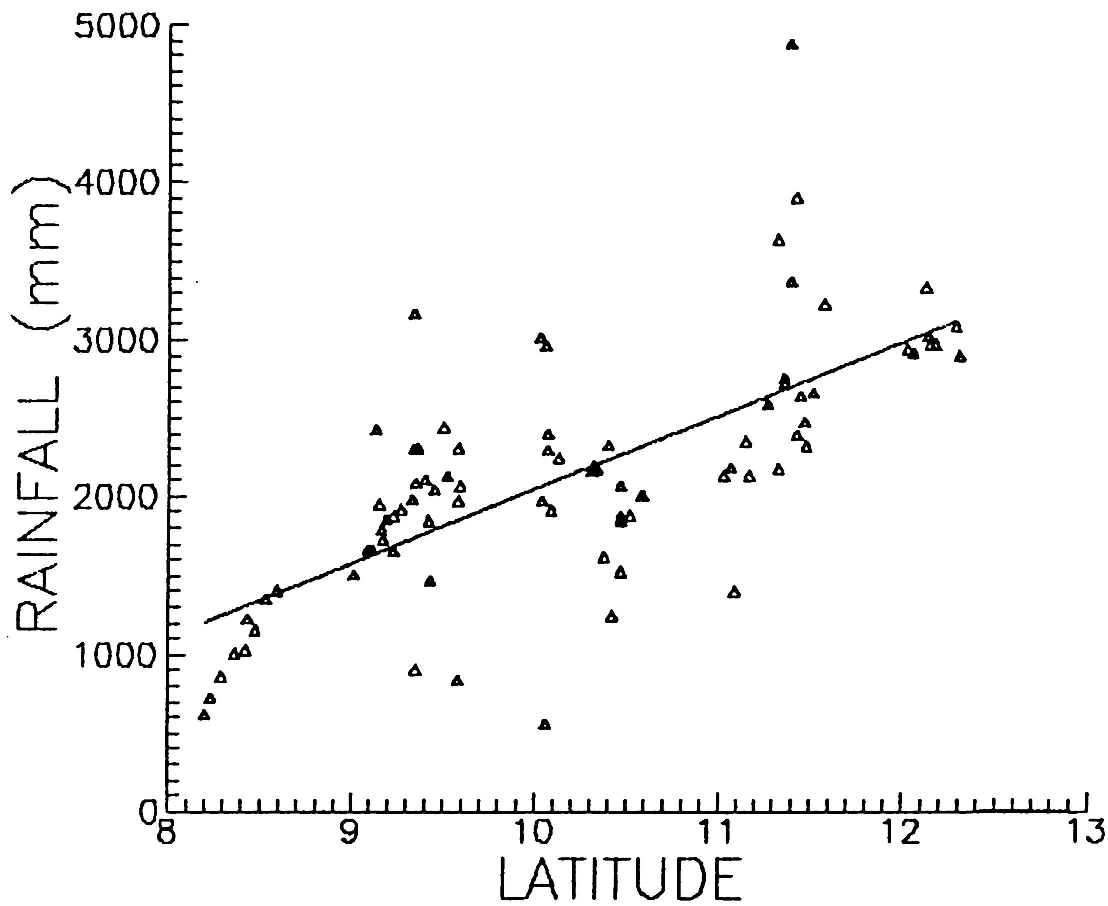


Fig. 5.5 Scatter plot of southwest monsoon rainfall versus latitude

experienced rainfall on the higher side of the regression line of the scattergram.

The linear regression equation obtained from the latitudinal distribution of southwest monsoon rainfall over Kerala shows a positive slope and derives an increase in rainfall of the order of 464 mm for every 1° latitude distance. In other words, assuming the latitudinal distance is approximately 110 km, then the increase in rainfall during the southwest monsoon season is of the order of 4.2 mm /kilometer distance. Computed correlation coefficient between southwest monsoon rainfall and the latitude is 0.697 for the 84 stations considered for the study reveal that the computed correlation coefficient (see Table 5.1) is highly significant of the order of >99% level of significance with 82 degrees of freedom.

Table 5.1 : Correlation and regression coefficients between latitude and rainfall/rainy days

	Rainfall		Rainy days	
	Corr. coeff.	Reg. coeff. (mm/°lat)	Corr. coeff.	Reg. coeff. (days/°lat)
Annual	0.445	307.1	-0.111	-1.62
Southwest Monsoon	0.697	464.0	0.595	6.45
Northeast Monsoon	-0.606	-79.1	-0.752	-3.71

5.7.1 Number of Rainy Days in Southwest Monsoon

As the case of the amount of rainfall during the southwest monsoon season, the number of rainy days during the period also showed a linear increase with latitude over Kerala. A scattergram plotted between the number of rainy days and latitude and the linear regression line are shown in Fig. 5.6. The number of southwest monsoon rainy days are less in the southern part of Kerala which increases towards the northern part of the State.

The number of rainy days in southwest monsoon period also showed a positive correlation with latitude. The correlation coefficient computed between the number of rainy days and latitude during the summer monsoon season gives a positive and statistically significant correlation of 0.595. The regression coefficient show that the number of rainy days during the southwest monsoon increases of the order of 6.45 days per latitude from the south of Kerala to the north.

5.8 SPATIAL DISTRIBUTION OF NORTHEAST MONSOON RAINFALL

Spatial variation in rainfall, represented by the 3-dimensional graphical presentation of rainfall during the northeast monsoon season is depicted in Fig.5.7. The decrease in rainfall from south to north of Kerala can be seen in the

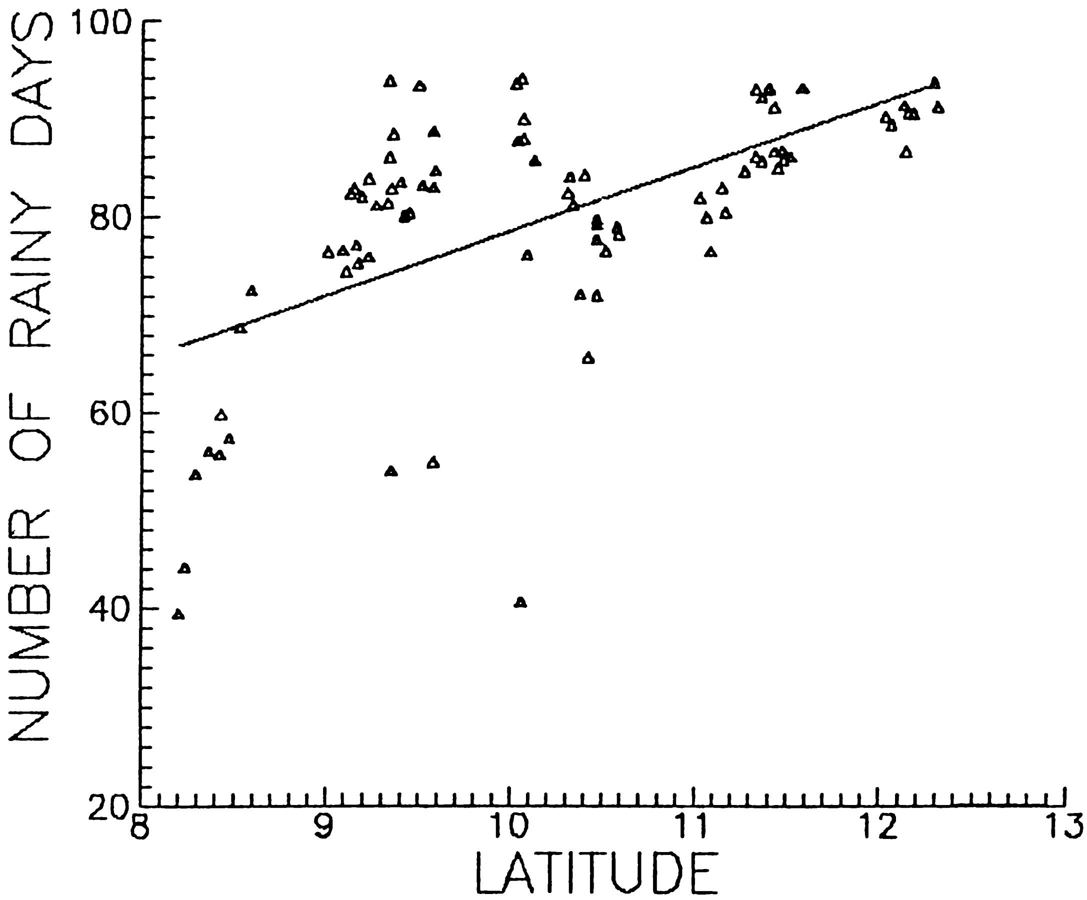


Fig. 5.6 Scatter plot of normal SW monsoon rainy days against latitude

Fig.5.7. Apart from localised high rainfall zones noted in the distribution, the rainfall during the northeast monsoon season have a strong inverse dependence on latitude.

5.9 LATITUDINAL VARIATION OF NORTHEAST MONSOON

Latitudinal variation in northeast monsoon rainfall over Kerala observed during the season October to December is plotted in the scattergram and the linear regression line is drawn as shown in Fig. 5.8. The rainfall during the northeast monsoon season is found to be decreasing with increasing latitude, which is just opposite to that observed in the case of southwest monsoon season. Higher rainfall during the months of October to December is noted in the southern part of Kerala and it decreases towards the northern latitudes. Relatively higher rainfall is noted between 9° and 10° N latitude in the southern half of Kerala and around 12° N in the northern part of the State. Rainfall in both these regions, showed higher values than the regression line drawn in the scatter diagram.

In the southern region, the mean rainfall during the northeast monsoon period is estimated as 700 mm, which decreased to its half of 350 mm in the northern part of Kerala. The regression coefficient between rainfall and latitude showed that the rainfall during the northeast monsoon season is decreasing at the rate of 79 mm per degree

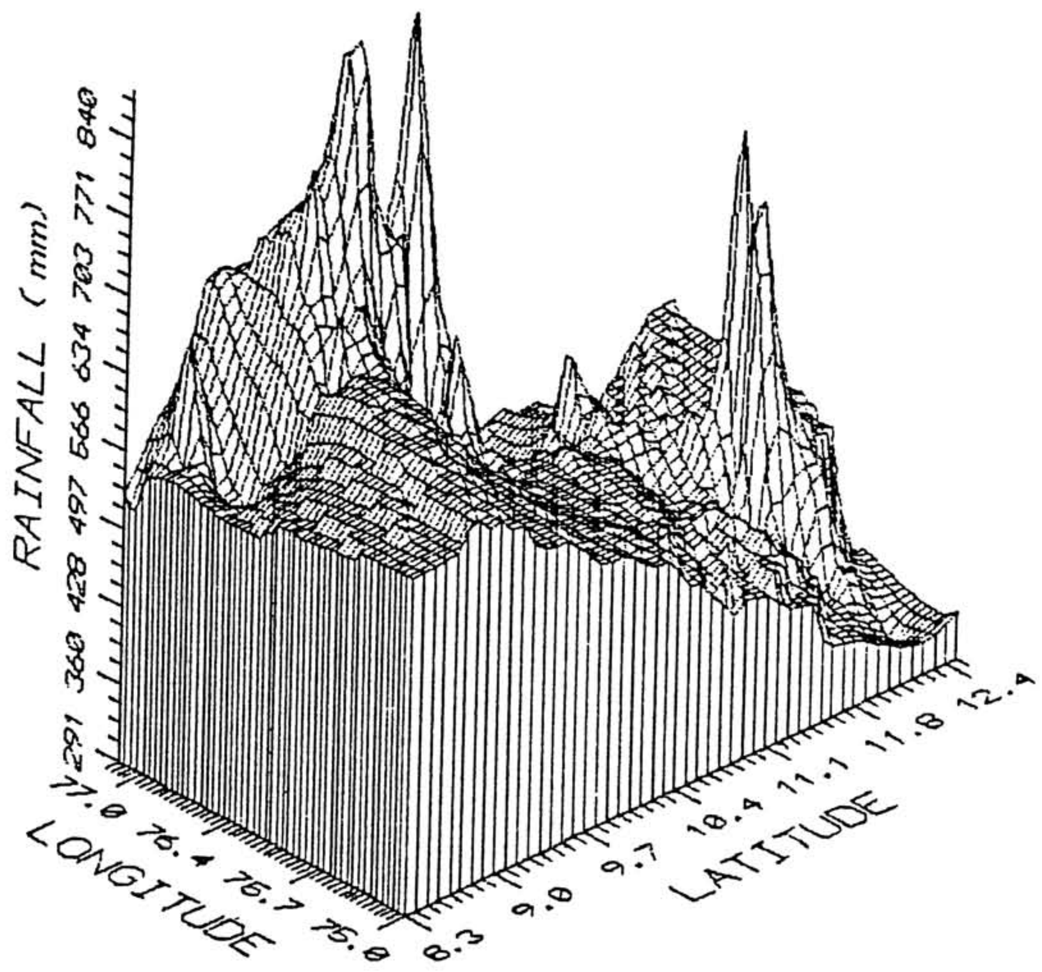


Fig. 5.7 3-Dimensional representation of NE monsoon rainfall over Kerala

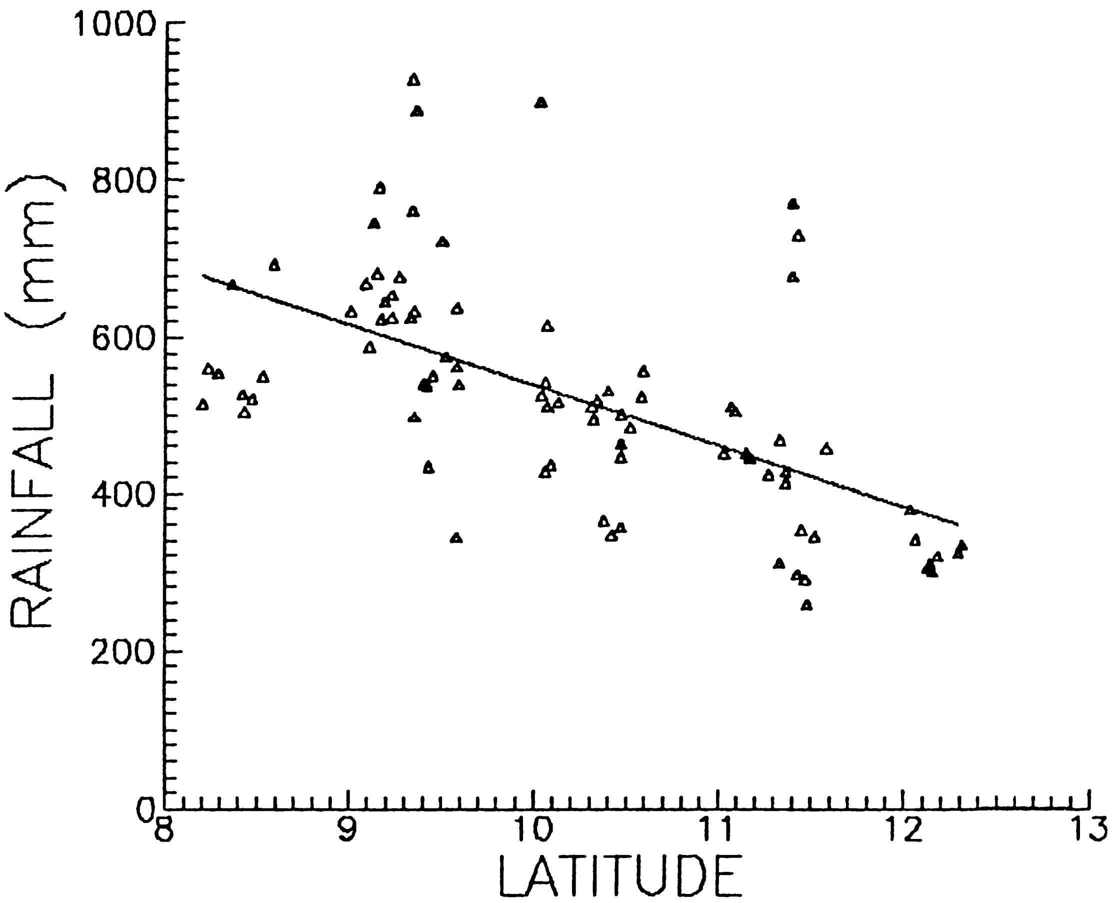


Fig.5.8 Northeast monsoon rainfall versus latitude

latitude. The computed correlation coefficient between latitude and rainfall for the 84 stations considered for the study showed a value of -0.606, which is negatively significant at 99% level of significance.

5.9.1 Number of Rainy Days in Northeast Monsoon

Average number of rainy days during the northeast monsoon season versus latitude is plotted in Fig. 5.9. As in the case of rainfall during this season, the number of rainy days are also decreasing with latitude. South of 9°N latitude, average number of rainy days are less to that of the regression line. Higher number of rainy days are noted between 9° and 10° N latitude region in the southern part and around 12° N in the northern part of Kerala. Both these regions showed higher rainfall than that estimated by the regression equation. The region located between 10° and 11° 30' N latitude belt experiences lower number of rainy days during this season. The average number of rainy days in the south is estimated as 32 is decreased to its half in the northern region.

The estimated correlation coefficient between latitude and number of rainy days during the northeast monsoon season is -0.752, which is also highly significant. The regression coefficient between the above two parameters showed a value of -3.71 rainy days per degree latitude.

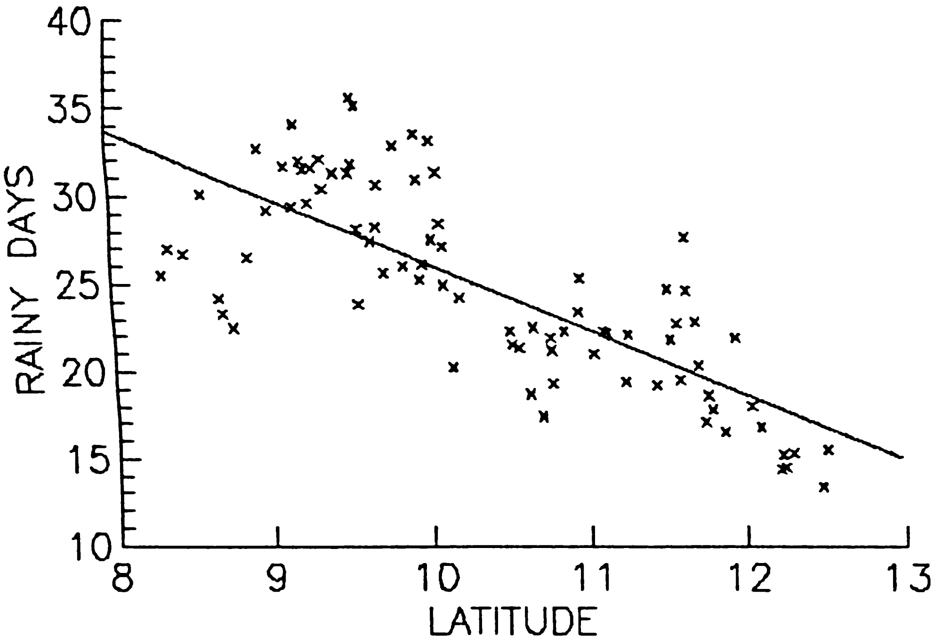


Fig. 5.9 Scatter plot of NE monsoon rainfall days against latitude

5.10 SPATIAL DISTRIBUTION OF STATION HEIGHT

Fig. 5.10 represents the height of stations above mean sea level considered for the study and their geographical location, which is represented in a 3-dimensional graphical manner using the SURFER graphics software. High altitude stations are generally situated in the south-central part of the State. High range stations like Munnar (1150 m), Devikulam (1650 m), Kumily (1100 m) and Santanpara (1097 m) are all situated in this part of the State. These stations are located above 1 km from the mean sea level. The location of Palghat Gap can be clearly depicted in the Fig. 5.10. In the northern part of Kerala, high altitude stations, such as Ambalavayal (974 m), Vythiri (945 m), Manathavady (900 m) and Chedalath (800 m) are situated. Other stations with lower height above mean sea level can also be seen from the Fig.5.10.

