COASTAL HYDROGEOLOGY OF KOZHIKODE, KERALA

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BY

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Mr. M. Nazimuddin under my supervision and guidance in the Centre for Earth Science Studies for Ph.D. Degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any university.

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CONTENTS

PREFACE

As recently as a couple of decades ago groundwater was a very sparsely exploited water resource. Very little information was available regarding the extent of aquifer, its recharge, processes etc. Only during the last 20 years groundwater has achieved the status of a major water resource and that too when it was subjected to man-made interferences resulting in drying up of wells due to excessive exploitation. Now there is the problem of pollution. Today groundwater is finding its way to the headline as the latest faddish resource to be conserved and protected so as to cope up with the increasing demand for fresh water due to population expansion, industrial and agricultural growth.

The information needed in planning the, crucial, early phase of groundwater development comprises of the mapping of the aquifer, understanding of the mechanism of natural replenishment which differ in different hydrologic setups. The requisite information can, in principle be assembled by a systematic campaign of field investigation. Detailed exploration for groundwater and systematic mapping in the country are restricted to only a few areas. Systematic evaluation of groundwater has been started only recently and broad regional characteristics are known but with insufficient reliability. The method of investigations especially for crystalline rocks, still need to be improved, inspite of the fact that many new techniques and aids are available. There is still a wide gap between a viable scientific method and it's routine application by field workers.

High population density, the rapid growth of industry and also the repeated occurrence of natural hazards including the drought situation calls for an efficient management of the coastal areas of our country. Due to the unusual shortage of surface water and a great demand for groundwater resources in the coastal regions of Kerala, particularly in Kozhikode, a detailed understanding of the latter is required. A reliable estimate of groundwater availability, utilization and quality aspects have to be obtained to improve the present water demand and also to meet the future requirements. The monitoring of coastal hydrogeology is a complex process requiring establishment of long term and short term monitoring programmes. This is required for the development, protection and management of coastal groundwater resources. Practically no systematic studies on the coastal hydrogeology to cover both the coastal aquifers above the basement and below the basement rocks are not made for any part of Indian coast except for a few restricted areas. Hence a comprehensive study of the coastal aquifers above the basement and coastal crystalline aquifers below the basement of the rocks are undertaken as a model in Kozhikode coast. The results of the investigations are presented in this thesis.

The thesis comprises of eleven Chapters. In the first introductory Chapter, the status of the problem, the need and the objectives of the investigation and the relevance of the study in coastal groundwater system and it's management are presented. General features of Kozhikode coast is discussed in second Chapter. The sub-surface geology of Kozhikode coast is examined on bore hole data. The details are highlighted in Chapter - 3. Hydrogeology of coastal and crystalline aquifers are presented in Chapter 4 and 5 respectively. Groundwater availability and utilisation of coast is given in Chapter 6 and 7 respectively. Groundwater quality and salinity problems are highlighted in Chapter 8 and 9. Groundwater management problems of Kozhikode coast are outlined in Chapter 10. The last Chapter presents the summary of the present investigation and reccomendations for coastal ground water development and for further research.

The following research papers are published based on the work reported in this thesis.

1. Planning for urban water supply schemes through Remote Sensing. Journal of the Institution of Engineers Vol. 66, part EN 3, June 1986. (M. Nazimuddin and P. Basak)

2. Sea water intrusion in coastal unconfined aquifer of south western peninsula - a case study. Jal Vigyan Sameesksha, Vol. II, No.I, 1987. (P. Basak and M. Nazimuddin)

3. Seasonal variation of groundwater quality along coastal areas of Kozhikode district. Jal Vigyan Sameeksha - Vol. III, No.I, 1988. (M. Nazimuddin and P. Basak)

4. Groundwater availablity and its distribution along the coastal belt of Kozhikode District. National Seminar on Groundwater Development in Coastal tracts Thiruvananthapuram, January 29-30, 1988. (M. Nazimuddin and P. Basak)

5. Coastal groundwater utlisation in Indian Peninsular - A case study. Sixth World Congress on Water Resources May 29 - June 3, 1988, Ottawa, Canada, 1988. (P. Basak and M. Nazimuddin)

6. Problems of groundwater development in Kozhikode coast and adjoining areas of Kozhikode corporation - suggestions for better management. National Conference on Coastal zone Management. February 20-23,Cochin, 1989. (M. Nazimuddin)

7. Groundwater in the coastal belt: Kozhikode District. GW/R-77/83. (P. Basak and M. Nazimuddin)

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CHAPTER I

INTRODUCTION

The total fresh water availability of any region normally remains more or less constant subject to the vagaries of the climatic and environmental conditions. With a rapid increase in the population, the per capita availability of fresh water resources decreases. During the last 100 years, India's per capita water availability has decreased four-fold whereas for Kerala State, it has decreased five-fold (Basak, 1992).

Water is a critical input for any developmental activity. In many of the developed nations the per capita water consumption is over 900 litres per day. While in India it is only 45 litres per day. Perhaps Kerala ranks first among the States in per capita consumption rate with 90 litres per day. The low availabilty and high consumption rate are the problems confronting the State. Groundwater investigation and development have gained momentum in this context not only in Kerala but throughout the world to cope up with the increasing demand for fresh water.

1.1 Hydrogeology

Hydrogeology is essentially groundwater geology and is defined as the study of the laws of occurrence and movement of groundwater. Hydrogeology has become an important branch of geology in the past 3 decades. The important reason for this development is the water resources have become extremely precious in some parts of the world, due to constant increase in population and consequent, increased water consumption.

1.2 Coastal Hydrogeology

Coastal hydrogeology deals with water-bearing rocks along the coast. Most aquifers can be defined as geological units or parts of them. Many coastal plains in the continents are underlain by subsiding basins which hold a thick accumulation of Cenozoic sediments below surface. In the coastal areas different aquifers separated by aquitards and aquicludes are present.

A special problem of aquifers in coastal areas can be the quality of groundwater and, in particular, the occurrence of salt and brackishwater. One of the most disastrous man-induced geological hazards in coastal areas is land subsidence, which is caused due to groundwater withdrawal. The subsidence results in tidal encroachment which can cause saltwater intrusion in the aquifer and flooding of settlements. Other problems are differential changes in elevation and gradient of streams, channels, drains and canals. Water well casings may fail, due to compressive stresses caused by compaction of aquifers. These problems have to be taken into account if heavy withdrawal is allowed.

1.3 Kerala's Coastal Management

Physiographically, the Kerala State is divided into three units, viz. lowland, midland and highland (Fig.1.1). Though this division is mainly based on elevation from Mean Sea Level (MSL), geomorphologically, lowland is mainly sandy alluvium, midland consists of thick laterites and highland is made up of hard rocks, occasionally with a thin lateritic cover. The three belts (Fig. 1.1) run almost parallel to each other. The lowland, which is considered here as the coastal zone, which is about 560 km long, extends from Thiruvananthapuram in the south to Kasaragod in the north. It attains a maximum width of about 25km near Cherthalai and tapers out in the north and south. Though coastal zone constitutes only 10% of the total land mass, it supports more than 25% of state's population. (Baba, 1986) This obviously is putting a heavy pressure on the limited resources available in this narrow stretch.