5.11 EFFECT OF ALTITUDE ON RAINFALL

In this section, a study on the linear relationship between the height of the station above mean sea level and the normal annual rainfall of the station has been carried out. The study is further extended to find the changes in rainfall during both southwest and northeast monsoon seasons.

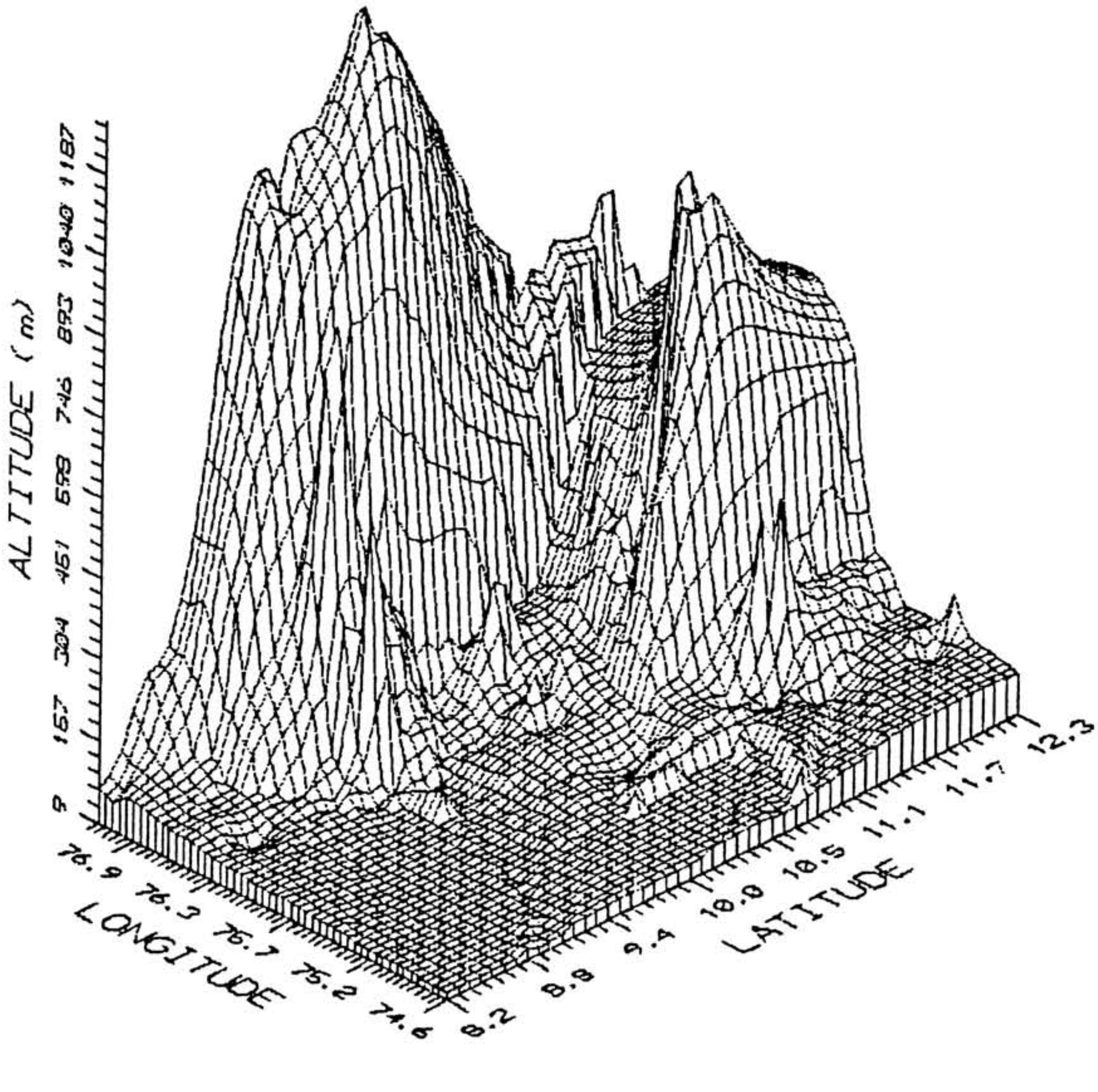


Fig. 5.10 3-Dimensional representation of the height of rainfall stations above msl

The influence of the height of the station above mean sea level on rainfall during annual, southwest monsoon and northeast monsoon periods are illustrated in the three scatter diagrams shown in Figs. 5.11, 5.12, and 5.13, respectively. From these figures, it seems that the altitude factor alone does not have significant influence on the rainfall of a station. In the case of annual rainfall, the stations near mean sea level experiences rainfall in the range of 500 mm to 3500 mm, in which most of the stations have rainfall around 2000 mm. Stations located at high altitude regions are also recorded rainfall in the same range. It is evident that the criteria of altitude factor alone does not hold good for relatively higher rainfall compared to that of the mean sea level stations. Similarly, southwest and northeast monsoon rainfall are also not shown significant influence by the station height (see Figs. 5.12 and 5.13).

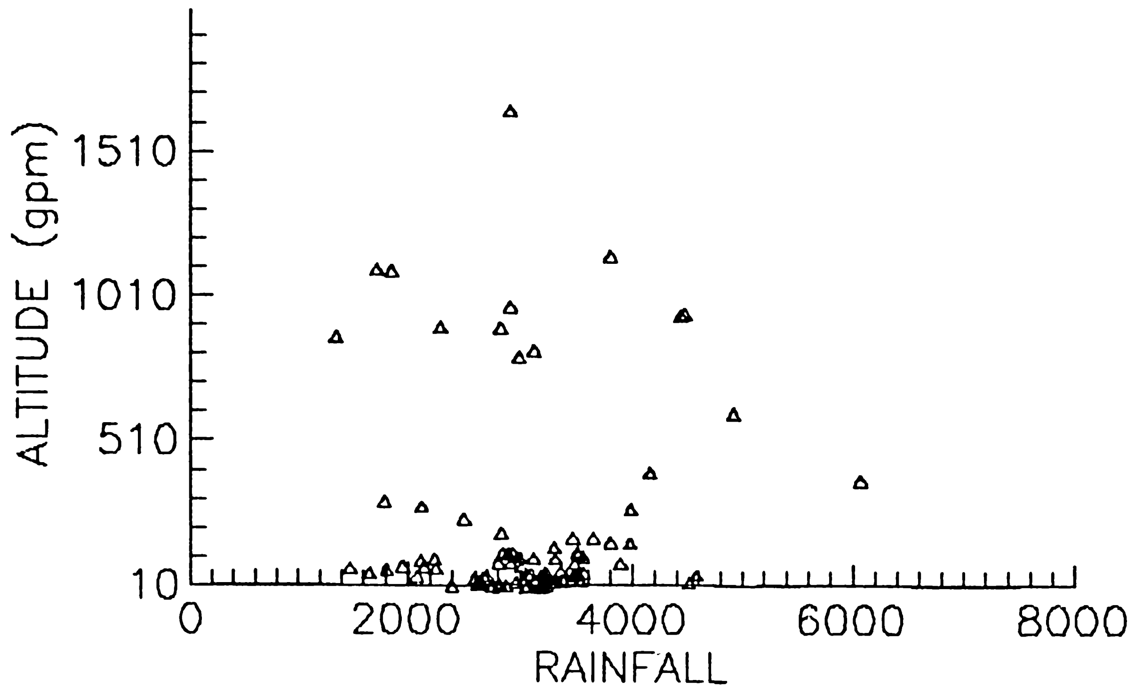


Fig. 5.11 Scatter plot of annual rainfall versus altitude

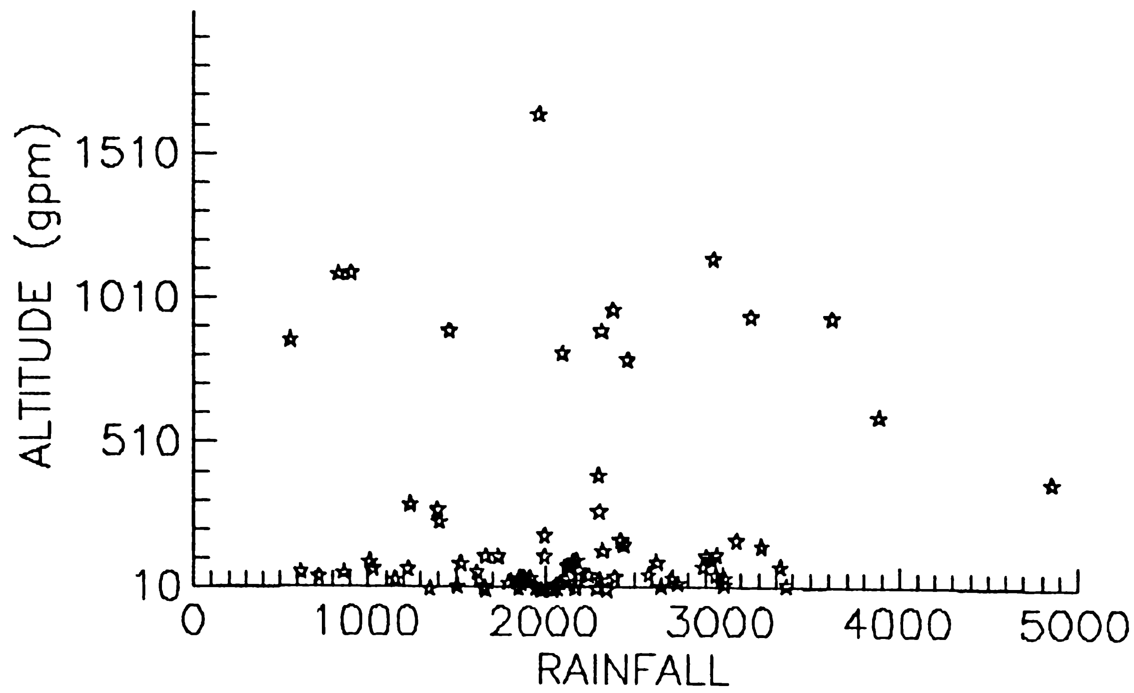


Fig. 5.12 Scatter diagram of SW monsoon rainfall vs altitude

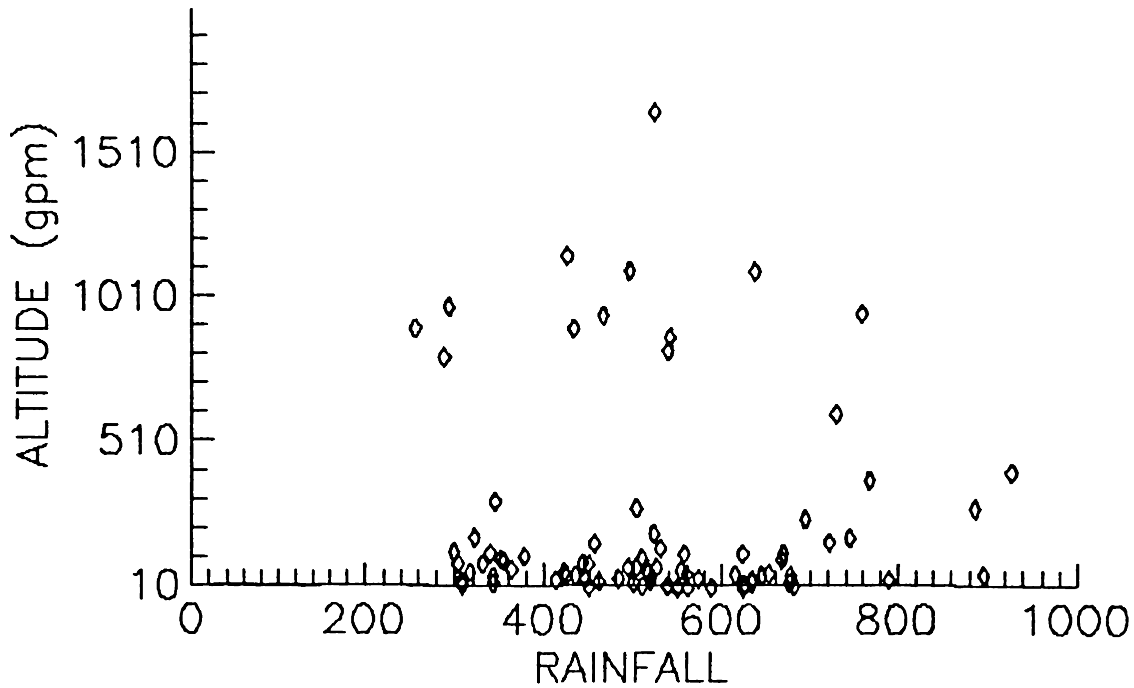


Fig. 5.13 Scatter diagram of NE monsoon rainfall versus altitude

CHAPTER 6

SPATIAL VARIABILITY ON THE SEASONAL CYCLE IN RAINFALL PATTERN OF KERALA

6.1 GENERAL

Kerala gets abundant rainfall but the disparity and distribution vary in space that some areas experience relatively less rainfall and in some other regions the major portion of the rain goes unutilised. The year-to-year variation is also considerably large, that the same area may have dry in one year and flood in another. Devastating floods and parching droughts at some portion or other of the Kerala State are usual features. The average annual rainfall of 3000 mm spread over about 10 months in the southern parts and about 8 months in the northern parts of Kerala. Most of this rainfall is received during the southwest and northeast monsoon seasons, with the maximum in June-July months.

The aim of the study in this Chapter is to find the spatial changes in the precipitation pattern at different parts of the State, based on monthly mean precipitation data obtained from various stations located all over Kerala. Harmonic analysis is employed for the purpose of the investigation.

6.2 METHOD OF ANALYSIS

The harmonic analysis is a powerful tool to understand the spatial and temporal variations of different meteorological parameters (Panofsky and Brier, 1960). A harmonic analysis study on the annual precipitation patterns reveal the spatial variations of various rainfall characteristics over the region. It delineates the geographical extent of various precipitation regimes and highlights the boundaries between them. The method of harmonic analysis have widely been used to investigate seasonal precipitation (e.g.: Horn and Bryson, 1960; Hsu and Wallace, 1976; Kirkyla and Hameed, 1989).

In the present study, the formula used by Kirkyla and Hameed (1989) has been adopted for the computations of the seasonal changes in precipitation based on harmonic analysis. The harmonic analysis is based on the mathematical principle that a curve viewed as a function may be represented by a series of trignometric function. The mathematical formula given by Kirkyla and Hameed (1989) for the computation is

$$X = \langle X \rangle + \sum_{i=1}^{N/2} A_i \cos((360\, it/P) + \phi_i)$$

where $\langle X \rangle$ is the arithmetic mean, A_i is the amplitude of the harmonics, ϕ_i is the phase angle of the corresponding harmonics, N is the number of observations and X is the value at time t. In the present analysis we used the monthly mean values and P is therefore, 12 months.

Monthly mean values of precipitation from 84 rainfall stations located at different parts of the Kerala State, as shown in Table 4.1 of this thesis, have been utilised for the study.

The nature of the seasonal variations demonstrating the curve can be understood by a comparison of the sizes of the amplitudes, A_i. A large first harmonic amplitude shows strong seasonal variation, while a relatively large second harmonic amplitude indicates strong semiannual variations. The phase angle ϕ_i can be used to determine the time of the year of maximum of a given harmonic.

In general, long period harmonics represents large scale feature of atmospheric circulation while short period harmonics indicate influences of local phenomena. The method of harmonic analysis, therefore, helps to delineate and emphasis various boundaries and areas of transition as well as regional characteristics that may otherwise be undetected.

6.3 RESULTS AND DISCUSSION

6.3.1 Spatial distribution of rainfall variance

Rainfall variance, represented by the sum of squares of all the six amplitudes in the seasonal cycle are plotted at each stations on a map of Kerala and are illustrated in Fig. 6.1. There are two variance maxima, correspond to the two heavy rainfall pockets in Kerala are noted. Larger variance in rainfall is found in Kozhikode District. The second maximum variance is found in the Idukki District, but the variance is only half of that noted in Kozhikode District. Comparatively low variability in rainfall is found in the southern part and central part of Kerala. The central low variance region is associated with the low rainfall zone due to the Palghat Gap. Southern District of the State, Trivandrum experiences the lowest variance in the rainfall.