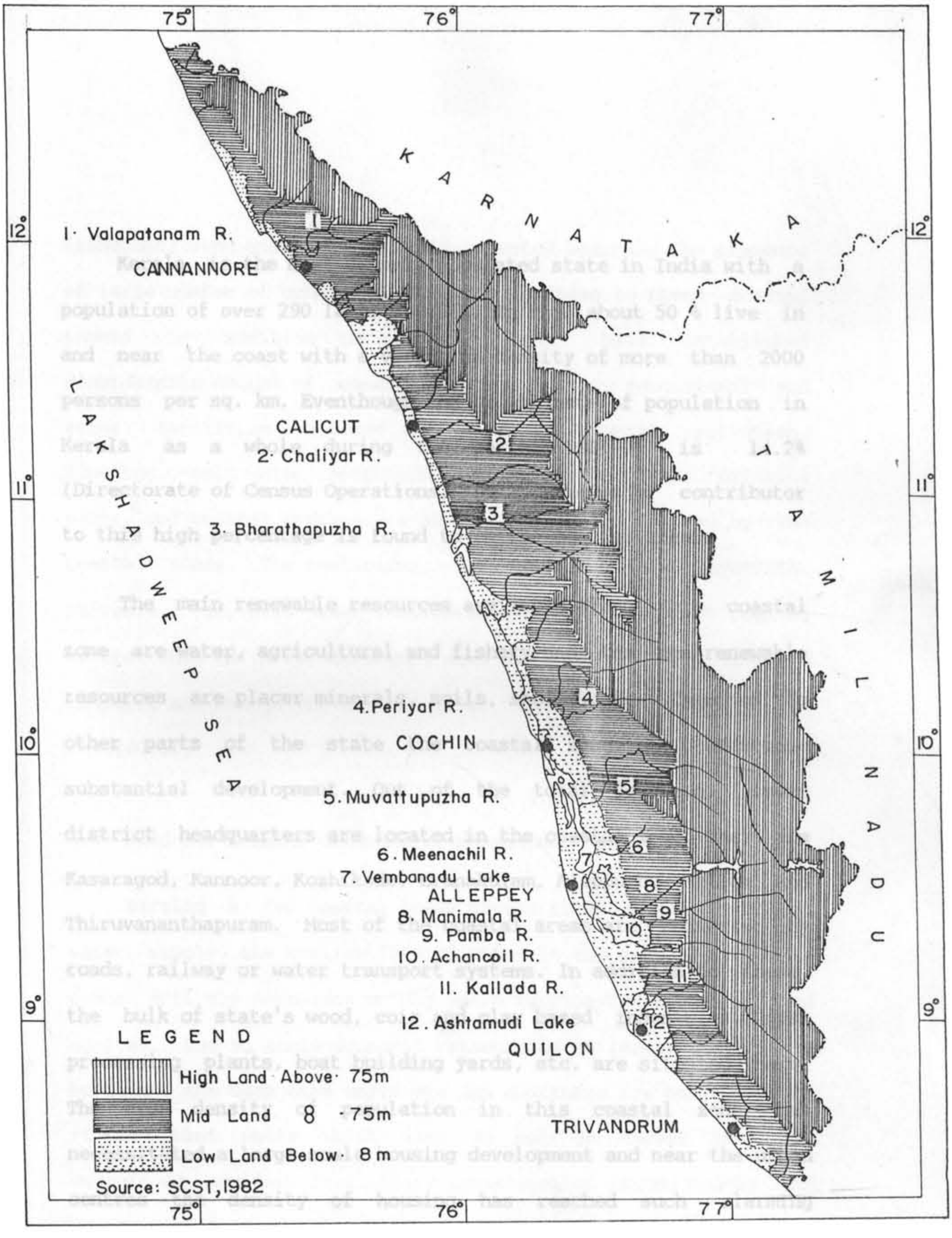


FIG. 1.1 PHYSIOGRAPHY OF KERALA

Kerala is the most densely populated state in India with a population of over 290 lakhs in 1991. In this about 50 % live in and near the coast with a very high density of more than 2000 persons per sq. km. Eventhough the growth rate of population in Kerala as a whole during the period 1981-91 is 14.2% (Directorate of Census Operations, 1991) , the major contributor to this high percentage is found to be the coastal areas.

The main renewable resources available along this coastal zone are water, agricultural and fishery and the non-renewable resources are placer minerals, soils, shells, etc. Compared to other parts of the state the coastal zone has undergone substantial development. Out of the total fourteen, seven district headquarters are located in the coastal zone. They are Kasaragod, Kannoor, Kozhikode, Eranakulam, Alappuzha, Kollam and Thiruvananthapuram. Most of the coastal areas are connected by roads, railway or water transport systems. In addition to these, the bulk of state's wood, coir and clay based industries, fish processing plants, boat building yards, etc. are situated here. The high density of population in this coastal zone has necessitated a large scale housing development and near the urban centres the density of housing has reached such alarming proportaions that the people of the lower starta (mainly fishermen) even encroach the newly accreted beaches. The presence of large number of urban and industrial centres in these coastal tracts in addition to all the above, have established considerable amount of commercial, recreational, educational and other facilities. Wetland reclamation, coastal pollution, flooding, salt water instrusion, quality problems for drinking water, and coastal erosion are some of the problems faced by the coastal zones. The pesticides, insecticides, water hyacinth, salvenia, etc. also cause considerable problems in the coastal waters. This calls for an urgent need for studies with a view to conserve and manage the coastal areas, the groundwater system in particular.

1.4. Need for Coastal Groundwater Management System

Barring a few coastal towns having river based municipal water supply, the availability of water in the coastal zone is almost entirely dependent on dug wells tapping the top unconfined aquifer. Due to socio-economic reasons and extremely small land holdings, the deep tube wells are few and there are only shallow filter point wells which also do not go deeper than the unconfined aquifer. Preliminary investigation (Bindu Madhav and Basak, 1982) indicates that in the Kerala coastal zone 30,000 litres of groundwater per day per sq.km. is drawn mainly through dug wells (about 300). Withdrawal of such fresh water from the coastal aquifer adjacent to shore, particularly in the absence of appropriate recharge in the non-monsoon season causes lowering of the fresh water table. Heavy groundwater withdrawal in coastal aquifers connected to the sea can result in salt water intrusion.

At present these coastal aquifers - specifically the top unconfined aquifer is being indiscriminately used without any knowledge of safe yield, safe method of withdrawals, extent of recharge, salinity intrusion and extent of pollution in it.

In spite of the pre-eminent position of groundwater for water supply in the coastal belt, it is surprising that no concrete efforts have been made to systematically assess the quantity and quality of this natural resource. Also the lack of knowledge stands in the way of formulation of any viable policy for the management of groundwater system of the coastal zone. The present study will be an attempt to fulfil this longstanding gap and vital need.

1.5. Objectives of the Present Study

The full development of coastal groundwater resources may pose number of management problems. Studies on all possible aspects including re-charge, optimum water use, recycling of waste water and prevention of groundwater pollution are already being undertaken to equip scientists, engineers and planners with a high level knowledge and proficiency so that they can manage this situation likely to arise in future.

Kozhikode coast has been selected as a model for such a comprehensive study. This is one among the major coastal zones of the State, where the demand for groundwater resources has accelerated in recent times. This coast, in addition to the issues mentioned earlier, has

(i) limited thickness of coastal aquifers;

(ii) several constraints in groundwater exploration;

(iii) difficulty in studying the complicated hard rock aquifer underlying the coastal basement rocks and

(iv) seawater intrusion problems.

It is in this context, a detailed hydrogeological study is thought necessary in this coastal zone with an ultimate objective of scientific evaluation (both quality and quantity) of optimum utilisation and proper management of the available groundwater resources.

The study proposed aims to explore these aspects for the coastal region of Kozhikode. The main objectives of the present hydrogeological investigations are:

(i) To delineate various aquifer systems along the coast from the existing borehole data;

(ii) To study the aquifer characteristics through field tests;

(iii) To assess the groundwater availability and it's quality;

(iv) To study the extent and pattern of groundwater utilisation in the study area;

(v) To study the saltwater instrusion problems of the coastal aquifer;

(vi) To suggest areas for detailed groundwater development and

(vii) To suggest a management strategy for coastal groundwater system.

CHAPTER 2

KOZHIKODE COAST

2.1 Physiography

The District of Kozhikode comprises of three taluks viz. Kozhikode, Vadakara and Quilandy which are subdivided into 12 blocks and 77 panchayats. Topographically the district has three regions, the sandy coastal zone (low land), the rocky highland covering the hilly portions of Western Ghats and the lateritic midland. The Headquarters of the district, viz.Kozhikode city is one among the three city corporations in the State.

Kozhikode coast is 72.5 km. long and it stretches from Kadalundikadavu in south to Aliyur in the north near Mahi covering an area of 91 sq.km excluding the backwater areas (Fig. 2.1). This area is bounded between the sea and the laterite formations. Vadakara, Quilandy, Kozhikode, Beypore and Kadalundi are some of the important towns in the coastal tract.