6.3.2 Variation in the amplitude of annual cycle (A_1)

The distribution of the square of the amplitudes of annual cycle in precipitation over Kerala is depicted in Fig. 6.2. Higher amplitudes of annual cycle in rainfall are noted at two regions over the State. Near the north central

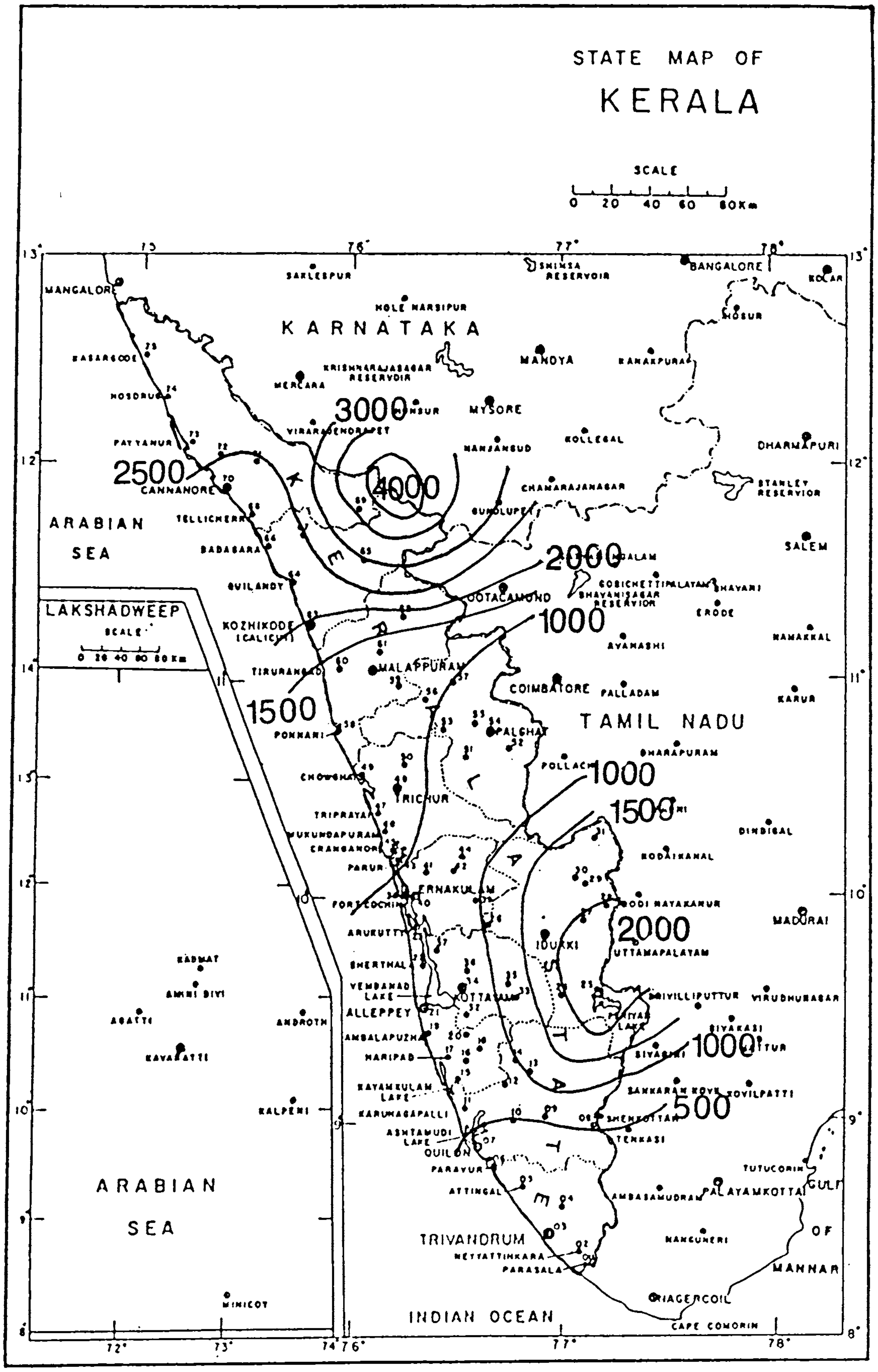


Fig. 6.1 Spatial distribution of rainfall variance

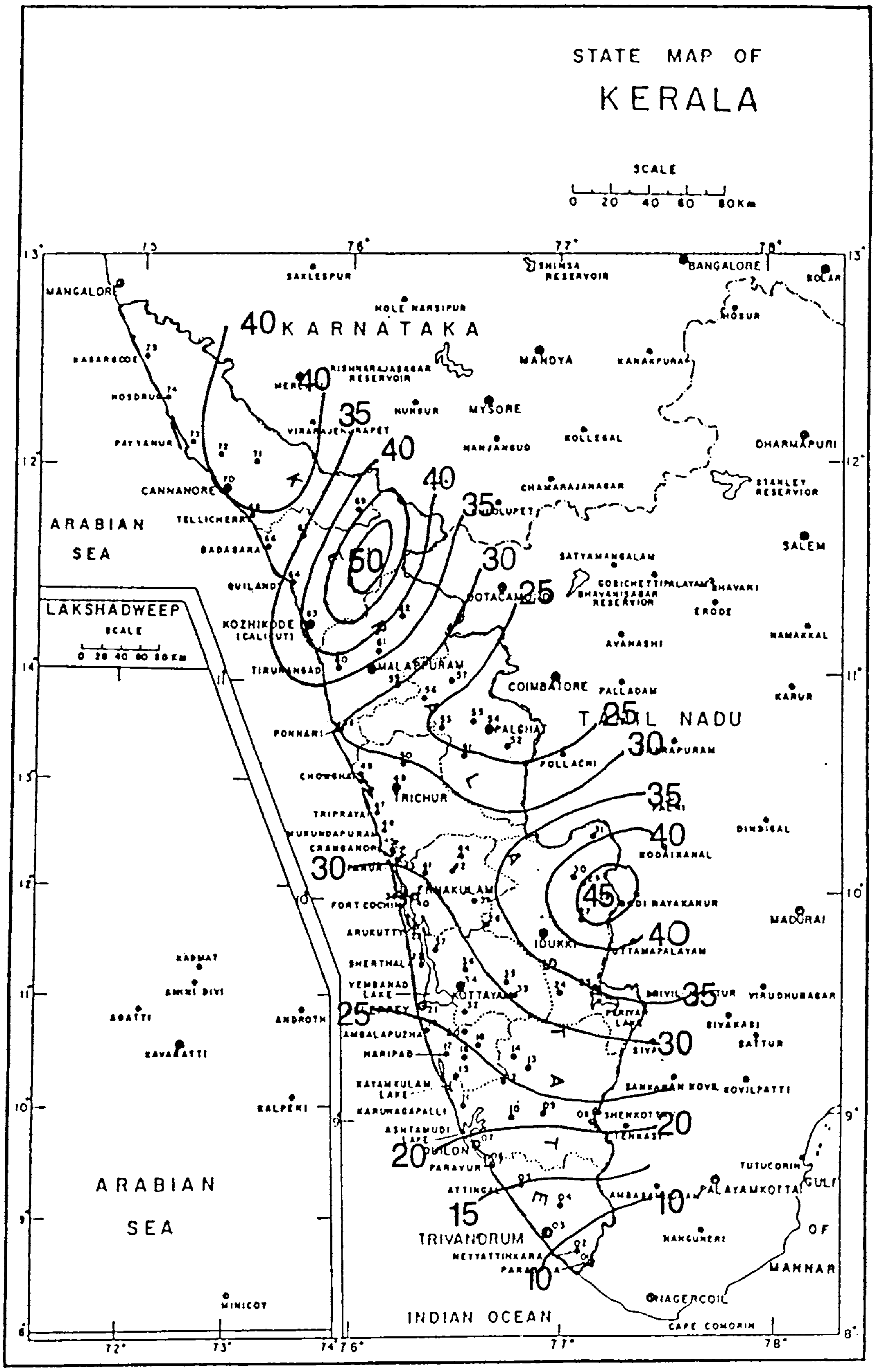


Fig. 6.2 Amplitude of annual cycle in rainfall(cm)

Kerala, centered between 11 and 12° N latitude, highest amplitudes in annual cycle of the order of 50 cm and above are noted. A secondary maxima of the annual amplitude is found in the high range regions of Idukki District, where the orography plays a major role in the annual precipitation pattern of the State. Central part of interior Kerala, in Palakkad District showed lower amplitude in the annual rainfall pattern. The annual amplitudes gradually decrease towards the northern Districts beyond Kozhikode. The southern districts showed rapid decrease in the annual amplitude in rainfall from 45 cm to 7 cm from Idukki to the southern tip of Kerala.

The coastal regions of Kerala showed a linear increase in the annual amplitude with latitude. The southern coastal station at Trivandrum showed an amplitude of 12 cm, which increased to 44 cm at the northern coastal station, Kasargod. Larger variability in the annual amplitude in rainfall can be observed in the interior part of Kerala. Similar to the annual precipitation pattern, the annual amplitude showed two maxima, one centered near the Idukki District and another in Kozhikode District. In between these two annual amplitude maxima, there is a minimum amplitude zone can be noted in Palakkad District. In this region the annual rainfall also show lower values due to the Palghat Gap in the Western Ghat mountain ranges.

In general, the amplitude of the annual cycle is found to be directly connected with the annual mean precipitation pattern. The region of highest rainfall shows larger magnitude and low rainfall areas exhibit lower amplitude in annual cycle.

6.3.3 Variation in the amplitude of semi-annual cycle (A_2)

The spatial distribution in the semi-annual amplitude in rainfall are plotted at various stations in Kerala and the isolines are drawn as indicated in Fig. 6.3. Semi-annual amplitudes are generally weak compared with the magnitude of the annual oscillations. In the northern part of Kerala, the magnitude of the annual amplitude is found to be nearly double to that of the semi-annual amplitude. In the central part of the State, the semi-annual amplitude become only one-third or still less to its annual amplitude. Semi-annual amplitude attains its magnitude near to the annual amplitude towards the southernmost part of the State.

The large amplitude semi-annual oscillations (30 cm) are noted in the Kozhikode District, where the annual oscillations are also found to be maximum. South-central

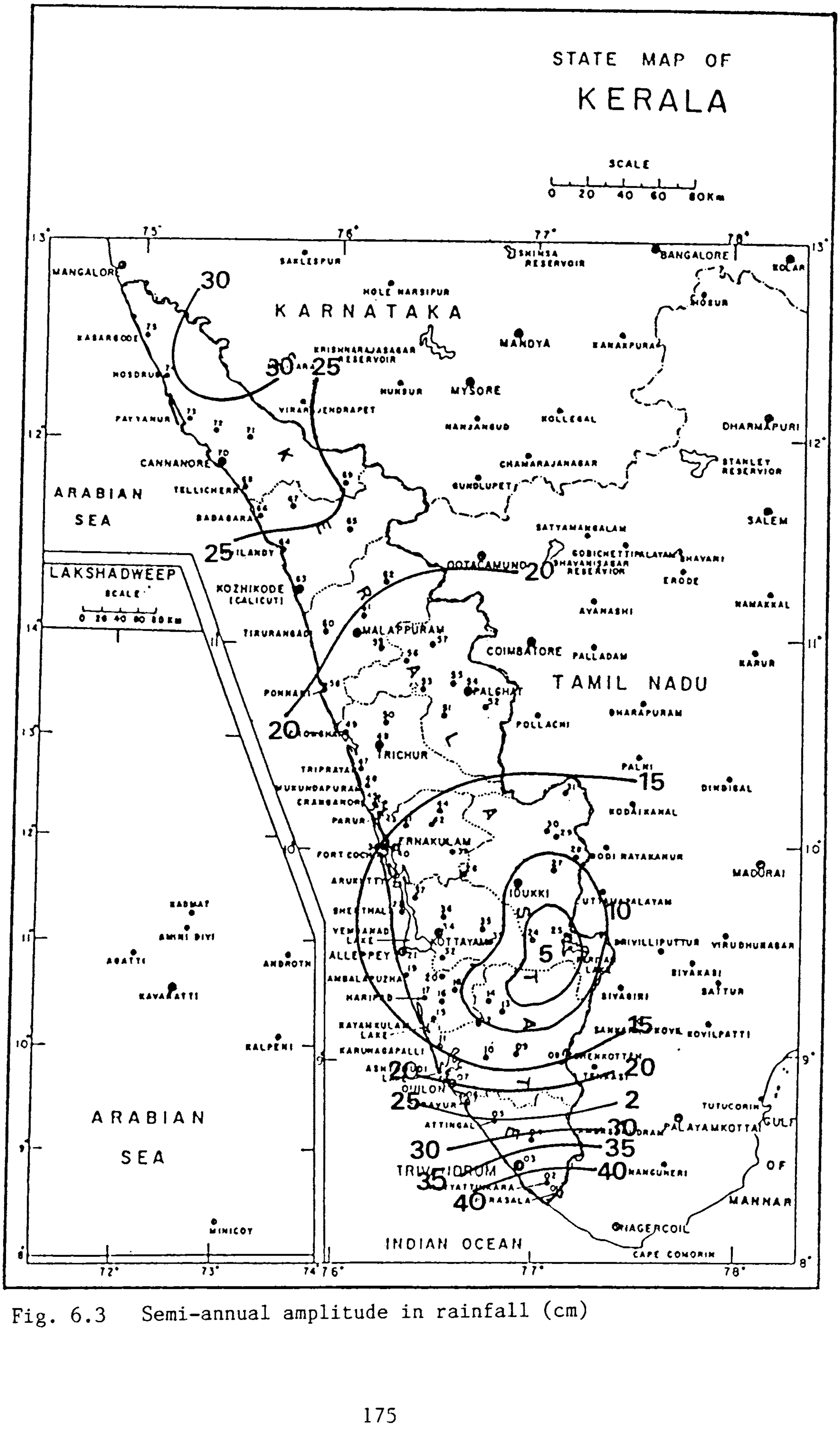


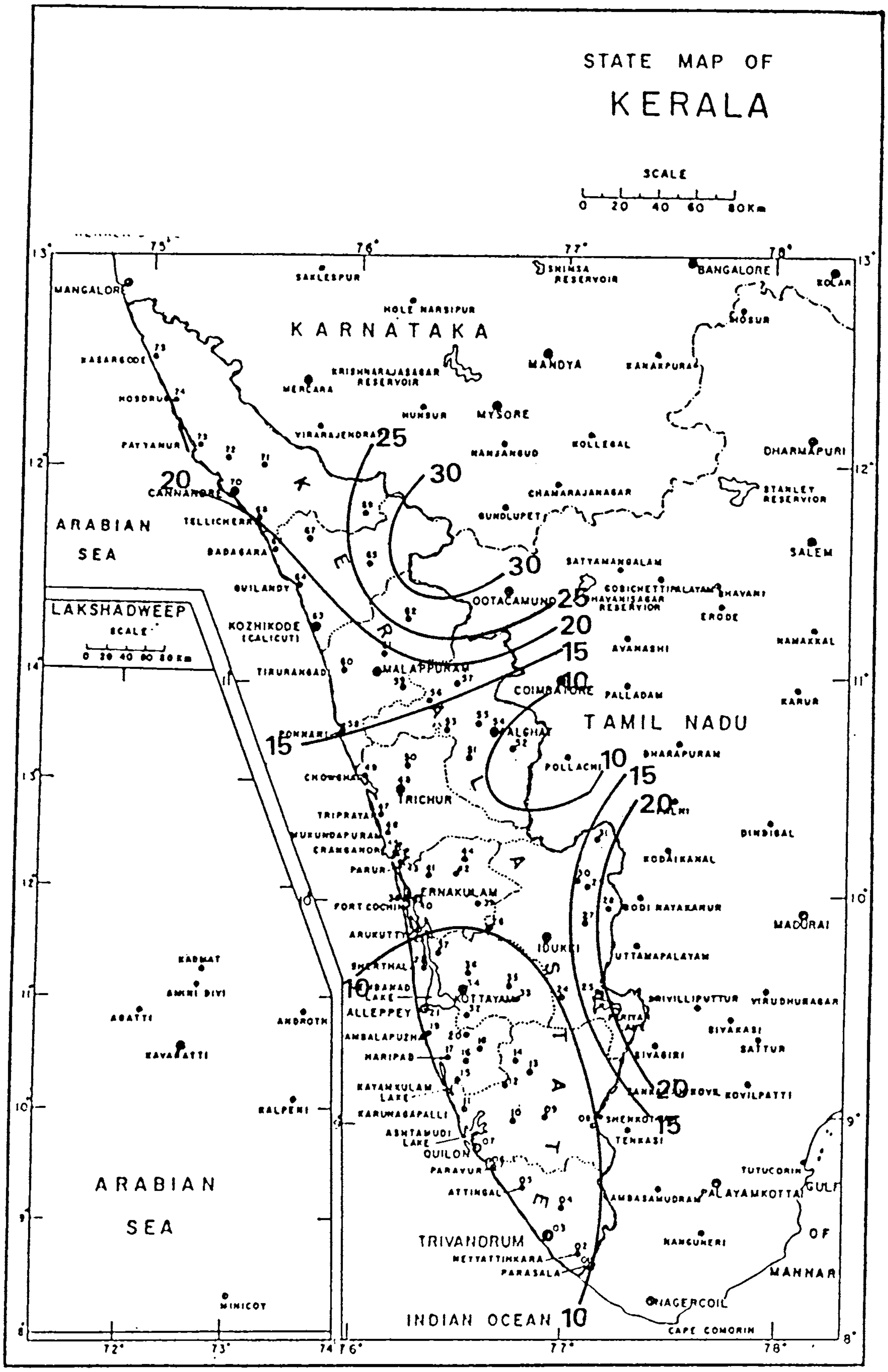
Fig. 6.3 Semi-annual amplitude in rainfall (cm)

interior part of Kerala, situated in Idukki District also experiences relatively high magnitude in semi-annual oscillations.

6.3.4 Ratio of Annual to Semi-Annual Amplitudes (A_2^2 / A_1^2)

The ratio of the square of the amplitudes of the first and second harmonics is a convenient way of determining the relative importance of these two harmonic components. Fig. 6.4. illustrates the percentage distribution of the ratio of the square of the annual to semi-annual amplitudes over Kerala. In the northern parts of Kerala, the square of the amplitude of second harmonic oscillation (semi-annual oscillation) is about 30% of the amplitude of the first harmonic (annual) oscillation. The ratio decreases from north to south and attain the lowest value of 0.12 near 9° 20'N. Thereafter, there is steep increase in the ratio of the amplitudes are noted towards the southern part of the State.

The spatial distribution of the percentage ratio of the square of the amplitude of the semi-annual to annual oscillations in the seasonal cycle indicate that, the annual oscillations are larger in magnitude in the northern Kerala region, which decrease towards the lower latitude region. In the southern part, especially in Trivandrum District, the


STATE MAP OF
KERALA
SCALE
0 20 40 60 80Km
KARNATAKA
TAMIL NADU
ARABIAN SEA
LAKSHADWEEP
ARABIAN
SEA
INDIAN OCEAN
MANGALORE
CANNANORE
TELLICHERRY
KOZHIKODE (CALICUT)
MALAPPURAM
PONNANI
TRICHUR
ERNAKULAM
ALLEPPEY
KOTTAYAM
IDUKKI
QUILON
TRIVANDRUM
COIMBATORE
OOTACAMUND
MYSORE
BANGALORE
DHARMAPURI
SALEM
MADURAI
TUTUCORIN
NAGERCOIL
GULF OF MANNAR
25
30
30
25
20
15
10
15
10
15
20
10
20
15
10

annual oscillations in the seasonal cycle are rather weak and the semi-annual oscillation become equally strong as that of the annual oscillations. In this part of the State, nearly ten months of the year experience rainfall, during both southwest and northeast monsoon seasons and the pre-monsoon thunder-shower period. The northeast monsoon are quite active in the southern part, where the southwest monsoon is not intense to that compared to the other part of the State.