2.2 Land Use

The latest data on land use pattern in Kozhikode is given

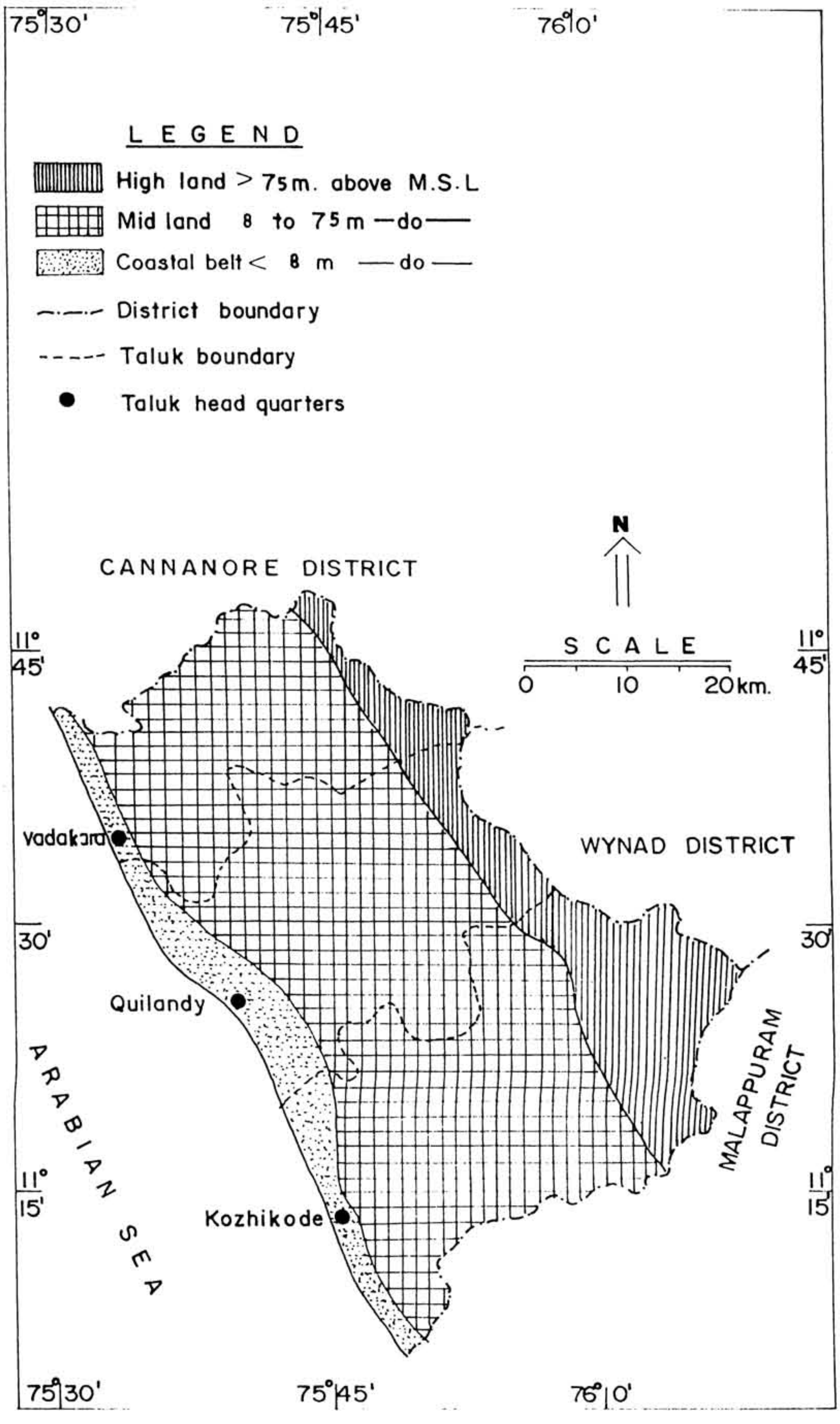


FIG. 2.1 MAP OF KOZHIKODE DISTRICT IN KERALA STATE

below (Kerala State Land Use Board, 1989).

	Area in hectares
Total geographical area	2,33,330
Forest	41,386
Land put to non-agricultural use	16,351
Barren and uncultivable land	2,262
Permanent pastures and grazing land	122
Land under miscellaneous tree crops	2,652
Cultivable waste	2,288
Fallow (other than current fallow)	1,293
Current fallow	2,282
Net area sown	1,64,694
Area sown more than once	35,060
Total cropped area	19,954

Being thickly populated, a substantial portion of Kozhikode coastal belt is utilized for residential purposes and in the remaining areas, the crops grown are coconut, tapioca, banana and vegetables.

2.3. Rivers and Backwaters

Kozhikode District has 4 major rivers (Fig. 2.2). All are

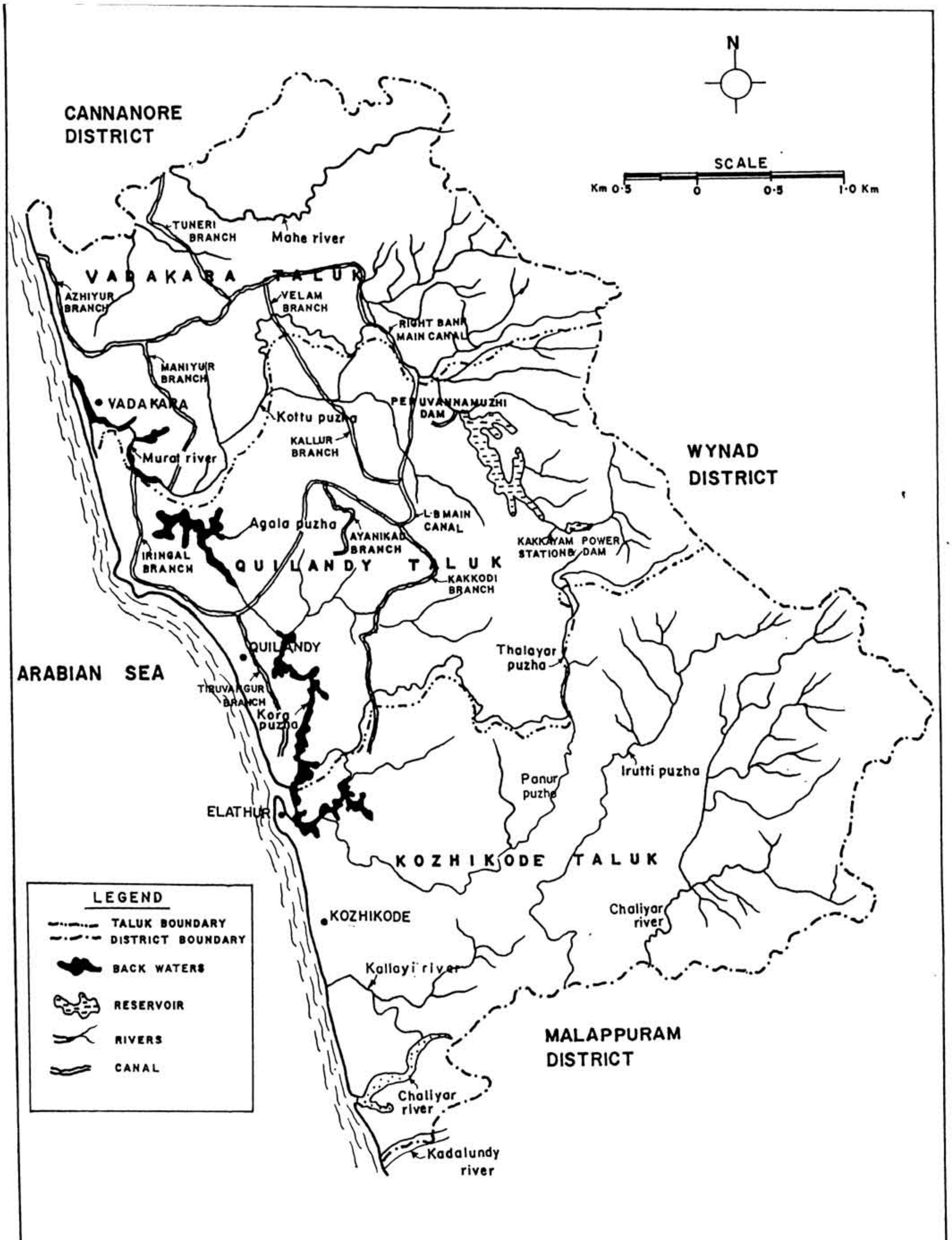


FIG. 2.2 DISTRIBUTION OF SURFACE WATER BODIES IN KOZHIKODE DISTRICT

west-flowing and drain into Arabian Sea. The largest river is Kuttiyadi. The major features of the rivers are given in Table 2.1

Table 2.1 Characteristics of rivers in Kozhikode

Sl. No.	Name of river	Length in km.	Catchment in sq.km	Annual discharge in MCM
1	Kuttiyadi (Morat)	74	583	1224.3
2	Kallayi river	22	96	201.6
3	Chaliyar river (*only the portion in paranthesis falls in Kozhikode	169 (29.5)*	2535 (455.5)	5323.5 (956.4)
4.	Kadalundi river (only a small portion is in Kozhikode District)	130 (14)	1099 (120.42)	2307.4 (252.88)

Among the rivers, annual discharge of Kuttiyadi is maximum. Chaliyar is having more catchment area but 17% only falls in Kozhikode. Kallayi is the only river draining fully in Kozhikode.

Kozhikode District has a large backwater body, formed by the confluence of Agalapuzha with the Panurpuzha. It meets the sea at Elathur. Based on GTS maps the areal extent of this backwater body of Elathur is about 33.36 sq.km. If 3 m is taken as average depth then total water stored in this backwater body works out to be 100.68 MCM.

2.4 Rainfall and Temperature

The coastal area in Kozhikode district enjoys a humid tropical climate with an average rainfall of about 3000 mm, whereas the average rainfall for the whole district is about 3424 mm. Kozhikode coast experiences two monsoons. The southwest monsoon enters the coast in June and lasts till September and is the main cause of rainfall. About 20% to 25% of the annual rainfall is recorded in the month of November and December due to northeast monsoon.

The minimum and maximum temperatures are around 23.5 ^{o}C and 34 ^{o}C.

2.5 Soils

According to the soil survey report of Department of Agriculture (1978), Kozhikode District has basically six types of soils eg: coastal alluvium, reverine alluvium, brown hydromorphic, laterites, forest loam and grayish onattukara (Fig. 2.3.)