6.3.5 Contribution of the Annual, Semi-annual and Tri-annual Oscillations

The relative contribution from the first three harmonics to the seasonal variance is given by the ratio of the squares of their amplitudes to the sum of squares of all six amplitudes. The ratio close to unity suggests that the first three harmonics account for most of the seasonal variations in the curve; on the other hand, a smaller fraction implies a more complex annual curve with a greater amount of variability contained in the high frequency harmonics . Fig. 6.5 illustrates the contribution of the first three harmonics to the sum of all the harmonics of the seasonal cycle in precipitation. Except, in the southern tip of the State, Kerala experiences more than 96% of the total

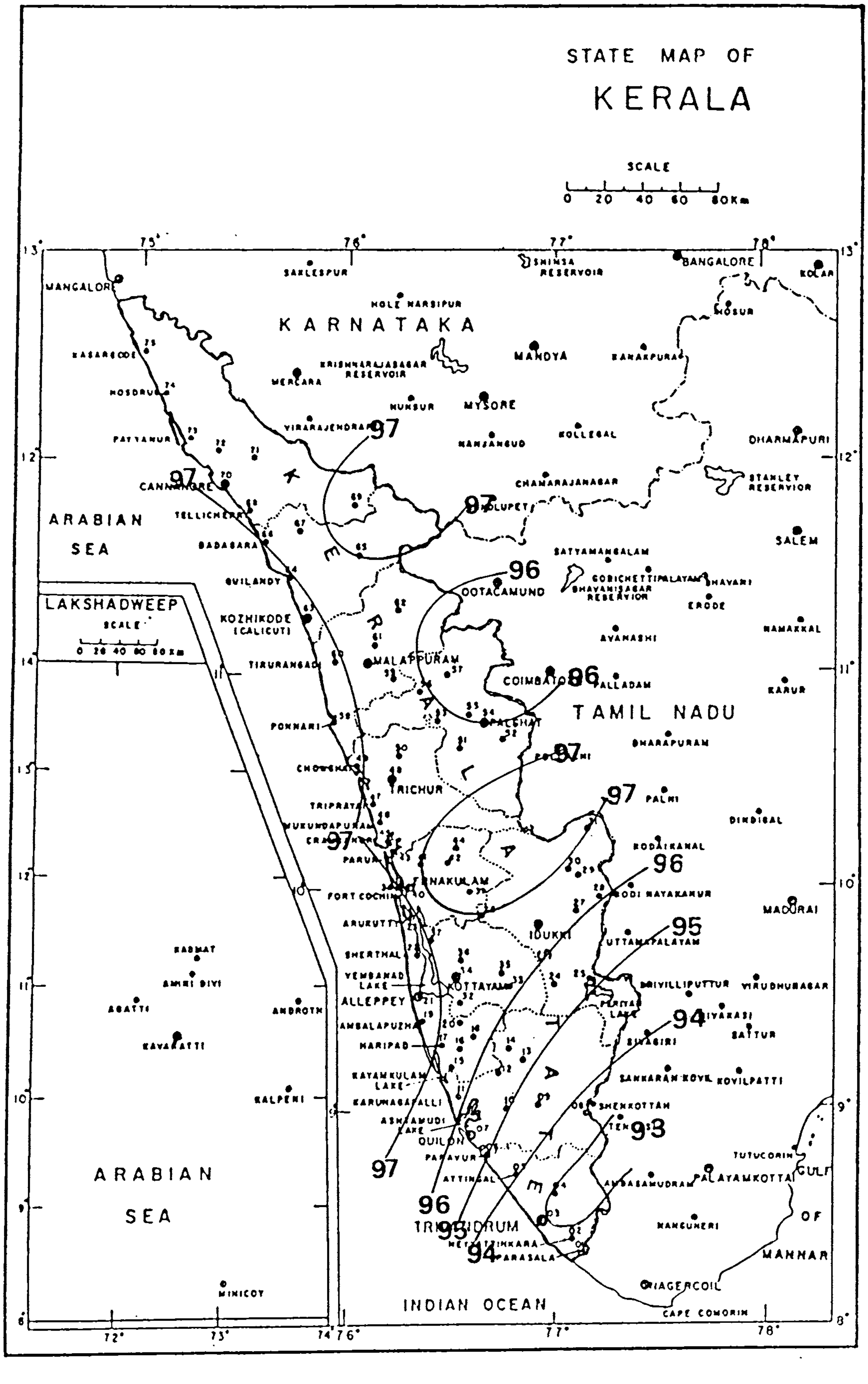


Fig. 6.5 : Contribution of the amplitude of the major oscillations in the seasonal cycle (in per cent)

variability in rainfall is due to the contribution from the first three harmonics. Coastal part of the State, showed more than 97% of the contribution due to the first three harmonics of the seasonal cycle. Short period oscillations are not found to be significant in the major portion of the State. The localised short period cycles seem to have some influence on the southern-tip of Kerala, where the ratio falls below 0.95. The contributions of the annual, semi-annual and tri-annual oscillations in precipitation contributes more than 96% of the total variability in the rest of the State.

6.3.6 Phase of Annual Cycle

Fig.6.6 is a plot of the phase of annual cycle, indicate the time of maximum occurrence of annual oscillations in rainfall, at various part of the State. The isolines in Fig. 6.6 represent the day of maximum occurrence starting from July 1. All regions in Kerala showed the maximum annual amplitude in the month of July, the month of intense southwest monsoon rainfall season. The isolines of the amplitude of first harmonics are found to be more or less parallel to the coastal belt, running from north to south of the entire Kerala State. Coastal stations showed the annual phase during early July, which gradually increased as moving towards the mid- and high land parts of Kerala. In other

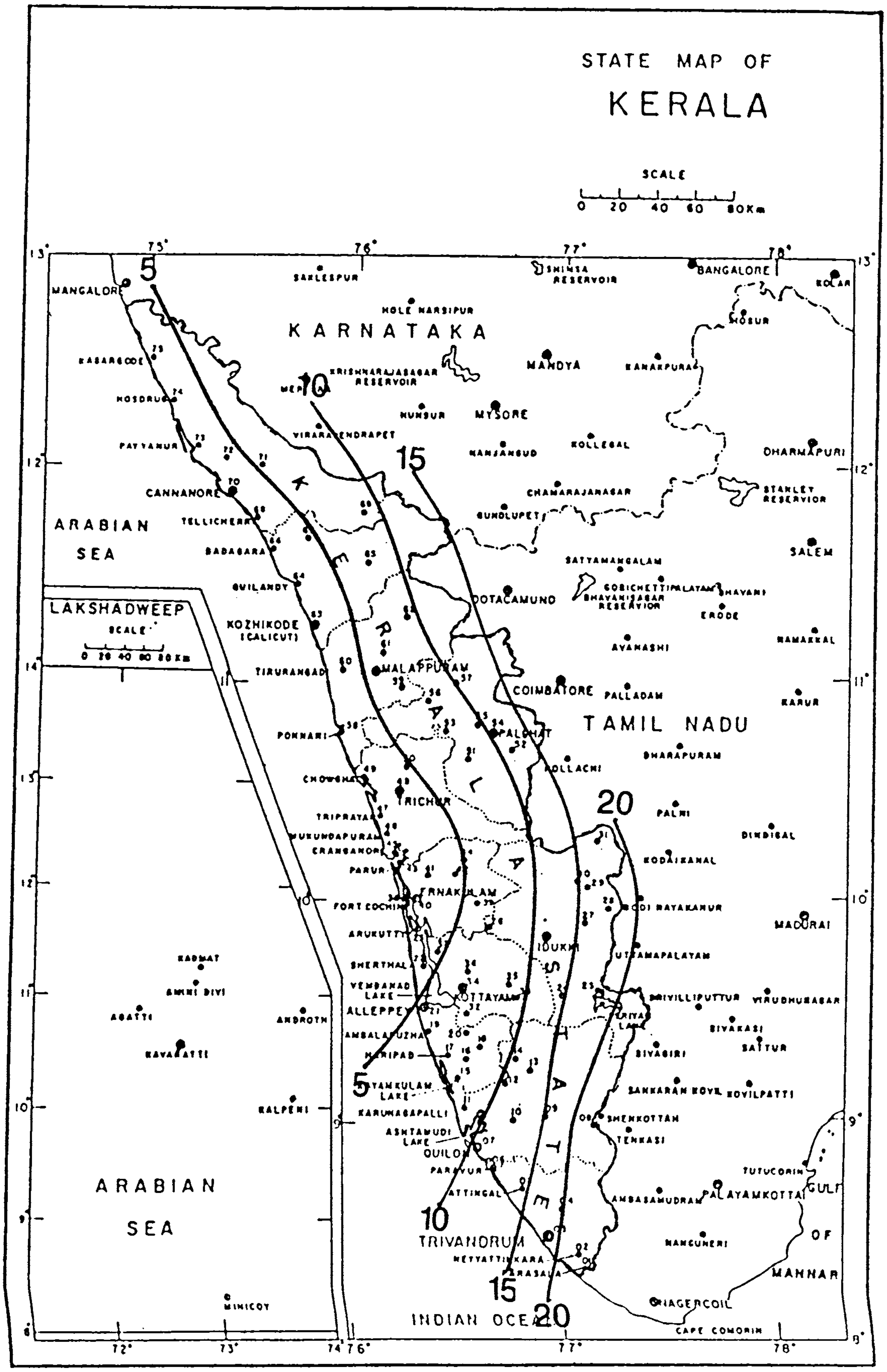


Fig. 6.6 Phase of the annual oscillation in the seasonal cycle

words, as moving interior from the coastal region, the phase of the annual oscillation increases almost in a linear manner as indicated in Fig. 6.6. Southern part of Kerala, get the highest annual rainfall after some delay compared to that in the central and northern part of Kerala. The spatial distribution of the phase of the annual oscillation in rainfall illustrate that Kerala experience its highest rainfall during the first two weeks in the month of July. The highest rainfall period in the seasonal cycle is earlier in coastal regions and later in the high land regions of the State.

6.3.7 Phase of Semi-Annual Cycle

The phase of the semi-annual oscillation at different parts of Kerala are illustrated in Fig. 6.7. The phase of the semi-annual oscillations represented in Fig. 6.7 are as days with reference to January/July 1. For example, the isolines in the northern part of Kerala is represented by the semi-annual oscillation (SAO) peaks on 25th day of January/July. In the extreme south, the phase of SAO is shown as -25, which represents the time of maximum amplitude of SAO is 25 days before January/July 1, i.e., on 6th of the previous month. The pattern of the isolines of the phase of

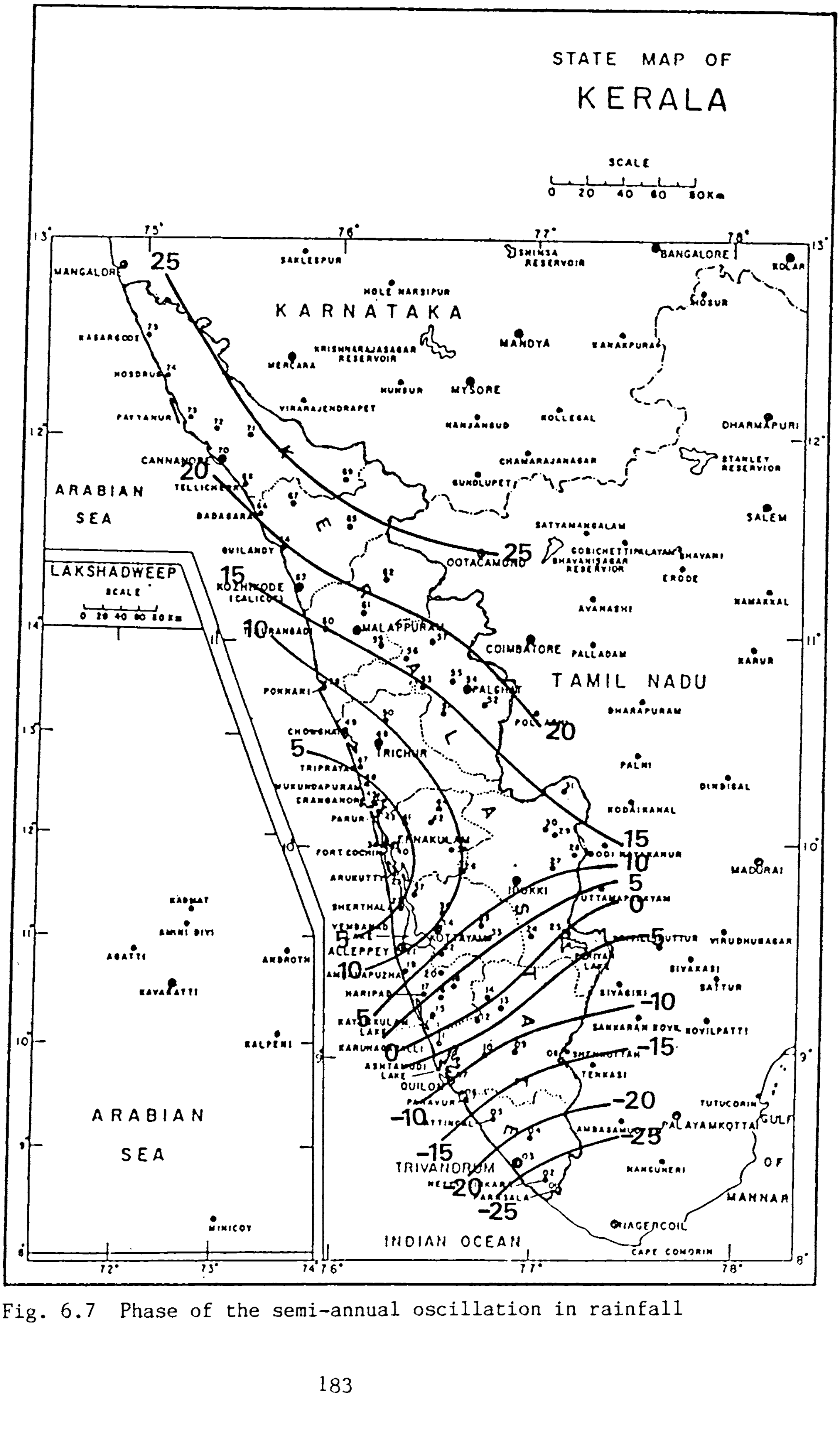


Fig. 6.7 Phase of the semi-annual oscillation in rainfall

the second harmonics show that the amplitude maximum of SAO is different in northern and southern part of Kerala. In the northern region, the phase of the second harmonics is late, and the isolines are oriented in the northwest to southeast direction. In southern Kerala, the occurrence of the semi-annual oscillation maximum is earlier and the isolines are oriented in the southwest to northeast direction. The phase gradient is larger in the southern part than the northern part of the State. From south to north, the phase of the second harmonics showed a difference of about 50 days.

In the northern half of Kerala, the phases of both annual and semi-annual oscillations showed more or less latitudinal variations. On the other hand, the southern region showed latitudinal dependent variation in the phase of the first harmonics and longitudinal dependent variation in the phase of the second harmonics.

CHAPTER 7

RAINFALL OVER FOREST REGIONS - INTERCEPTION LOSS

7.1 GENERAL

Interception is the portion of the precipitation falling on the earth's surface which is stored or collected by vegetal cover and subsequently evaporated. The volume of water so lost is called interception loss. In studies of major storm events and floods the interception loss is generally neglected. But in water balance studies it is a very significant parameter. Precipitation falling on vegetation may be retained on leaves or blades of grass, flow down the stem of plants and become 'stem flow', or fall off the leaves to become part of the 'through fall'. The amount of water intercepted is a function of (i) the storm character; (ii) the species, age and density of plants and trees; and (iii) the season of the year.

A number of studies on interception have been reported from different parts of the world. Studies on rainfall interception in the forests of New Zealand have been reported by Miller (1963) and Aldridge and Jackson (1973). Rowe (1975, 1979) has reported studies in the mountain beech on the Craigieburn Range of Canterbury and also for a mixed beech hardwood forest near Reefton. Dolman (1987) has compared summer and winter rainfall interception in an Oak forest and tried to predict with an analytical and a numerical simulation model. Studies conducted in Britain

(Calder, 1976; 1978) reveal that in some climates interception losses can be double that of the water used by transpiration. Yadav and Mishra (1985) have given an idea about the distribution of precipitation under a tropical dry deciduous forest stand of central India.

The present Chapter describes the interterception study carried out during the southwest monsoon months (June - September) of 1986 in the dense forest at Peruvannamuzhi, Kozhikode District.

7.2 EXPERIMENTAL SITE

The site chosen for the study is a small deciduous forest catchment at Peruvannamuzhi, 75 km northeast of Kozhikode city. It lies on the Western Ghats at 11° 35' N and 75° 29' E (Fig 7.1). The average altitude above mean sea level is 350 m having a catchment slope of 9.76 per centage. Average annual rainfall of the region is about 4500 mm, of which 70% is during southwest monsoon (June-September), 20% during northeast monsoon (October-December) and the remaining 10% distributed during the rest of the period.

The mixed forest of the study area comprises about 17 tree species. The height of the trees vary from 5 m to 25 m and the average is 11 m. Diameter at breast height (dbh) varies from 5 cm to 100 cm having an average of 24 cm.