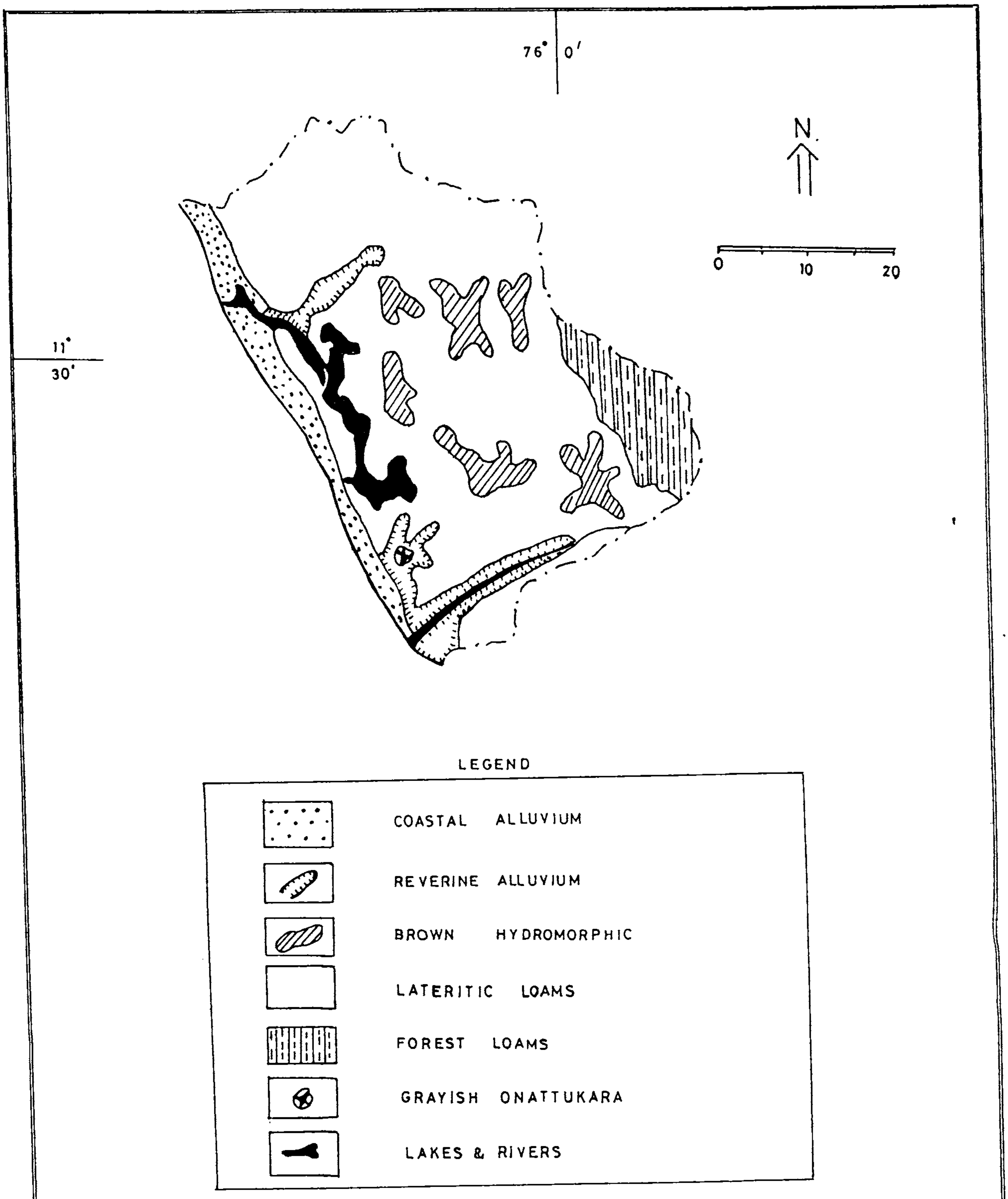


Fig.2.3 SPATIAL DISTRIBUTION OF SOILS IN KOZHIKODE DISTRICT

SOURCE _ DEPARTMENT OF AGRICULTURE . 1978

The coastal alluvium is distributed all along the coast. The low clay content and organic matter has been responsible for low cation exchange capacity. The crops irrigated in it include coconut, tapioca, paddy and fruits.

The reverine alluvium composed of moderately well-drained soils distributed mainly on the banks of rivers and tributaries. They occur on flat to gently sloping lands. They are light to medium textured with good physical properties and good productivity. The usual crop cultivated in it are coconut, arecnut, banana, vegetables and fruits.

2.6 Geomorphology

The shoreline of Kozhikode coast generally is with minor undulations at Kadalur near Quilandy. The shoreline is seen more or less straight from Kadalur to Beypore. The various major geomorphic units identified from the coastal areas include beach, sand bars, shore platforms, lateritic hills, and valleys. (Ahmed 1973) Naduvattom - Panniyankara area in Kozhikode represents a typical sand bar, with small valleys. Paddy is cultivated in these valleys.

Two major types of shore-lines are identified in Kozhikode coast, namely cliffed and nuetral shoreline (Nair, 1987[b]). In cliffed shoreline the cliffs are bordered by platforms with gentle slopes extending across the shore. These are developed abviously due to cliff recession by wave attack. They extent from high tide level at the base of receeding cliffs, to the low tide level in the nearshore zone and are termed intertidal shore platforms. Such platforms are found developed on laterites around Quilandy west and gneisses in the north of Aliyur near Mahe. The shoreline between Elathur and Beypore falls under the neutral category. These shorelines are found more or less straight.

CHAPTER 3

GEOLOGY AND SUBSURFACE GEOLOGY

3.1 Geology

The Kozhikode coast is chiefly underlain by hardrocks of Archaean age forming part of peninsular shield. Quaternary formations of Sub- Recent to Recent ages overlie the hardrocks occuring along this coast. Geologically the coastal tract of Kozhikode district is more or less similar to that of Thiruvananthapuram coast (C W R D M, 1983) but for the clear absence of tertiary sediments. Further the Khondalites which occur in southern part of Thiruvananthapuram coast also are not seen here. Archaean rocks include charnockites and gneisses. Veins of rocks and pegmatite of varying dimensions traverse all along these rock types. Exposures of gneissic rocks are seen at Iringal, east of Quilandy and south-east of Kottackal port. Laterite occupies wide areas in the Kozhikode coast. The Recent and Sub-Recent formations include coastal sands, alluvium, delta and flood plain deposits. Flood plain deposits are seen only along the rivers. All along the coast the beaches are sandy. The sand is made up of fine to medium quartz grains.

Based on the lithological units the Kozhikode coast can be classified into the following geological formations (Fig. 3.1 & 3.2)

(i) Coastal-sandy formation: This zone (Ref. Photograph - 1) lies very close to the sea. Generally the zone is composed of medium to fine sand with admixture of shells. Clay content is less in this zone. Groundwater occurs under the water table condition.

(ii) Coastal-Alluvial formation: This zone is characterised by argillaceous-sediments with a higher proportion of clay. Clay, clayey sand, shells and sands are common in the lithological units present in this zone. (Ref. Photograph - 2) Perched water table condition is common.

(iii) Coastal Alluvial-Laterite formation: This zone lies between the coastal alluvial zone and the laterite formation. (Ref. Photagraph - 3) Most important feature of this zone is that it is a mixture of the sediments, mostly sand, clay and laterite. Here water level of wells is found deeper, when compared to other zones. Groundwater occurs under phreatic conditions in this zone.

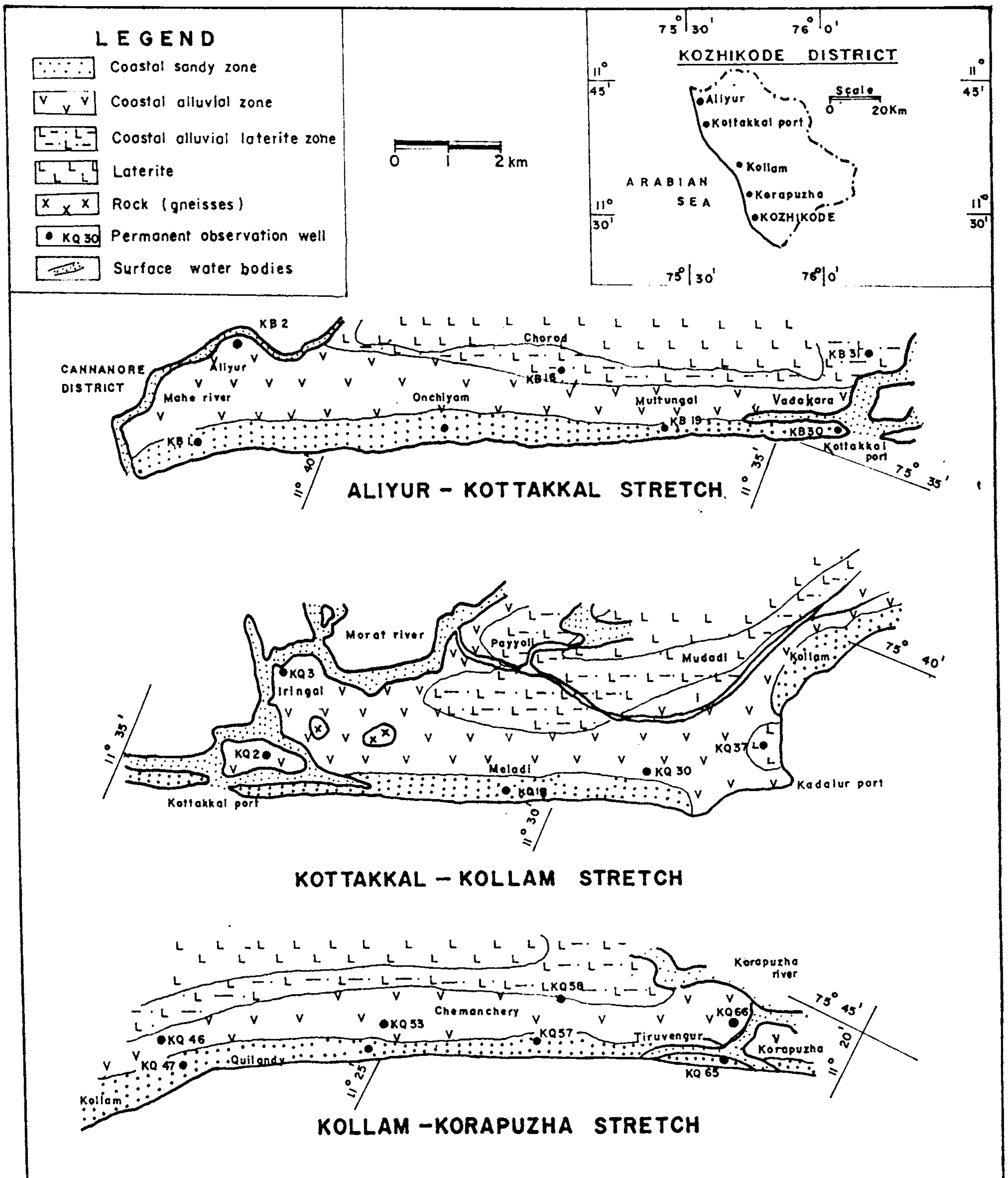


Fig.3.1 SURFACE GEOLOGICAL MAP OF KOZHIKODE COAST ALIYUR - KORAPUZHA STRETCH

PHOTOGRAPH - 1 COASTAL SANDY ZONE

PHOTOGRAPH - 2 COASTAL ALLUVIAL ZONE

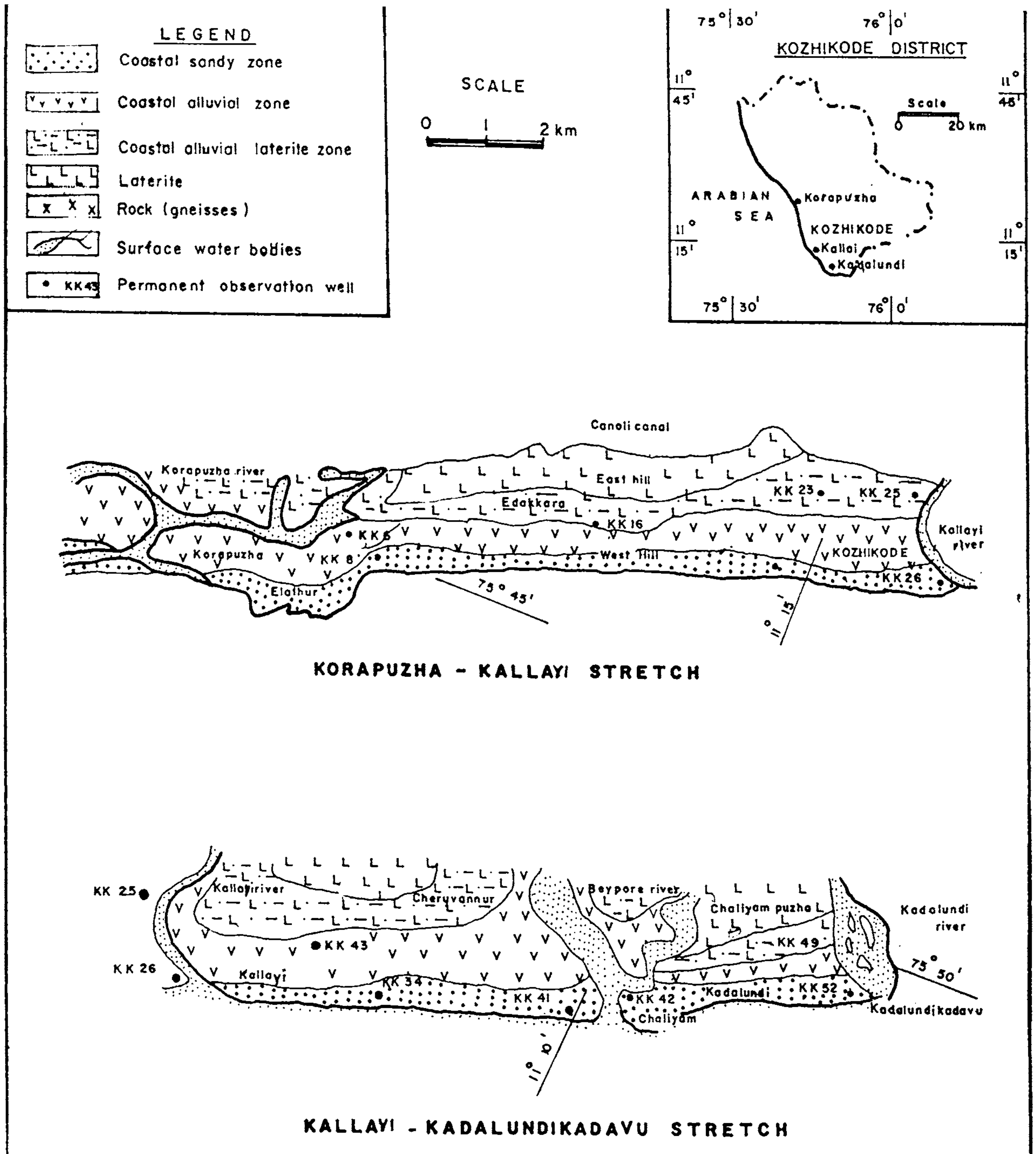


Fig. 3.2 SURFACE GEOLOGICAL MAP OF KOZHIKODE COAST KORAPUZHA – KADALUNDIKADAVU STRETCH

(iv) Laterite formation underlain by crystalline rocks: The thickness of the laterite formation in the study area varies from 10m to more than 40m. Water level of wells is generally found to be deeper among all the zones. (Ref. Photograph - 4) In summer months dug wells tapping the laterite clay zones get dried up. Wells tapping lateritic gravels supply water during summer. Groundwater occurs under watertable conditions in these formations. The distribution of various geological formations is given in Fig. 3.1 and 3.2. The order of superposition and classification of various formations in Kozhikode coastal belt is given in Table 3.1.

Table- 3.1 Geological formations in Kozhikode coast

Group	Age	Classification of the geological formation
Quaternary	Recent Sub-Recent Sub-Recent to Pleiostocene	Coastal Sandy formation Coastal Alluvial formation Coastal Alluvial Laterite formation
	Pleiostocene	Laterite formation
Proterozoic	Archaean	Hornblende/biotite gneisses, veins of pegmatite and quartz, charnockites.

PHOTOGRAPH - 3 COASTAL ALLUVIAL-LATERITE ZONE

PHOTOGRAPH - 4 LATERITE ZONE

3.2 Sub-surface Geology

The subsurface geology of Kozhikode coast is studied on the bore hole data. For this purpose lithological logs of about twentysix bore holes are studied. These bore hole data are used to prepare various geological cross sections along and across the Kozhikode coast. Table 3.2 presents the fractured aquifer zones in the hard rock below the basement of the coast. Delineation of different aquifer horizons,discharge and other hydraulic parameters of fractured zones tapping the bore wells (Fig. 3.3) are presented. The different sections are explained below.

3.2.1 Ferok-Nadakkavu-WestHill-Tikkodi(longitudinal)Section

Fig. 3.4 and 3.5 give the schematic representation of various lithological units present along this section. Analysis of sections indicate that Kozhikode coast has four important water bearing formations(aquifers).They are(a)sandy (b)laterite (c)weathered rock and(d)fractured aquifers below the basement.

The depth horizons of various aquifers are shown in Fig. 3.4 and 3.5 and are self explanatory. The basement rocks encountered at all bore hole sites are granite gniesses,quartzo-feldspathic gneisses and biotite-gneisses.The different geologic