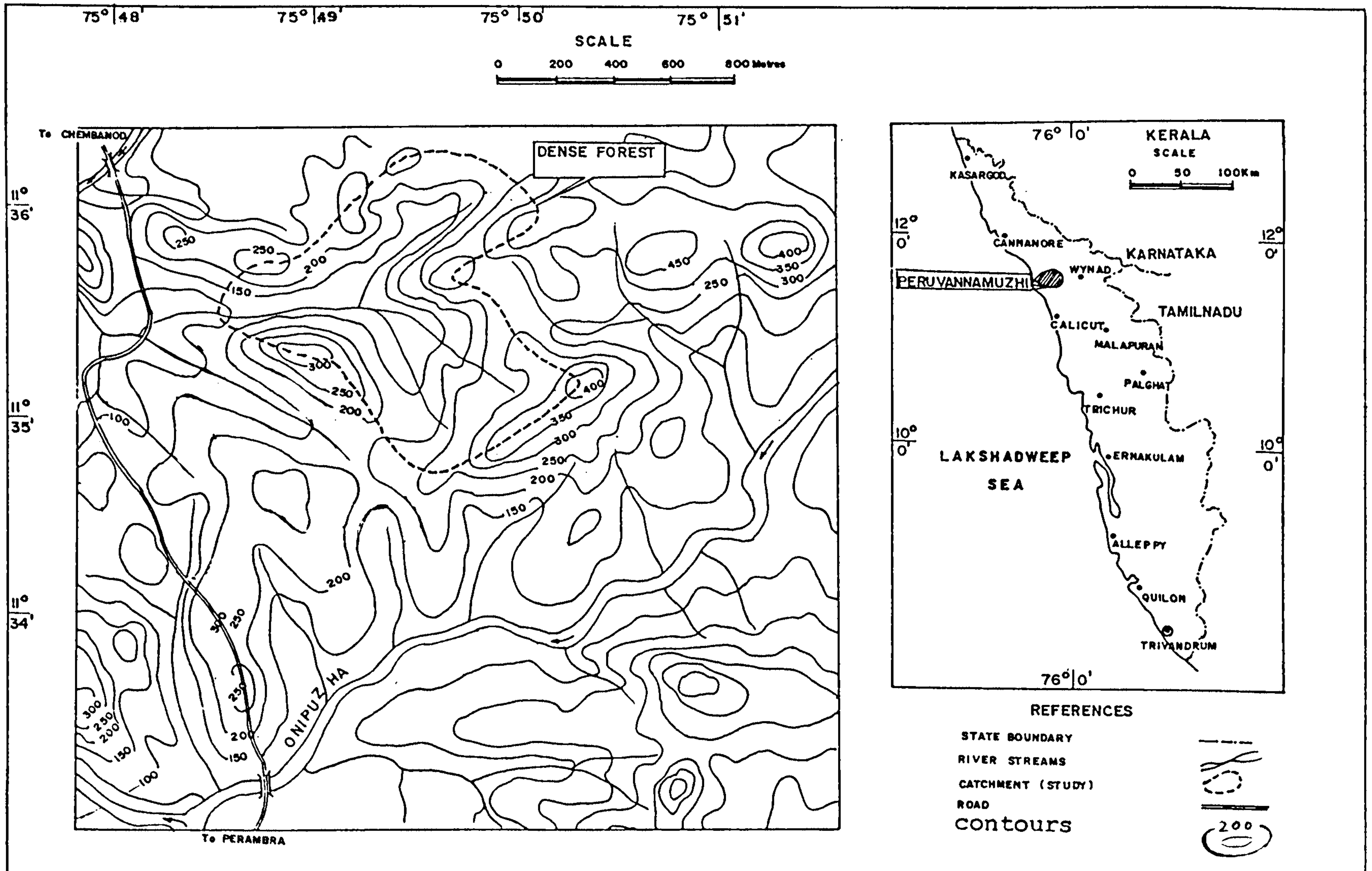


FIG. 7.1 INTERCEPTION STUDIES - EXPERIMENTAL SITE AT PERUVANNAMUZHI

varies from 5 cm to 100 cm having an average of 24 cm. Canopy thickness of the region varies from 1.5 m to 17.0 m. In the 5-15 cm dbh class, the average tree density is 275 trees/ha, 16-30 cm class it is 125 trees/ha; 31-50 cm class 75 trees/ha and 51-100 cm class 33 trees/ha. During the study period crown cover of the study area was visually estimated to be about 75-90 percentage opaque to direct sunlight. The important species in the study area are Dalbergia latifolia, Elaeocarpus serratus, Acacia ferruginea, Aporusa lindleyana, Machilus macrantha, Euodia lunuakenda, Terminalia paniculata, Diospyros candolleana, Caloplyllum apetalum, Grewia tiliefolia, Ficus arnottiana, Terminalia bellirica, Ailanthus triphysa, Sehleichera oleosa, Bombax insigne, Strychnos nux-vomica, Tectona grandis, etc. Ground flora is rich in species and mostly consisted of shrubs and grasses. Since the study area is a mixed thick forest the branches of the trees are overlapped each other and most of the cases the canopy thickness is not of a single tree but a mixture of different trees.

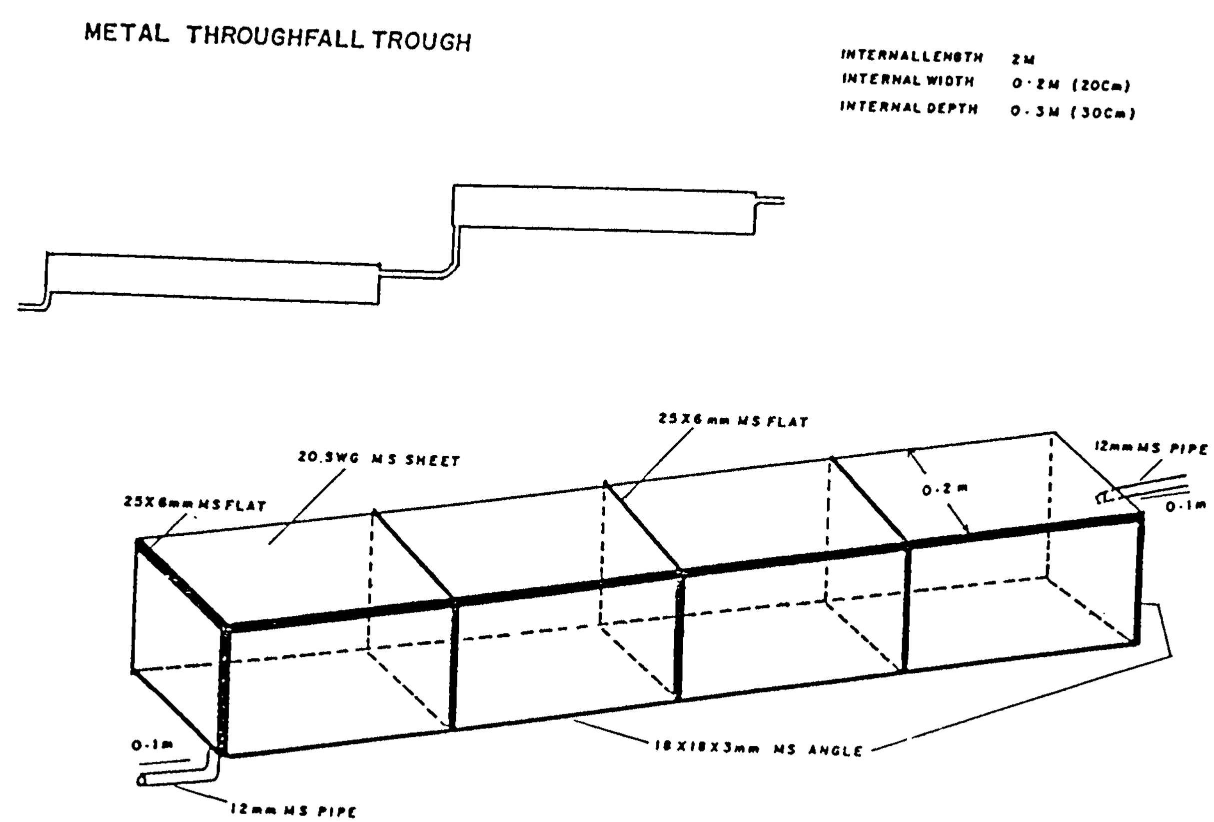
7.3 EXPERIMENTAL METHODS

7.3.1 Incident Daily Rainfall :

No attempt was made to measure rainfall immediately above the forest crown. Standard ordinary and automatic recording raingauges installed at the ground level just outside the forest edge are used to estimate the direct incident rainfall. Records from the six raingauges installed on the boundary of the forest show that there may not be much difference between the rainfall inside the forest and just outside the forest edge.

7.3.2 Throughfall :

Metal Throughfall troughs (Wright, 1977) of size 200 cm x 20 cm x 30 cm (Fig 7.2) were used to measure the throughfall. They were constructed of pre-fabricated mild steel sheet. The troughs were placed, 5 to 10 at a spot interconnected with each other, below the crown at the ground level. The troughs were tilted for rapid transfer of the water to the measurement device. A shallow tilt increases the response time of the gauge and also increases evaporation loss. A steep tilt menas that the shallow flow is fast enough to wash any trash towards the drain hole. The water collected through the troughs were measured and compared, in depth, with the readings in the raingauges kept just outside the forest. The troughs were kept as clean as possible to minimise evaporation loss from damp trash in the trough. Ten troughs were used for keeping randomly under different tree crowns. Daily average values were computed and compared with the incident rainfall.



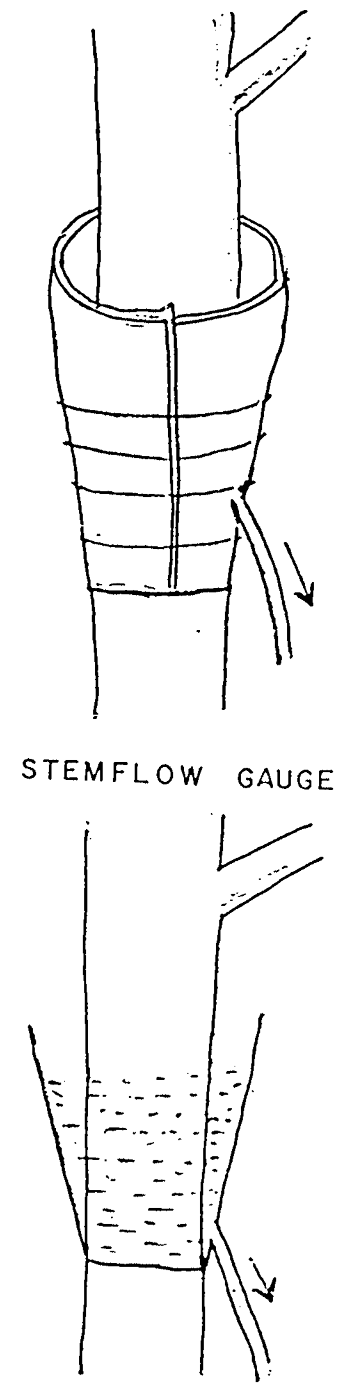


FIG 7.2 THROUGHFALL TROUGH AND COLLAR TYPE STEMFLOW GAUGE

Since the position of the troughs were changed frequently, it was observed that on an average the excess readings obtained due to 'drip points' had neutralised with the 'null points'. During large storms water leave branches at some bends and low points in a steady trickle; it is meant by 'drip point'. 'Null Point' is where there are no drop even during large storms.

7.3.3 **Stemflow :**

Collar type gauge has been used to compute the stemflow. Thick (1 mm) and stiff polythene collars were sealed to the trunks with bitumastic sealing compound and had drain-tubes to conduct the water to the measuring device. The crown areas were estimated from the vertical projection of the edge of the crown to the ground and used in computing the net stemflow. In the present study six trees were selected, of which the crown areas ranging from 11.34 sq.m to 40.69 sq.m. and dbh from 12.1 cm to 51.6 cm. The height of the trees selected for the study ranges from 5 m to 22 m.

Stemflow varies mainly with dbh, crown area, canopy thickness. Therefore the trees for stemflow studies were selected in such a way that the average of each parameter of the selected trees are almost coinciding with the averages of the total trees in the study area.

During the southwest monsoon period, most of the days the rainfall is either continuous or with very less time-gap between showers in the Western Ghats region of Kerala. Hence, measurements were made daily during June, July, August and September of 1986. To minimise the evaporation losses from the measuring devices, polythene covers were used on the top of the collecting jars and a thin layer of coconut oil was applied daily over the water content. By these methods it was found that the evaporation loss was almost zero from the measuring devices of the gauges. During heavy raining, intermittent measurements were made to prevent overflow from the collectors and in most of the cases data was collected immediately after very mild showers. General views of throughfall troughs and stemflow gauges are given in Figs 7.3 and 7.4, respectively.

7.4 RESULTS

7.4.1 Throughfall

The values in Table 7.1 indicate that during the monsoon period throughfall did not occur when the daily rainfall is less than 2.0 mm. In the range of 2 to 2.9 mm rainfall, only an average of 6% of the rainfall occurred as throughfall under the thick mixed forest, but it increased with the rainfall. In the case of 4 to 4.9 mm range of

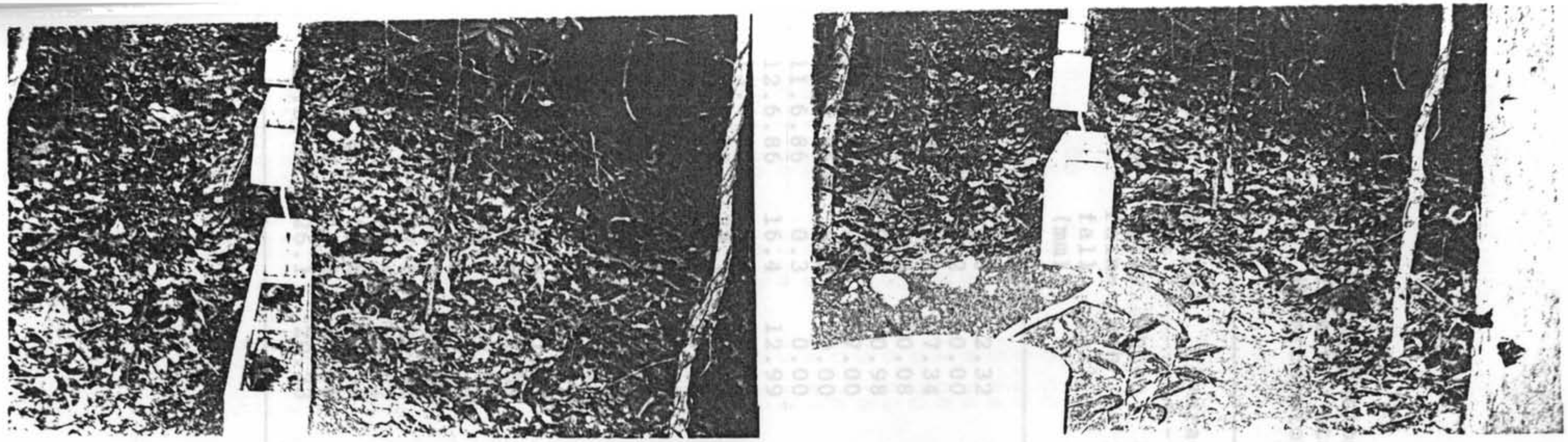


FIG.7.3 THROUGHFALL MEASUREMENT

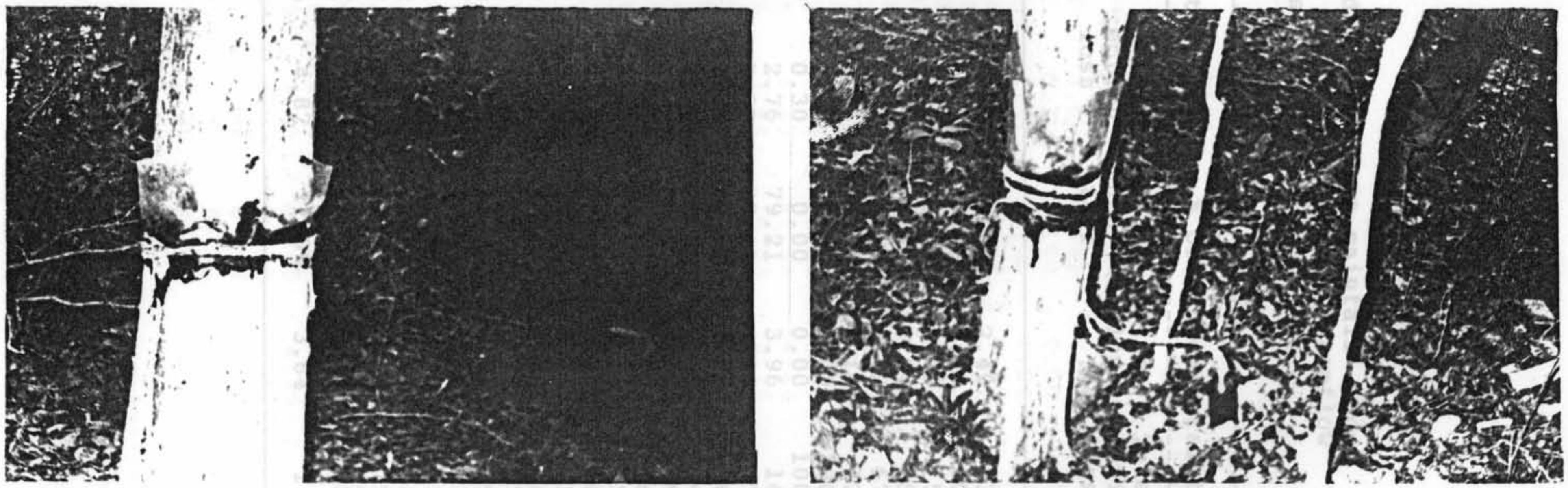


FIG.7.4 STEMFLOW MEASUREMENT

Table 7.1: Distribution of daily incident rainfall under the forest stand as throughfall, stemflow and interception loss

Date of measurement	Incident daily rainfall (mm)	Average total (mm)			% of incident rainfall		
		Through fall	Stem flow	Interception loss	Through fall	Stem flow	Interception loss
01.6.86	4.3	2.32	0.10	1.88	53.95	2.40	43.65
04.6.86	0.2	0.00	0.00	0.20	0.00	0.00	100.00
06.6.86	110.2	97.34	6.76	6.11	88.33	6.13	5.54
07.6.86	2.3	0.08	0.02	2.19	3.48	1.04	95.48
08.6.86	3.3	0.98	0.08	2.24	29.70	2.42	67.88
09.6.86	32.5	27.00	1.35	4.15	83.08	4.15	12.77
10.6.86	0.3	0.00	0.00	0.30	0.00	0.00	100.00
11.6.86	0.3	0.00	0.00	0.30	0.00	0.00	100.00
12.6.86	16.4	12.99	0.65	2.76	79.21	3.96	16.83
13.6.86	44.4	38.90	1.98	3.52	87.61	4.46	7.93
14.6.86	73.7	65.23	3.60	4.87	88.51	4.88	6.61
15.6.86	97.5	87.65	5.17	4.68	89.90	5.30	4.80
16.6.86	68.4	58.57	3.30	6.53	85.63	4.82	9.55
17.6.86	28.6	22.86	1.12	4.62	79.93	3.92	16.15
18.6.86	72.5	64.79	3.73	3.97	89.37	5.15	5.48
19.6.86	75.1	64.45	4.02	6.63	85.82	5.35	8.83
20.6.86	71.3	63.67	3.67	3.96	89.30	5.15	5.55
21.6.86	66.4	57.77	3.19	5.44	87.00	4.80	8.20
22.6.86	27.5	21.89	0.92	4.69	79.60	3.35	17.05
23.6.86	84.2	72.09	4.48	7.63	85.62	5.32	9.06
24.6.86	79.2	69.33	4.17	5.69	87.54	5.27	7.19
25.6.86	102.7	90.65	6.11	5.94	88.27	5.95	5.78
26.6.86	37.5	32.83	1.62	3.05	87.55	4.33	8.12
27.6.86	34.5	30.02	1.32	3.16	87.01	3.82	9.17
28.6.86	61.5	52.98	2.76	5.76	86.15	4.49	9.36
29.6.86	66.6	58.66	3.17	4.77	88.08	4.76	7.16
30.6.86	26.1	20.33	0.95	4.82	77.89	3.64	18.47

Table 7.1 (contd.)