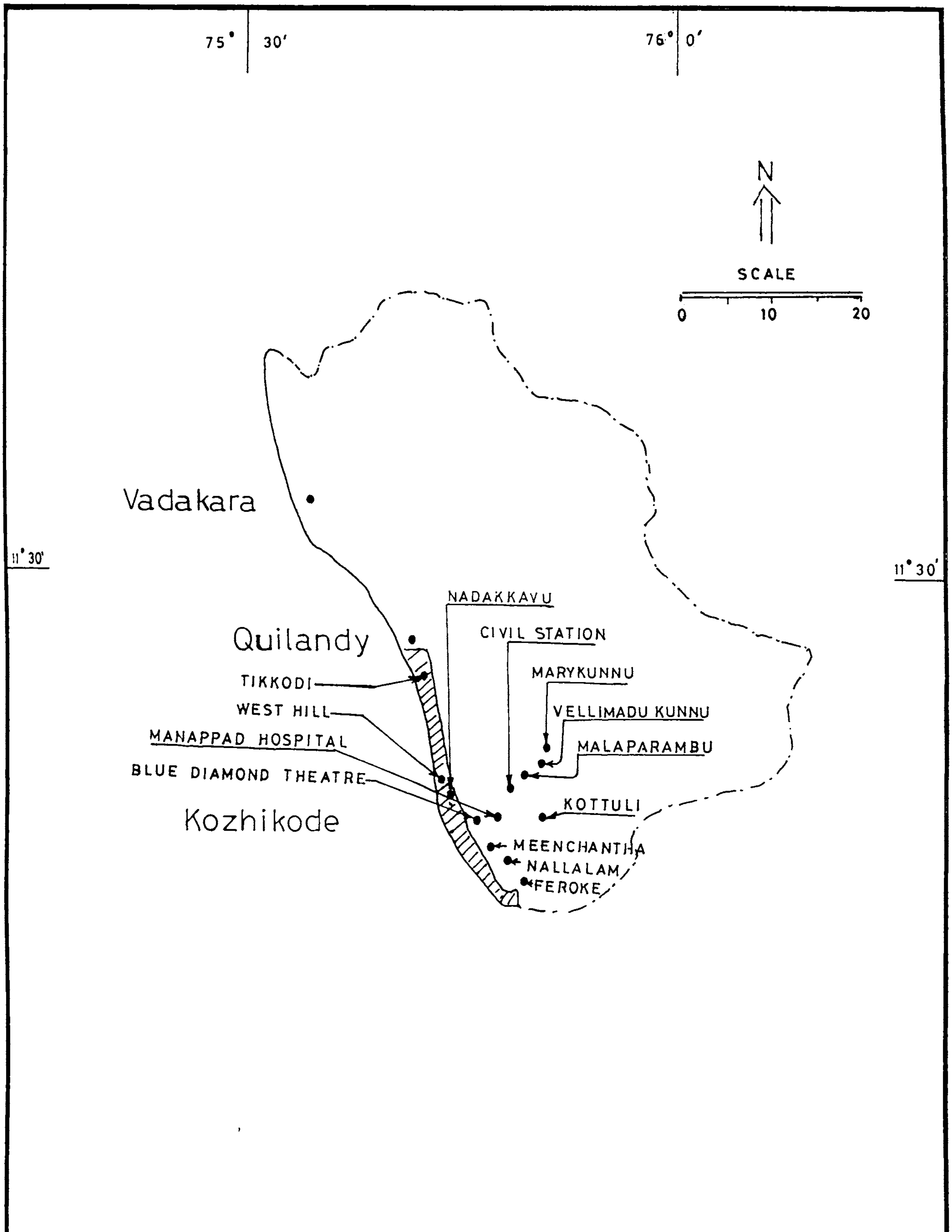


Fig. 3.3 SELECTED BORE HOLE SITES

Table 3.2 Fractured aquifer zones in the hard rock underlying the study area

Serial No.	Location	Diameter of the bore well in mm	Depth drilled in m	Depth of over burden in m	Depth horizons of Fracture zones in m	Quality of water
1.	Nallalam	152.4	51	36	36 - 42	Good
					45 - 48	
2.	Elathur	152.4	80	14	14 - 19	Good
					70 - 73	Good
3.	Nadakkavu	152.4	70	24	24 - 26	Saline
					40 - 44	
4.	Meenchanda	152.4	77	33	33 - 34	
					38 - 39	Good
					53 - 56	
					76 - 77	
5.	Marykunnu	152.4	97	36	39 - 34	
					45 - 48	
					58 - 64	Good
					83 - 87	
6.	Baby Hospital	152.4	30	15	16 - 21	
					22 - 30	Saline
7.	Kottuli	152.4	50	22	22 - 25	
					31 - 33	Saline
					45 - 47	
8.	Ferok College	152.4	73	24	51 - 54	
					64 - 68	Good
					71 - 73	
9.	Paryancheri	152.4	67	24	24 - 26	
					33 - 35	
					36 - 51	Good
					56 - 61	
10.	Civil Station	152.4	74	24	31 - 32	
					40 - 42	
					42 - 45	Good
					54 - 61	
11.	A.D.M. Quarter's Malaparamba	152.4	79	35	36 - 38	
					41 - 42	Good
					45 - 48	
					51 - 54	
					60 - 64	

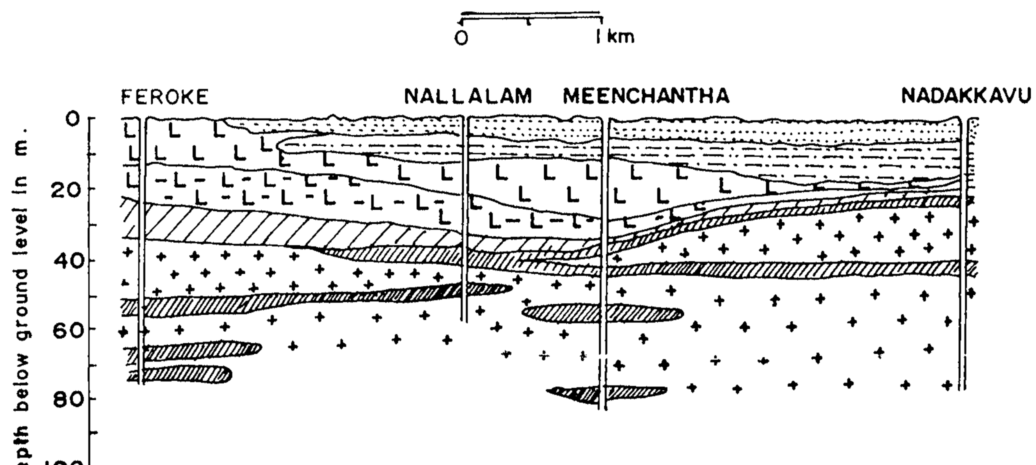


FIG.3.4-FEROKE – NADAKKAVU SECTION

SCALE

Horizontal 1 cm = 2 km
Vertical 1 cm = 5 km

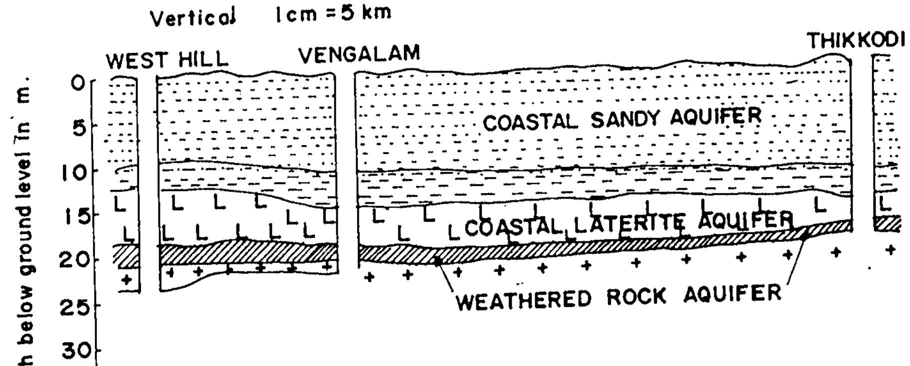
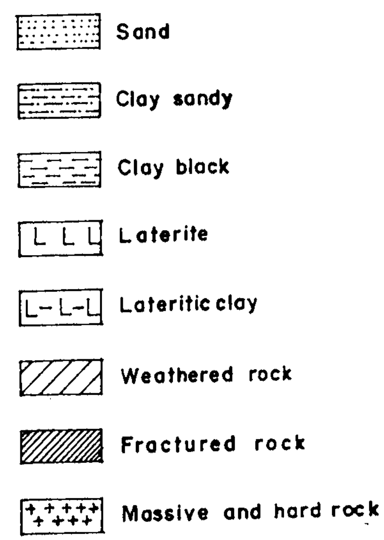


FIG.3.5 WEST HILL – THIKKODI SECTION

LEGEND



strata found in these sections in the sequence with which they occur below the ground level are (a)sand (b)clayey sand, (c)clay, (d)laterite (e)lateritic clay (f)weathered rock (g)hard basement rock(gneiss) (h)fractured rock and (i)hard rock (gneiss).

In West-Hill-Tikkodi section no data is available beneath the basement rocks and hence fractured rock aquifers could not be studied in this section. The different aquifers encountered in this section are similar to those found in the Feroke-Nadakkavu section.

3.2.2 Civil station-Marykunnu and Bluediamond-Kottuli (cross) sections

The geological strata are schematically presented in Fig. 3.6 and 3.7. These bore hole sites are 4 to 10km away from the coast.Coastal sandy aquifer is absent in this section. The other three types of aquifer such as laterite, weathered rock and fractured aquifers are found to be common in these sections. The basement rocks are gneisses and the bed rock depth varies from 20 to 35m. Bore wells drilled in the Civil station-Marykunnu section are used for drinking water.

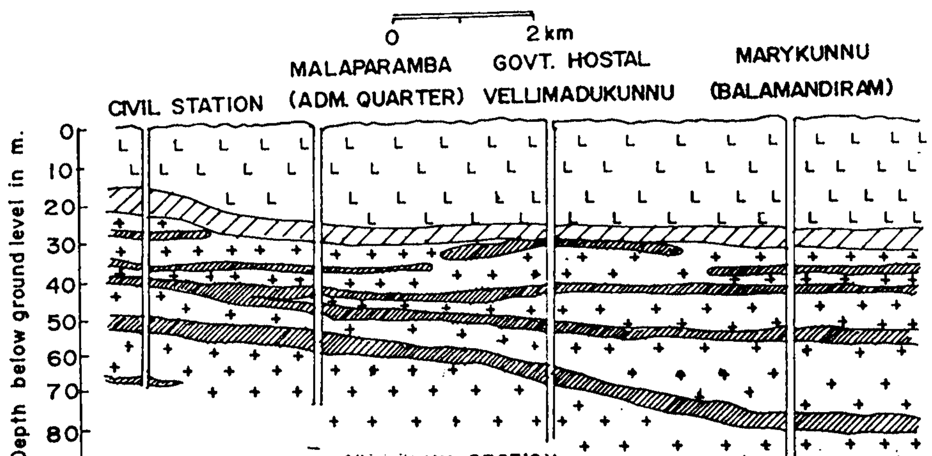


FIG-3-6-CIVIL STATION MARYKUNNU SECTION

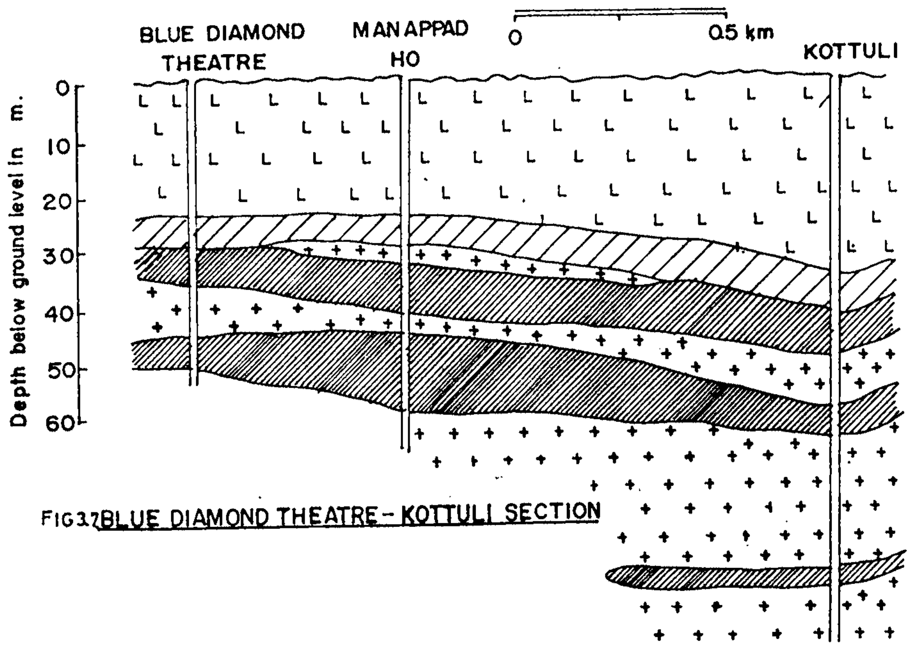
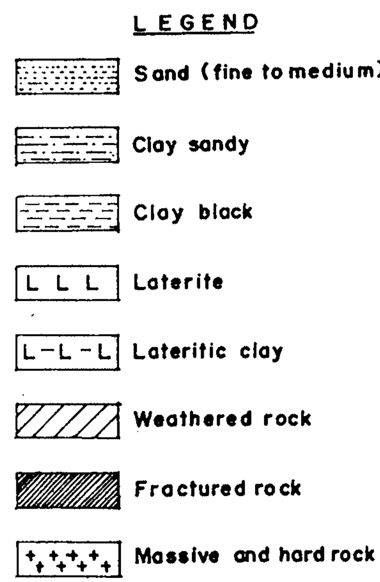


FIG 3.7 BLUE DIAMOND THEATRE - KOTTULI SECTION



3.3 Summary and Conclusions

(i) The sequences of geologic substrata which occur along the coastal stretches of kozhikode are sand, clayey-sand, clay, laterite, lateritic clay, weathered rock gneiss, hard rock (basement) gneiss and fractured rock.

(ii) Bore holes across the Kozhikode coast show the following geologic strata: laterite, lateritic clay, weathered rock-gneiss, hard rock-gneiss and fractured rock.

(iii) The bore hole data indicate that the coastal stretches of Kozhikode comprises of four types of aquifer zones, namely: sand, laterite, weathered rock and fractured rock (below the hard basement rocks).

(iv) The bed rock depth of the coast varies from 20 to 35 m. The bed rock encountered in all the bore holes are found biotite-gneisses, quartzo-feldspathic gneisses and granite gneisses.

(v) The average thickness of various aquifers tapped from the existing bore well data are shown below:

	Aquifer	Thickness in m.
(a)	sand	6.00 to 12.00
(b)	laterite	3.00 to 33.50
(c)	weathered rock	3.00 to 14.00
(d)	fractured rock	2.70 to 16.70

(vi) The bore well data analysis indicates that there are three types of fractured rock aquifers beneath the basement rock along and across the coast. They are: weathered rock aquifer associated with fractured zone, fractured rock aquifer lies below the basement rock at shallow depth (say 10m below) and moderately low to permeable, sub-horizontal to horizontal fractures occuring at higher depth between the massive gneissic rocks.

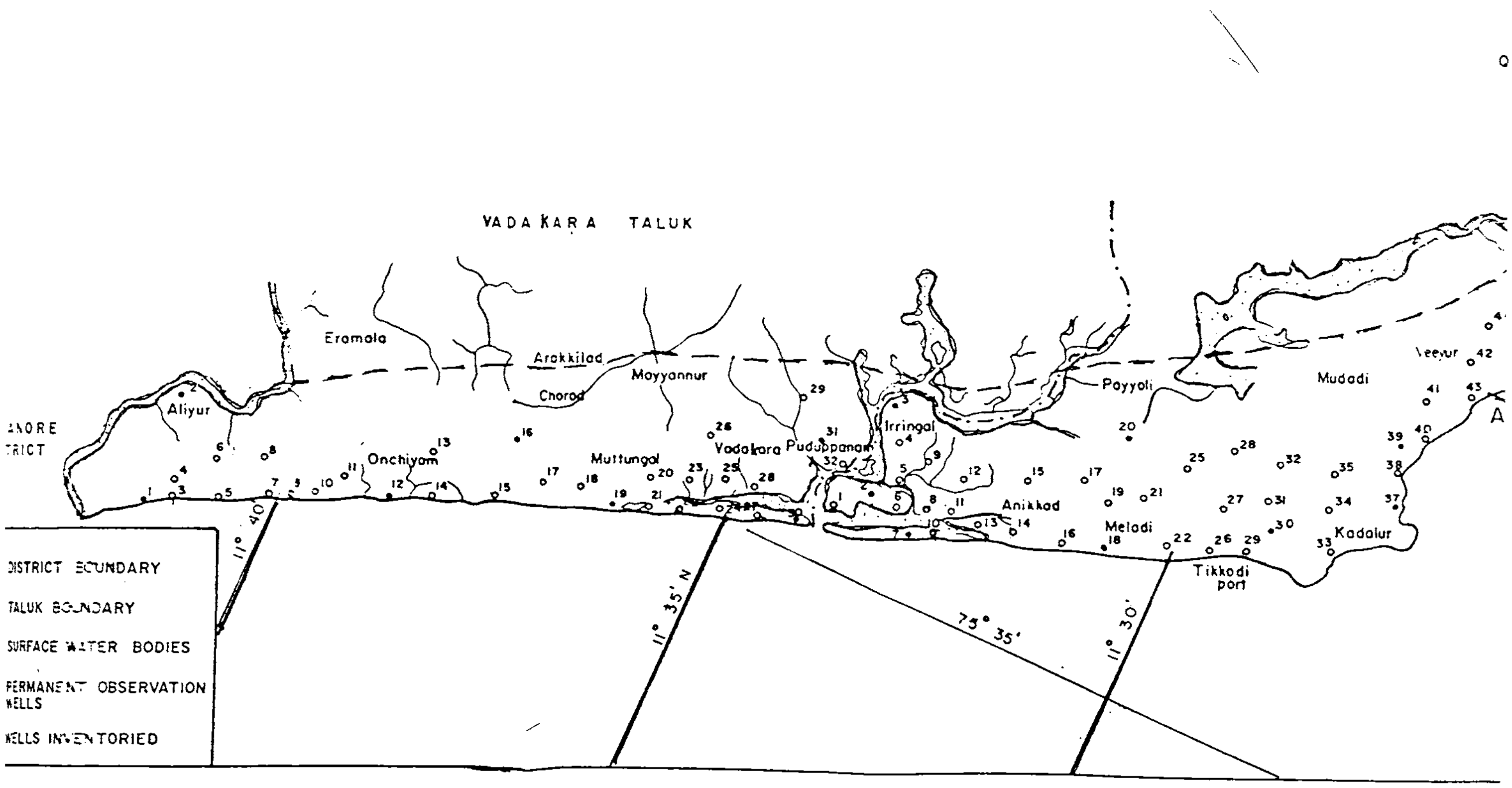
CHAPTER 4

HYDROGEOLOGY OF COASTAL AQUIFER

4.1 Introduction

Coastal aquifers are one of the basic groundwater sources for the coastal population. This source is extracted mainly through open wells and filter point wells. For the balanced utilization of these aquifers, which are under tremendous stress due to overexploitation and pollution , there is a need to understand its availability and distribution. This Chapter examines the aquifers of the Kozhikode coast and tries to quantity the groundwater availabity in this zone. A total of 150 dug wells are first inventoried based on a reconnaitory hydrogeological survey. These inventoried wells are so chosen, such that there is atleast one well within a radius of 1 to 2 km. The detailed location of these wells are shown in Fig. 4.1. During field survey all relevant geological features are noted. A boundary is fixed between the coastal and laterite formation. The present study is limited only to the coastal formation .