Date of measurement	Incident daily rainfall (mm)	Average total (mm)			% of incident rainfall		
		Through fall	Stem flow	Interception loss	Through fall	Stem flow	Interception loss
01.7.86	62.6	55.97	3.00	3.62	89.41	4.80	5.79
02.7.86	0.2	0.00	0.00	0.20	0.00	0.00	100.00
06.7.86	2.4	0.06	0.02	2.32	2.50	0.94	96.56
07.7.86	19.2	15.64	0.76	2.80	81.46	3.94	14.60
08.7.86	12.6	8.88	0.44	3.28	70.48	3.52	26.00
09.7.86	15.5	11.06	0.58	3.86	71.34	3.76	24.90
10.7.86	0.4	0.00	0.00	0.40	0.00	0.00	100.00
12.7.86	9.3	5.66	0.24	3.40	60.86	2.60	36.54
13.7.86	138.8	125.16	8.72	4.93	90.17	6.28	3.55
14.7.86	60.3	50.28	2.81	7.21	83.38	4.66	11.96
15.7.86	54.5	44.47	2.53	7.49	81.60	4.65	13.75
16.7.86	32.4	26.73	1.44	4.23	82.50	4.44	13.06
17.7.86	4.2	0.27	0.09	3.84	6.43	2.26	91.31
19.7.86	16.3	12.76	0.64	2.90	78.28	3.92	17.80
20.7.86	42.2	36.28	1.76	4.17	85.97	4.16	9.87
21.7.86	65.2	56.35	3.12	5.73	86.43	4.78	8.79
22.7.86	15.6	11.35	0.59	3.66	72.76	3.77	23.47
23.7.86	15.4	11.07	0.58	3.75	71.88	3.75	24.37
24.7.86	12.5	8.99	0.41	3.10	71.92	3.30	24.78
25.7.86	31.7	26.49	1.27	3.94	83.56	4.02	12.42
26.7.86	12.7	9.32	0.42	2.96	73.39	3.31	23.30
27.7.86	2.3	0.36	0.02	1.92	15.65	0.91	83.44
29.7.86	0.3	0.00	0.00	0.30	0.00	0.00	100.00
30.7.86	20.2	15.73	0.80	3.67	77.87	3.94	18.19
31.7.86	9.0	6.23	0.24	2.53	69.22	2.65	28.13
02.8.86	27.5	22.75	1.10	3.65	82.73	4.01	13.26
03.8.86	18.5	13.43	0.72	4.35	72.59	3.87	23.54
04.8.86	6.3	2.41	0.16	3.73	38.25	2.54	59.21
05.8.86	84.4	75.49	4.26	4.65	89.44	5.05	5.51
06.8.86	41.4	35.77	1.78	3.85	86.40	4.30	9.30
07.8.86	135.3	121.13	8.35	5.82	89.53	6.17	4.30
08.8.86	67.4	59.09	3.35	4.96	87.67	4.97	7.36
09.8.86	58.5	51.90	2.73	3.87	88.71	4.67	6.62
10.8.86	40.3	34.09	1.85	4.36	84.59	4.59	10.82

Table 7.1 (contd.)

Date of measurement	Incident daily rainfall (mm)	Average total (mm)			% of incident rainfall		
		Through fall	Stem flow	Interception loss	Through fall	Stem flow	Interception loss
11.8.86	68.1	60.51	3.42	4.17	88.85	5.02	6.13
12.8.86	37.3	29.24	1.60	6.46	78.39	4.29	17.32
13.8.86	18.0	13.39	0.69	3.92	74.39	3.82	21.79
14.8.86	22.6	17.63	0.86	4.12	78.00	3.79	18.21
15.8.86	7.2	3.24	0.18	3.78	45.05	2.45	52.50
16.8.86	2.3	0.14	0.02	2.14	6.09	0.99	92.92
22.8.86	4.4	2.14	0.09	2.17	48.64	1.94	49.42
06.9.86	16.3	11.15	0.59	4.56	68.40	3.63	27.97
07.9.86	22.2	17.47	0.86	3.87	78.69	3.86	17.45
08.9.86	12.3	8.70	0.43	3.17	70.73	3.53	25.74
09.9.86	1.3	0.00	0.00	1.30	0.00	0.00	100.00
10.9.96	3.2	0.36	0.07	2.77	11.25	2.24	86.51
11.9.86	2.4	0.22	0.02	2.16	9.17	0.99	89.84
16.9.86	4.1	1.92	0.08	2.10	46.83	1.99	51.18
17.9.86	9.3	6.52	0.26	2.52	70.11	2.83	27.06
18.9.86	56.2	49.70	2.44	4.06	88.43	4.34	7.23
19.9.86	38.0	32.46	1.55	3.99	85.42	4.09	10.49
20.9.86	51.4	44.68	2.24	4.48	86.93	4.36	8.71
21.9.86	175.6	157.34	11.62	6.64	89.60	6.62	3.78
22.9.86	36.0	30.01	1.49	4.50	83.36	4.13	12.51
23.9.86	2.0	0.00	0.00	2.00	0.00	0.00	100.00
24.9.86	4.0	0.98	0.08	2.94	24.38	2.12	73.50
26.9.86	42.3	36.18	1.77	4.35	85.53	4.18	10.29
27.9.86	2.2	0.09	0.02	2.09	4.09	1.01	94.90
28.9.86	0.4	0.00	0.00	0.40	0.00	0.00	100.00

rainfall, the average throughfall was 36% and in the range of 15 to 19.9 mm it was 75%. When the rainfall exceeded 50 mm there was no much steep change in the through throughfall percentage (Fig. 7.5).

Linear regression analysis was used to determine relationship between daily rainfall and throughfall. In Fig. 7.6 the throughfall is shown in relation to daily rainfall. The linear regression of mean throughfall (T mm) on daily rainfall (R mm) using the data for 79 days gave the equation.

$$T = 0.909 R - 2.325$$

Daily rainfall versus throughfall is plotted in Fig. 7.7 and the regression line is drawn. It can be seen that throughfall linearly increases with the daily rainfall and has a strong relationship with each other. The correlation coefficient between throughfall and daily rainfall is computed as $r = 0.9996$, which is almost a perfect correlation and is highly significant.

Separate regression analysis were done for different ranges of rainfall. The regression equations and the correlation coefficients are given in Table 7.2 for different ranges of rainfall. All the equations give almost identical results when used to estimate the mean throughfall from daily rainfall.

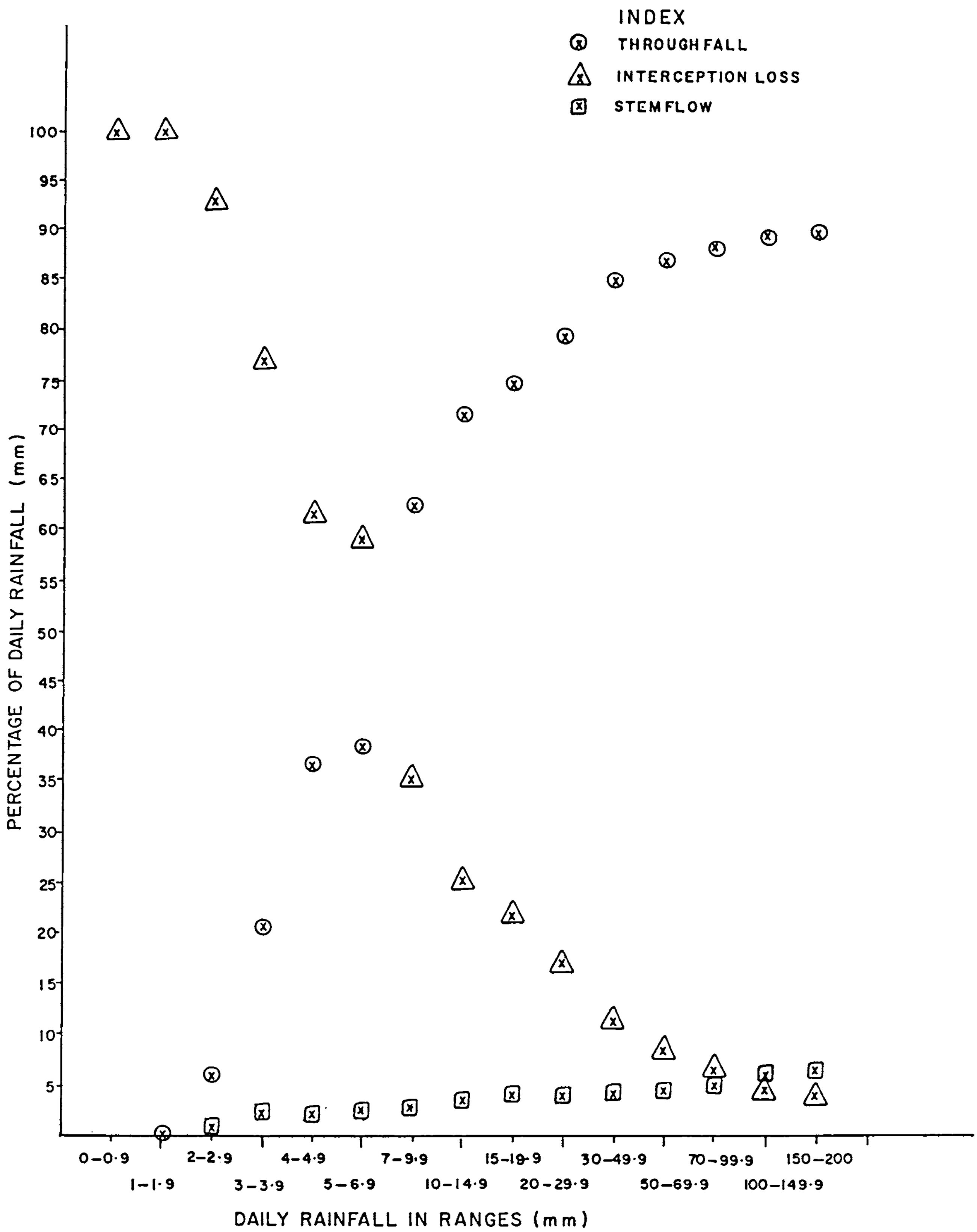


Fig 7.5 AVERAGE THROUGHFALL, STEMFLOW AND INTERCEPTION LOSS IN DIFFERENT RANGES OF DAILY RAINFALL

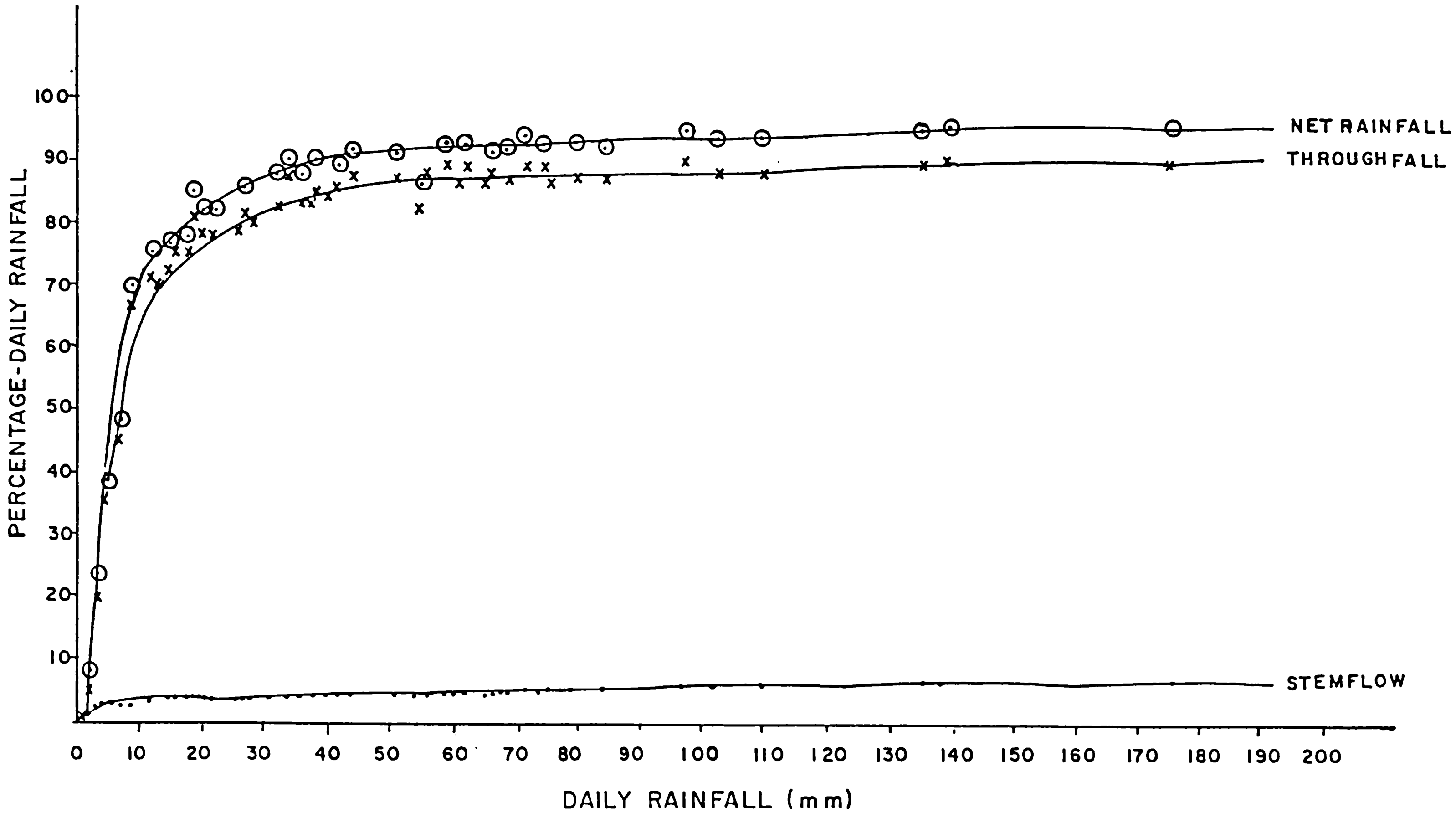


Fig 7.6 STEMFLOW, THROUGHFALL AND NET RAINFALL AS PERCENTAGE OF DAILY RAINFALL

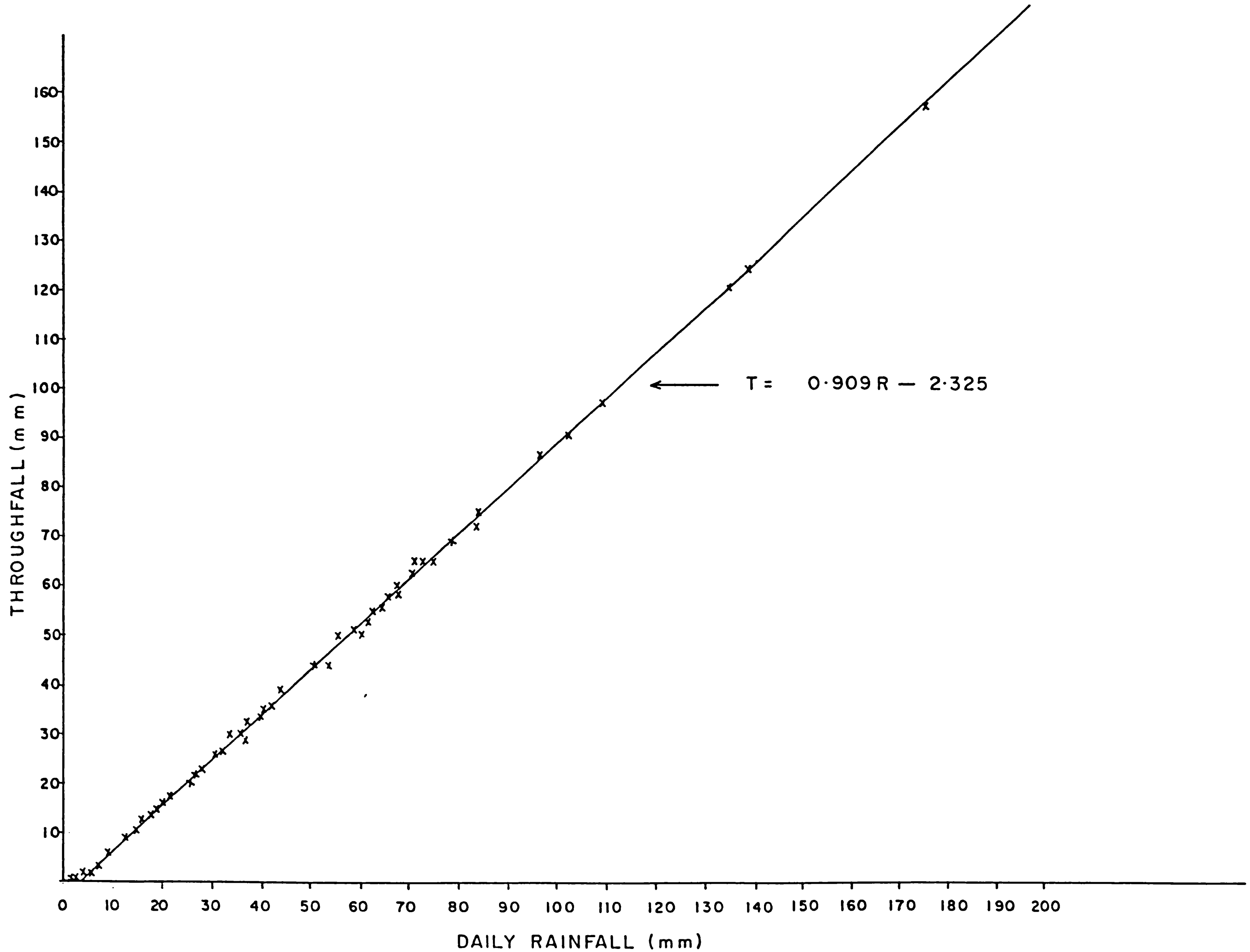


Fig 7.7 RELATION OF THROUGHFALL (T) TO DAILY RAINFALL (R)

Table 7.2: **Regression equations and correlation coefficients between throughfall and rainfall**

Ranges of rainfall(mm)	Regression equation (T)	Correlation coeff. (r)
0 - 19.9	0.832 R - 1.567	0.9904
20 - 49.9	0.950 R - 3.857	0.9947
50 - 99.9	0.929 R - 3.719	0.9925

7.4.2 Stemflow

As in the case of throughfall, average stemflow increased with the increase of rainfall. In the range of 2 to 2.9 mm of rainfall the average stemflow was less than one percentage. In some cases it was very little, not even measurable. In Fig 7.6 the increase in stemflow with the rainfall is shown. From the data collected, it was noticed that for a rainfall of 175.6 mm, the average stemflow was only 11.62 mm. The characteristics of the trees selected for the stemflow studies are shown in Table 7.3 and the variations in average stemflow in different trees with different ranges of rainfall are illustrated in Table 7.4.

Table 7.3 Characteristics of the forest trees selected for stemflow recording

Sl No.	Species	Height (m)	dbh (cm)	Crown area (sq.m)	Crown thickness* (m)	Crown coverage* (%)
1.	Aporusa lindleyana	5	16.5	11.34	2.5	75
2.	Machilus macrantha	8	12.1	19.63	6.0	85
3.	Euodia lunuakenda	12	27.7	30.18	5.5	75
4.	Terminalia paniculata	13	26.4	28.26	8.0	80
5.	Terminalia paniculata	22	51.6	40.69	12.0	85
6.	Ailanthus triphysa	12	20.1	15.20	5.5	75

* Crown thickness and coverage including branches of nearby tress

Table 7.4 : **Variations in average stemflow (%) in the selected trees (as shown in Table : 7.3) with different ranges of rainfall**

Range of rainfall (mm)	Trees selected for stemflow measurements					
	1	2	3	4	5	6
0-0.9	0.00	0.00	0.00	0.00	0.00	0.00
1-1.9	0.00	0.00	0.00	0.00	0.00	0.00
2-2.9	0.82	0.88	0.75	0.75	0.75	1.13
3-3.9	2.31	1.69	2.46	2.00	3.85	1.54
4-4.9	1.76	1.38	2.29	2.00	3.86	1.76
5-6.9	2.50	1.75	2.22	2.86	4.13	1.75
7-9.9	2.56	1.98	2.41	2.64	4.45	1.84
10-14.9	2.89	2.32	3.93	3.21	5.13	3.01
15-19.9	3.23	2.59	4.06	3.90	5.83	3.12
20-29.9	2.96	2.45	4.06	3.88	6.15	2.92
30-49.9	3.39	2.60	4.67	4.42	6.38	3.72
50-69.9	4.30	3.16	4.77	4.67	7.19	4.13
70-99.9	4.89	3.41	5.20	5.37	7.64	4.60
100-149.9	6.24	4.05	6.42	6.46	8.39	5.39
150-200.0	6.67	4.79	6.80	6.80	8.82	5.84

Linear regression analysis using the data of the monsoon months, in which rainfall varies from 0 to 175.6 mm, gave the following relation between the average depth of stemflow (S) and daily rainfall (R).

$$S = 6.026 \times 10^{-2} R - 0.439$$

In Fig. 7.8, stemflow versus daily rainfall is plotted and the regression line is drawn. Between 20 and 90

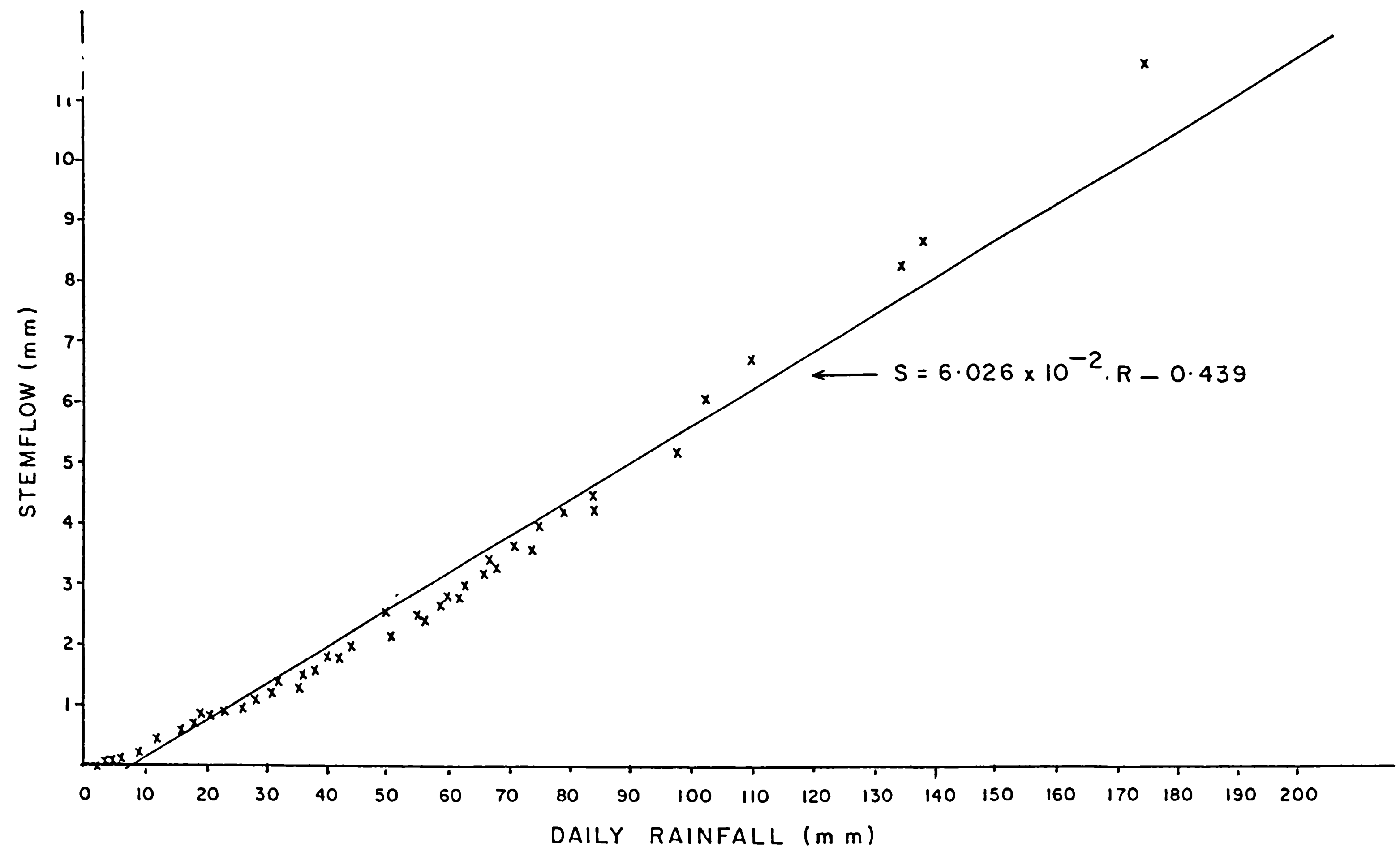


Fig 7.8 RELATION OF STEMFLOW (S) TO DAILY RAINFALL (R)

mm of rainfall the stemflow showed a slight decrease compared to the line of best fit. The correlation coefficient between stem flow and the daily rainfall is found to be 0.9881, which is significant. The regression equations and the correlation coefficients between stemflow and daily rainfall for different ranges are illustrated in Table 7.5.

Table 7.5 : **Regression equation and correlation coefficient coefficients between stemflow and rainfall**

Ranges of rainfall(mm)	Regression equation (S)	Correlation coeff.(r)
0 - 19.9	0.04138 R - 0.0726	0.9918
20 - 49.9	0.04983 R - 0.2880	0.9813
50 - 99.9	0.06600 R - 1.1330	0.9908

7.4.3 Net Rainfall

Net rainfall is the water that reaches the surface of the ground as throughfall and stemflow. The sum of mean throughfall (T) and the mean stemflow (S) was used as the net rainfall (N). That is the difference between the incident rainfall and the lost rainfall due to interception. Since N is dependent of T and S, naturally when T and S increase N also increases.

The percentage of lost rainfall is less in the range of 100 to 149.9 mm, when compared to 0 to 19.9 mm rainfall. But when it was considered in quantity-wise the lost rainfall was high in the first case. Specifically, in the range of 2 to 2.9 mm rainfall, the average lost rainfall was 93.21% of incident rainfall and in 100-149.9 mm range, it was 4.68%. Depth-wise it was 2.12 mm and 5.7 mm, respectively.

Linear regression analysis using the net rainfall and the daily rainfall, varies from 0 to 175.6 mm, gave the following relation between the net rainfall (N) and daily rainfall (R).

$$N = 0.969 R - 2.764$$

Using the above equation the line of best fit is obtained and is ploteed in Fig. 7.9. The correlation coefficient computed between net rainfall and daily rainfall show a value of r = 0.9995, which is positive and highly significant.

Separate regression analysis were also done for different ranges of rainfall. The regression equations and the correlation coefficients are given in Table 7.6 for different ranges of rainfall.

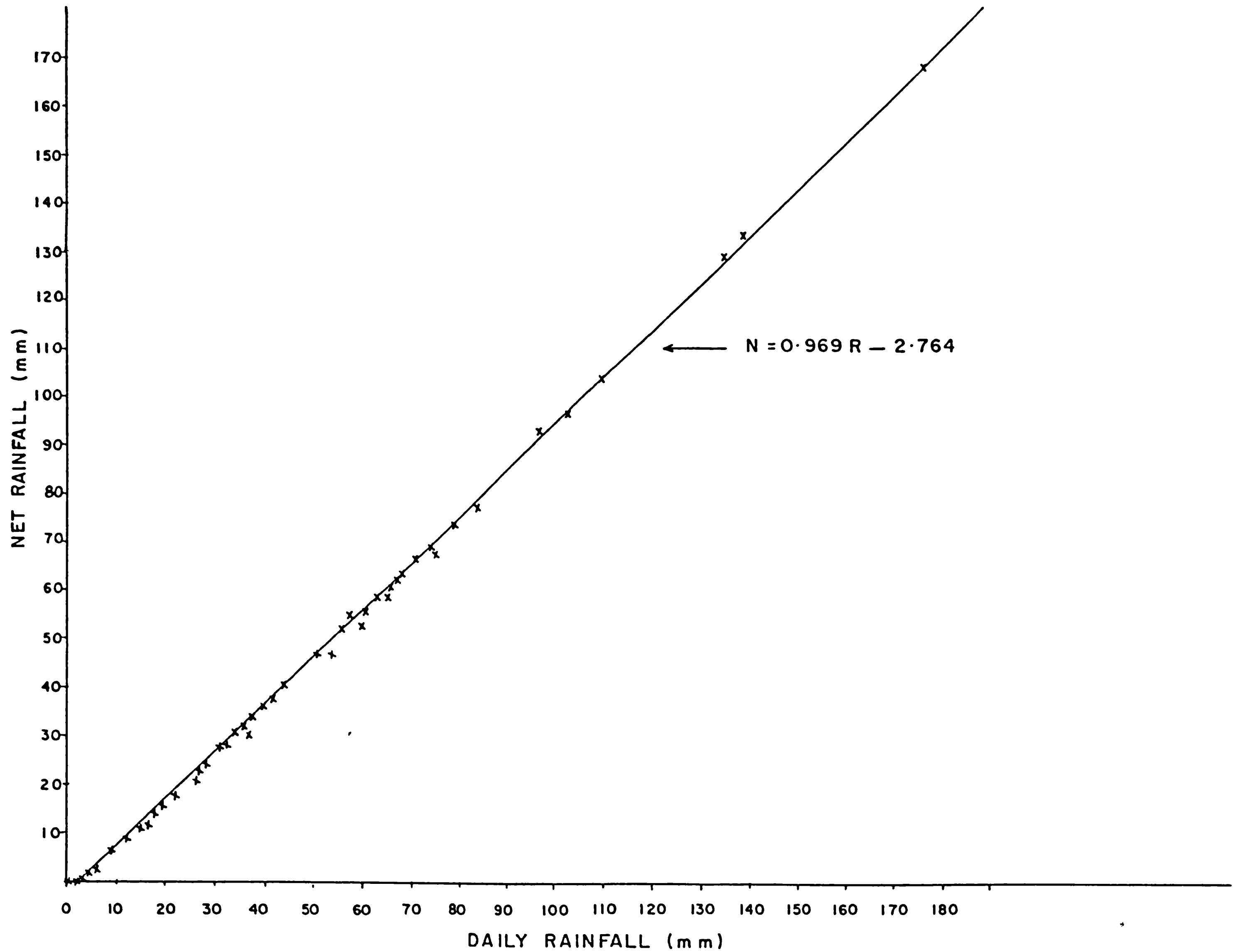


Fig 7.9 RELATION OF NET RAINFALL (N) TO DAILY RAINFALL (R)

Table 7.6 Regression equations and correlation coefficients between net raintall and daily raintall

Ranges of rainfall(mm)	Regression equation (N)	Correlation coeff.(r)
0 - 19.9	0.8740 R - 1.639	0.9908
20 - 49.9	0.9996 R - 4.145	0.9952
50 - 99.9	0.9940 R - 4.853	0.9937

The results based on the data of southwest monsoon months of 1986 reveal that 10.45% of the total incident rainfall has been lost as inteception. During the period, throughfall is 84.67% and stemflow is 4.88%. In terms of depth correlation between throughfall and interception loss is positive but it is negative between percentage throughfall and percetnage interception loss which indicates that the percentage interception loss decreases with the increasing proportion of throughfall and also with stemflow and amount of incident precipitation.

Because of the retention of a good amount of rain water in the forest canopy, it was noticed that the humidity of the region is very high compared to the open area. This will prevent evaporation from forest soil. Because of the good coverage of green leaves, the gravitational force of rain drops are minimised on the way, which is a natural prevention against soil erosion.

The study reported is only a footstep of novel studies to be carried out in the forest region of Western Ghats. The study has to be continued in the months other than southwest monsoon period and it should be extended to different forest types. Since Kerala is covered by about 20% of forest, similar type of studies have got vital importance while considering the water balance of the region.

CHAPTER 8

SUMMARY AND CONCLUSIONS

The outcome of the study on the influence of physiographic features, such as orography, latitude, longitude, altitude, forest cover, etc., on the rainfall pattern of Kerala have been briefly documented in this chapter. The major results obtained from the spatial variability in the seasonal cycle of the rainfall pattern over the State based on Harmonic analysis have also been documented.

The major outcome of the study is as follows. The study on the effects of mountain barriers and hilly terrains on the rainfall pattern of Kerala reveal that the maximum rainfall is not at the peak of the mountains, but on the western slopes, much below the peak. Orography plays an important role in the distribution of rainfall, as the isohyets are parallel to the Western Ghats with a steep decrease to both sides from the pockets of heavy rainfall. Similar analysis have been carried out for Winter rainfall l(Dec - Feb), Hot weather period rainfall (Mar - May), Southwest monsoon (Jun - Sep) and Northeast monsoon (Oct - Nov).

Winter rainfall is the period of minimum rainfall in Kerala. The intensity of northeast winds during this period is more in southern region of Kerala compared to the northern region.

The southwest monsoon contribute about 80% of the annual rainfall in north Kerala. Physiographically in north Kerala more highlands are situated in between 11° N and 11°50' N and hence more rainfall is obtained in the segment of 11° - 11°50' N. It is also noticed that the winds during this season is almost perpendicular to the western Ghats of northern region of Kerala, which is a factor for heavy rainfalls in the region. In central Kerala at the region of Palghat gap, rainfall is less during southwest monsoon period, since the monsoon winds escape through the gap to the Tamil Nadu region. But in the Idukki District, the highlands block almost all the southwest winds and thus a good amount of orographic rainfall is obtained in this region. As in the case of northern Kerala, the peak of southwest monsoon rainfall is not at the peak of high lands, but towards the western side of it. It has been noticed that the winds during this season is not exactly perpendicular to the high ranges of southern part of Kerala. On an average in most of the places the winds are north westerly. While compared to the north and central portions of Kerala, the south portion is having less high ranges. This is another reason for having less rainfall over this part during this period.

Northeast monsoon is the second rainy season for Kerala State. In this period the rainfall pattern change spatially from north to south of the State. In southern Kerala, the seasonal rainfall is about 30% of the annual. At northern parts, this value is only about 10%.

Studies on the latitudinal variation in rainfall over Kerala show that the annual normal rainfall increase from 1479 mm in the extreme south latitude (8° 20' N) at Parassala to about 3500 mm in the northern-most latitude (12° 31' N) at Kasargode. There are two heavy rainfall pockets seen over Kerala. One of the heavy rainfall zone is located between latitudes 9° and 10° N and the other located near 12° N latitude.

The rainfall variation in the coastal zone of Kerala shows that the coastal belt from Cochin to Kozhikode receives an annual rainfall of around 3000 mm. The rainfall exhibits a sharp increase to the north of Kozhikode and a decrease to the south of Cochin along the coastal belt. There is a rapid decrease in rainfall is seen fròm Kayamkulam to the southern part of Kerala.

The area of peak rainfall is not always associated with the region of highest number of rainy days. The highest annual rainfall region is located in northern Kerala and the maximum number of annual rainy days are located in northern latitudes.

Southern Kerala experiences more rainy days with lower intensity of rainfall. On the other hand, northern Kerala gets higher amount of rainfall with relatively less number of rainy days. The duration as well as the intensity of rainfall is quite large in the northern part of Kerala.

The rainfall during the southwest monsoon season have an increasing trend from the southern part of Kerala to the North. Southwest monsoon rainfall over Kerala region showed an increasing tendency with latitude. Southwest monsoon rainfall is less in the southern part of Kerala, of the order of 1000 mm, and increase to four fold in the northern latitudes.

The linear regression equation obtained from the latitudinal distribution of southwest monsoon rainfall over Kerala shows a positive slope and derives an increase in rainfall of the order of 464 mm for every 1° latitude distance. Computed correlation coefficient between southwest monsoon rainfall and the latitude is 0.697, which is highly significant of the order of >99% level of significance with 82 degrees of freedom.

The number of rainy days in southwest monsoon period also showed a positive correlation with latitude. The correlation coefficient computed between the number of rainy days and latitude during the summer monsoon season gives a positive and statistically significant correlation of 0.595. The regression coefficient show that the number of rainy days during the southwest monsoon increases of the order of 6.45 days per degree latitude from the south of Kerala to the north.

The rainfall during the northeast monsoon season is found to be decreasing with increasing latitude, which is just opposite to that observed in the case of southwest monsoon season. In the southern region, the normal rainfall during this season is estimated as 700 mm, which decrease to its half, of 350 mm, in the northern part of Kerala. The regression coefficient between rainfall and latitude showed that the rainfall during the northeast monsoon season is decreasing at the rate of 79 mm per degree latitude. The computed correlation coefficient between latitude and rainfall for the 84 stations considered for the study showed a value of -0.606, which is negatively significant at 99% level of significance.

As in the case of rainfall during this season, the number of rainy days are also decreasing with latitude. The estimated correlation coefficient between latitude and number of rainy days during the northeast monsoon season is -0.752, which is also highly significant. The regression coefficient between the above two parameters showed a value of -3.71 rainy days per degree latitude.

The influence of the height of the station above mean sea level on rainfall during annual, southwest monsoon and northeast monsoon periods does not show significant effect on the rainfall of a station. The criteria of altitude factor alone does not hold good for relatively higher normal rainfall compared to that of the coastal stations.

Harmonic analysis study on the seasonal cycle in spatial distribution of rainfall pattern of Kerala reveal that the variance in annual rainfall is larger in north Kerala. Comparatively low variability in rainfall is found in the southern and central part of Kerala. The central low variance region is associated with the low rainfall zone due to the Palghat Gap. Southern District of the State, Trivandrum experiences the lowest variance in the rainfall.

The amplitude of the annual cycle is found to be directly connected with the annual mean precipitation pattern. The region of highest rainfall shows larger magnitude and low rainfall areas exhibit lower amplitude in annual cycle. Higher amplitudes of annual cycle in rainfall are noted at two regions over the State. Central part of interior Kerala, in Palakkad District showed lower amplitude in the annual rainfall pattern. The annual amplitudes gradually decrease towards the northern Districts beyond Kozhikode. The southern districts showed rapid decrease in the annual amplitude.

The coastal regions of Kerala showed a linear increase in the annual amplitude with latitude. The southern coastal station at Trivandrum showed an amplitude of 12 cm, which increased to 44 cm at the northern coastal station, Kasargod. Larger variability in the annual amplitude in rainfall can be observed in the interior part of Kerala.

Semi-annual amplitudes are generally weak compared with the magnitude of the annual oscillations. In the northern part of Kerala, the magnitude of the annual amplitude is found to be nearly double to that of the semi-annual amplitude. Semi-annual amplitude attains its magnitude near to the annual amplitude towards the southernmost part of the State.

The spatial distribution of the percentage ratio of the square of the amplitude of the semi-annual to annual oscillations in the seasonal cycle indicate that, the annual oscillations are larger in magnitude in the northern Kerala region, which decrease towards the lower latitude region. In the southern part, especially in Trivandrum District, the annual oscillations in the seasonal cycle are rather weak and the semi-annual oscillation become equally strong as that of the annual oscillations.

The spatial distribution of the phase of the annual oscillation in rainfall illustrate that Kerala experience its highest rainfall during the first two weeks in the month of July. The highest rainfall period in the seasonal cycle is earlier in coastal regions than in the high land regions of the State.

In the northern region, the phase of the second harmonics is late, and the isolines are oriented in the northwest to southeast direction. In southern Kerala, the occurrence of the semi-annual oscillation maximum is earlier and the isolines are oriented in the southwest to northeast direction. From south to north, the phase of the second harmonics showed a difference of about 50 days.

In the northern half of Kerala, the phases of both annual and semi-annual oscillations showed more or less latitudinal variations. On the other hand, the southern region showed latitudinal dependent variation in the phase of the first harmonics and longitudinal dependent variation in the phase of the second harmonics.

Interception studies were carried out for four monsoon months of 1986 in the dense forest at Peruvannamuzhi, 75 km northeast of Calicut city. The results based on the data reveal that 10.45% of the total incident raintall has been lost as interception. During the period, throughfall was 84.67% and stemflow 4.88%. In terms of depth correlation between throughfall and interception loss it is positive but it is negative between percentage throughfall and percentage interception loss which indicates that the percentage interception loss decreases with the increasing proportion of throughfall and thereby also with stemflow and amount of incident precipitation.

There are about 450 raingauge stations in Kerala, which are maintained by different agencies. Out of 330 non self-recording stations inspected, 103 stations have been found to be good, 90 to be satisfactory, 91 to be unsatisfactory and 46 to be defunct or dismantled. The major problems defects encountered pertain to measure glass, exposure/enclosure foundation, fence and funnel/tube/ receiver. In some stations proper records were not maintained, in some others, time of observation did not tally with that of IMD specifications. Many an observer require training in carrying out their duties. After installing raingauges, frequent inspections of the sites are required by the concerned officers for noting down the defects of the gauge or surroundings, if any. This is necessary to ensure that observes are in station and they are taking the readings regularly as instructed.

The major outcome of this research work and the other details furnished in this thesis will considerably help the planners and researchers in the various hydrologic analysis needed for assessing the water potential of Kerala as well as judicious planning of the water resources of the region. It will also be helpful for organising certain cultural and agricultural activities of the State.

REFERENCES

Aldridge, R and Jackson, R.J., 1968, Interception of rainfall by manuka at Taita, New Zealand. NZ Journal of Science, Vol. 11, pp.301-317.

Aldridge, R and Jackson, R.J., 1973, Interception of rainfall by hard beech at Taita, New Zealand. NZ Journal of Science, vol.16, pp.185-198.

Amorocho, J. and Brandstetter, A., 1967, The representation of storm precipitation fields near ground level, Journal of Geophysical Research, vol.72, pp.1145-1164.

Ananthakrishnan, R., Parthasarathy, B. and Pathan, J.M., 1979, Meteorology of Kerala. Contribution to Marine Sciences Dedicated to Dr. C.V. Kurian, pp. 60-125.

Ananthakrishnan, R., and Soman, M.K., 1988, The Onset of the southwest monsoon over Kerala 1901 - 1980. Journal of Climatology, vol.8, pp. 283-296.

Anderson, T., 1963, On the accuracy of rain measurements and stastical results from rain studies with dense net work. Ark. Geofysica, vol. 4 (13), pp. 307-332.

Andersson, T., 1964, Further studies on the accuracy of rain measurement. Ark. Geofysica, vol. 4 (16), pp.359-393.

Angstrom, A.K. and Drummond, A.J., 1966, Note on solar radiation in mountains regions at high altitude. Tellus, vol. 18, pp. 8701-8705.

Barry, R. G., 1981, Mountain Weather and Climate , Methuen & Co. Ltd., London.

Bleasdale, A. and Chan, Y. K., 1972, Orographic influences on the distribution of precipitation. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 322-333.

Brown, M. J. and Peck, E. L., 1962, Reliability of precipitation measurements as related to exposure. Journal of Applied Meteorology, vol. 1, pp 203-207.

Calder, I. R., 1976, The measurement of water losses from a forested area using a natural lysimeter. Journal of Hydrology, vol. 30, pp. 311-325.

Calder, I. R., 1978, A model of transpiration and interception loss from a spruce forest in Plynlimon, Central Wales. Journal of Hydrology, vol. 33, pp 247-265.

CESS, 1984, Resources Atlas of Kerala. Central for Earth Science Studies, Trivandrum.

Cheang, B. K., 1993, Inter annual variability of monsoons in Malaysia and its relationship with ENSO. Proc. Indian Academy of Sciences (Earth & Planetary Science), vol. 102, No.I, pp.219-239.

Chow, V. T., 1964, Handbook of Applied Hydrology, Mc Graw-Hill Book Co., New York.

CWRDM, 1983, Towards the establishment of a hydro-meteorological data bank in Kerala. Centre for Water Resources Development and Management, Kozhikode.

De, U.S. and Lele, R.R., 1992, Summer monsoon 1989 and southern hemispheric equatorial trough. Vayu Mandal, vol. 22, No.1-2, pp.9-17.

Delijanic, I., 1972, The characteristic changes of the amount of precipitation in connection with altitude in the mountainous areas of Yugoslavia. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Swtizerland, pp.278-289.

Delworth, T. and Manabe, S., 1993, Climate variability and land - surface processes. Advances in Water Resources, vol.16, No.I, pp. 3-20.

Department of Public Relations, 1988, A Handbook on Kerala. Dept. of Public Relations, Govt. of Kerala.

Dhar, O. N. and Bhattacharya, B. K., 1976, Variation of rainfall with elevation in the Himalayas - a pilot study. Indian Journal of Power and River Valley Development, vol. 26, pp 179-185.

Dhar, O.N., Nandal, B.N. and Ghose, G.C., 1978, Heavy rainfall stations of India. Indian Journal of Power and River Valley Development, vol.25, pp 123-134.

Divya, 1991, Increase in green house gases, climatic change and hydrological impacts. Hydrology Journal of IAH, vol. XIV, No.2, pp.62-82.

Dolman, A.J., 1987, Summer and winter rainfall interception in an Oak forest - predictions with an analytical and a numerical simulation model. Journal of Hydrology, vol.90, pp. 1-9.

Douglas, C.K.M. and Glasspoole, J., 1947, Meteorological conditions in heavy orographic rainfall in the British Isles. Quarterly Journal of Royal Meteorological Society, vol.73, pp.11-38.

Drummond, A.J. and Angstrom, A.K., 1967, Solar radiation measurements on Mauna Loa (Hawaii) and their bearing on atmospheric transmission. Solar Energy, vol.11, pp.133-144.

Finch, V.C. and Trewartha, G.T., 1949, Elements of Geography, Mc Graw - Hill, New York.

Flohn, H., 1974, Contribution to a comparative meterorology of mountain areas. J.D. Ives and R.G. Barry (eds), Artic and Alpine Environments, Methuen, London, pp.55-71.

Florence C. Khurshid Alam, 1972, Distribution of precipitation in mountainous areas of West Pakistan. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp.290-306.

Fujimara, I., 1971, The Climate and Weather of Mt. Fuji. Mt. Fuji, Scientifc Report, Fujikyuko Co, Ltd., Tokyo, pp. 215-304.

Fujita, T., Baralt, G. and Tsuchiya, K.; 1968, Aerial measurements of radiation temperatures over Mt. Fuji and Tokyo areas and their application to the determination of ground and water - surface temperatures. Journal of Applied Meteorology, vol. 7, pp. 801-816.

Gloyne, R.W., 1955, Some effects of shelter-belts and wind breaks. Meteorological Magazine, vol. 84, pp.272-81.

Green, F.H.W., 1972, Characteristics of precipitation in the Scottish Highlands. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 140-146.

Hastenrath, S.L., 1967, Rainfall distribution and regime in Central America. Arch. Meteorlogie Geophysica Bioklimatalogie., vol.15, pp.201-241.

Horn, L.H. and Bryson, R. A. 1960, Harmonic analysis of the annual march of precipitation over United States. Ann. Assoc. Amer. Geogr., vol. 50, pp. 157-171.

Hsu, C.P. and Wallace, J. M. 1976, The global distribution of the annual and semi-annual cycles in precipitation. Monthly Weather Review, vol. 104, pp. 1093-1101.

Huff, F.A., 1967, Time Distribution of rainfall in heavy storms. Water Resources Research, vol.3, pp.1007-1019.

IMD, 1981, Rainfall Registration (Revised Edition), Govt. of India Press, Nasik.

IMD, 1986, Climate of Kerala State. India Meteorological Department, Govt. of India.

Jackson, R.J. and Aldridge, R., 1972, Interception of rainfall by Kamahi, at Taita, New Zealand. N.Z. Journal of Science, vol.16, pp.573-90.

Kirkyla, K. I. and Hameed, S. 1989, Harmonic analysis of the seasonal cycle in precipitation over the United States: A comparison between observations and a general circulation model. J. Climate, vol. 2, pp.1463-1475.

KFRI (Kerala Forest Research Institute), 1981, Forest Resources of Kerala. Proc. Seminar on Resources Potential of Kerala, CWRDM, Kozhikode, pp. 26-38.

Lauscher, F., 1976. Weltweite Typen der Hohenabhangigkeit des Niederschlags. Wetter U. Leben, vol.28, pp.80-90.

Malayala Manorama, 1993, Manorama Year Book, Kottayam.

Menon, P. A., 1973 Weather to order, Vayu Mandal, vol. 2, No. 3, pp. 61-64.

Menon, P. A., 1975 MONEX, Vayu Mandal, vol.5, No.3, pp. 69-74.

Menon, P. A., 1979 Northeast monsoon, Vayu Mandal, vol.9, No.3, pp. 21-25.

Menon, P. A., 1989, Our Weather, National Book Trust of India, New Delhi.

Menon, P.A. and Rajan, C.K., 1989, Climate of Kerala. Classic Publishing House, Cochin.

Meteorological Office, 1982, Inspector's Note Book. Royal Meteorological Office, Bracknell, U.K.

Meteorological Office, 1982, Rules for rainfall observers. Royal Meteorological Office, Bracknell, U.K.

Miller, J. F., 1972, Physiographically adjusted precipitation - frequency maps. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 262-277.

Miller, R.B., 1963, Plánt nutrients in hard beech, 3, The cycling of nutrients. NZ Journal of Science, vol.6, pp.388-413.

Mohanty, U.C. and Ramesh, K.J., 1993, Characteristics of certain surface meteorological parameters in relation to the interannual variability of Indian summer monsoon, Proc. Indian Acad. Sci. (Earth Planet Sci.), vol. 102, No.I pp.73-87.

Muthuchami, A. and Revikumar, P.V., 1992, The inverse relationship between the activity of monsoon systems and the intensity of southern hemispheric equatorial trough. Vayu Mandal, vol. 22, No.1-2, pp.40-45.

Nagara, J.L., 1981, A real rainfall in the Khatmandu Valley. Mausam, vol. 38, No.4, pp. 256-263.

Panofsky, H. A. and G. W. Brier, 1960, Some applications of statistics to meteorology, The Pennsylvania State University, pp. 128-134.

Paul S. Pan, 1972, Precipitation in Taiwan mountainous areas. Proc. Symp. Distribution of precipitation in Mountainous Areas, WMO, Switzerland, pp.307-321.

Pearce, A.J. and Rowe, L.K., 1981, Rainfall interception in a multistoried evergreen mixed forest - Estimates using Gash's analytical model. Journal of Hydrology, vol.49, pp.341-353.

Peck, E. L., 1962, An approach to the development of isohyetal maps for mountainous areas. Journal of Geophysical Research, vol.67, pp.681-694.

Peck, E. L., 1972, Relation of orographic winter precipitation patterns to meteorological parameters. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp.234-242.

Pedgley, D.E., 1970, Heavy rainfalls over Snowdonia. Weather, vol.25, pp.340-349.

Plesko, N., 1972, Maximum daily precipitation in Gorski Kotar and Lika (Yugoslavia) in realtion to the overflying air-stream. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Swtizerland, pp. 186-197.

PWD, 1974, Water Resources of Kerala, Public Works Department, Govt. of Kerala.

Riedel, J.T. and Hansen, M. E., 1972, Extreme thunderstorm rainfall in the intermountain Western United States. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 334-345.

Reiter, E.R., 1963, Jet Stream Meteorology. University of Chicago Press, Chicago.

Rowe, L.K., 1975, Rainfall interception by mountain beech. NZ Journal of Forestry Science, vol.5, pp.45-61.

Rowe, L.K., 1979, Rainfall interception by a beech-podocarphardwood forest near Reefton, North Westland, NZ Journal of Hydrolology, vol. 18(2), pp.63-72.

Rowe, L.K, 1983, Rainfall interception by an evergreen beech forest, Nelson, New Zealand. Journal of Hydrology, vol.66, pp.143-158.

Ryden, B. E., 1972, On the problem of vertical distribution of precipitation, especially in areas with great height differences. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 362-372.

Sandsborg, J., 1969, Local rainfall variations over small, flat cultivated areas. Tellus, vol. 2, pp. 673-684.

Sandsborg, J., 1970, The effect of wind on the precipitation distribution over a hillock. Nordic Hydrolology, vol.1, pp. 235-244.

Satish Chandra and Ramasastri, K.S., 1988, Distribution of Precipitation with Elevation. Report of Natnl. Inst. of Hydrol., Roorkee.

Sawyer, J.S., 1956, The physical and dynamical problems of orographic rain. Weather, vol.11, pp.375-81.

Scorer, R.S., 1955, The growth of cumulus over mountains. Arch. Meteorolgie Geophysica Bioklimatologie, vol. A8, pp. 25-34.

Sharon, D., 1970, Areal patterns of rainfall in a small watershed as affected by wind and meteorological conditions. Symp. Results of Research on Representative and Experimental Basins, IUGG/IASH, Wellignton, New Zealand, pp. 3-11.

Sheppard, P.A., 1956, Airflow over mountains. Quarterly Journal of Royal Meteorological Society, vol. 82, pp. 528-9.

Sivkov, S.I., 1971, Computation of Solar Radiation Characteristics. Leningrad Gidromet Izdat, Israel Prog. Sci. Translations, Jerusalem.

Skaar, E., 1972, Distribution of precipitation in the Sognefjord region. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 171-185.

Smith, R.B., 1979, The influence of mountains on the atmosphere. Advances in Geophysics, vol.21, pp. 87-130.

Soman, M.K., Krishna Kumar, K. and Nityanand Singh, 1988, Decreasing trend in the rainfall of Kerala. Current Science, vol. 57, No.1, pp. 7-12.

Spreen, W.D., 1947, Determination of the effect of topography on precipitation. Transactions, American Geophysical Union, pp.285-290.

Sreedhara Menon, A., 1979, Social and Cultural History of Kerala. Sterling Pub. PVt. Ltd., New Delhi, pp. 165-166.

Srinivasan, K. and Ramanathan, N., 1992, Meso-scale climatological study of mean monthly temperature in Indian Peninsula. Vayu Mandal, vol.22, pp.112-115.

Storr, D. and Ferguson, H.L., 1972, The distribution of precipitation in some mountainous Canadian watersheds. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp. 243-263.

Stringer, E.T., 1972, Foundations of Climatology. W.H. Freeman and Co., San Francisco, pp. 141-167.

Thompson, W.F., 1964, How and why to distinguish between mountains and hills. Professional Geography, vol.16, pp. 6-8.

Tollner, H., 1972, Influence of orography on the share of precipitation in the East Alpine high mountains. Proc. Symp. Distribution of Precipitaion in Mountainous Areas, WMO, Switzerland, pp. 359-361.

Troll, C., 1973, High mountain belts between the polar caps and the equator: their definition and lower limit. Arct. Alpine Research, vol. 5 (3, Part 2), pp. 19-27.

Upadhyaya, D.S. and Jagdish Bahadur, 1982, On some hydrommeterological aspects of precipitation in Himalayas. Proc. Symp. Hydrological Aspects of Mountain Areas, pp. 58-65.

Verma, R.K., 1993, Variability of Indian summer monsoon, relationship with surface air temperature anomalies over northern hemisphere. Mausam, vol.44, pp.191-198.

WMO, 1983, Guide to Hydrological Practices, Vols. 1 and 2, Geneva

Wright, I.R., 1977, Net rainfall below the forest canopy. Report No. 43, Institute of Hydrology, Wallingford, U.K.

Yadav, A.K. and Mishra, G.P., 1985, Distribution of precipitation under a tropical dry deciduous forest stand of Central India. Journal of Tropical Forestry, vol. 8, pp. 181-197.

Zhidikov, A.P. and Lenin. A.G., 1972, About vertical gradients of liquid precipitation in mountains. Proc. Symp. Distribution of Precipitation in Mountainous Areas, WMO, Switzerland, pp.204-211.