Based on this information thirtysix permanent observation wells are identified (Fig.4.1). There is atleast one well within a radius of 2 to 3 km in this group. Factors like proximity to


VADAKARA TALUK
Eramala
Arakkilad
Chorod
Mayyannur
Aliyur
Onchiyam
Muttungal
Vadakara
Puduppanam
Irringal
Payyoli
Mudadi
Anikkad
Meladi
Tikkodi port
Kadalur
DISTRICT BOUNDARY
TALUK BOUNDARY
SURFACE WATER BODIES
PERMANENT OBSERVATION WELLS
WELLS INVENTORIED
11° 40'
11° 35' N
75° 35'
11° 30'

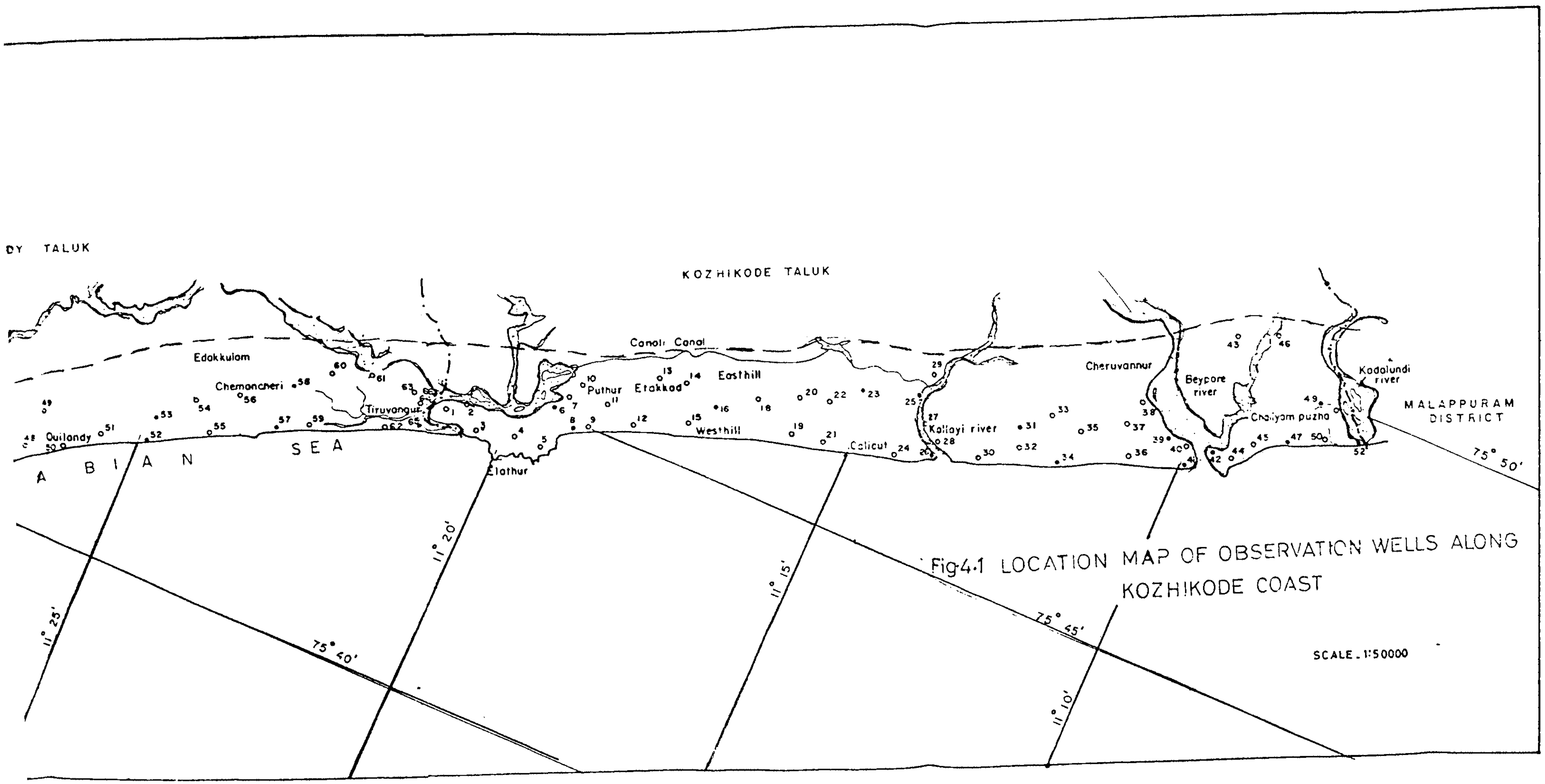


Fig.4.1 LOCATION MAP OF OBSERVATION WELLS ALONG KOZHIKODE COAST

the sea and various surface water bodies, accessibility of the areas, potential pollution sites, etc. are considered, while fixing the network of observation wells. The location of permanent observation wells are given in Appendix-1. Regular monitoring of water levels and water quality is, done in these wells. The monitoring has been done during April-May, July-August and December-January representing the pre-monsoon, monsoon and post-monsoon seasons respectively. The physical parameters of the wells and the depth -to- water level variations collected from the field are processed and used to bring out the hydrogeological characteristics of this coast.

4.2 Average Dimensions of Wells

Talukwise distribution of diameter and depth of the wells are given in table 4.1. The diameter of the dug wells vary from 0.70 to 3.50m and the depth varies from 1.25 to 6.00m. Small diameter of 0.70 to 0.80m are found in abundance in sandy formation. More than 1.00 m diameter wells are found distributed towards the coastal alluvium and laterite formations.

TABLE 4.1 : TALUKWISE DISTRIBUTION OF DIAMETER AND DEPTH OF OPEN WELLS IN COASTAL KOZHIKODE

(A) DIAMETER:

Taluk	Code	Maximum (m)	Minimum (m)	Range (m)	Mean (m)	Average Deviation (m)	Standard Deviation (m)
Vadakara	KB	3.08	0.85	2.20	1.85	0.35	0.48
Quilandy	KB	2.85	0.77	2.08	1.72	0.24	0.37
Kozhikode	KB	3.50	0.70	2.80	1.72	0.33	0.49

(B) DEPTH

Vadakara	KB	5.79	1.25	4.54	3.08	0.89	1.15
Quilandy	KQ	5.97	1.52	4.45	3.45	0.89	1.10
Kozhikode	KK	7.48	1.46	6.02	3.56	0.97	1.26

4.3 Classification of Wells

On the basis of the field data, the open wells along the Kozhikode coast can be classified in different ways:-

(A) According to depth of penetration they can be classified as

Classification	Depth Range (in m)
Shallow coastal well	0 to 3.00
Moderately deep coastal well	3.00 to 6.00
Deep coastal well	6.00 to 9.00
Very deep coastal well	> 9.00

(B) With cross sectional area as criteria they can be grouped as:

Classification	Range of Cross Sectional area in sq.m.
Small coastal well	0 to 6.00
Medium coastal well	6.00 to 12.00
Moderately large coastal well	12.00 to 18.00
Large coastal well	18.00 to 24.00
Very large coastal wells	> 24.00 m

(C) Based on the formation, they can be categorised as:

Classification	Description
Coastal wells	Open wells located along the coastal/coastal plains
Coastal alluvial wells	Open wells located between the coastal plain and coastal alluvial border.

Coastal alluvial-laterite wells	Wells lie between the coastal alluvial and the laterite formation.
Laterite wells	Located in the laterite formation.

4.4 Pattern of Ground Water Level Variations of the Coast

The important factors affecting the water level variations of the coastal zone are (a) elevation of an observation well (b) it's proximity to the surface water bodies and (c) nature of the geological formation of the water bearing stratum. Four years of groundwater level data monitored indicate that the coast can be grouped into 6 depth-to-water level zones such as <1m, 1-2m, 2-2.5m, 2.5-3m, 3-3.5m and >3.5m. Fig 4.2 shows the depth-to-water level variation along Kozhikode Coast.

Each of these depth-to-water level zones are described in the following subsections.

(i) Aliyur - Kottakkal coastal stretch

The depth-to-water levels along Aliyur - Kottakkal stretch varies from 0.15m to 3.35m (Appendix-2). The depth-to-water level varies between 0.15, near the shore and 3.35m at the other end of the coastal belt near the sand-laterite boundary (see Fig.

4.2) Average annual groundwater level fluctuation varies from 0.75 to 2.00m. Depending on the magnitude of groundwater table fluctuations, five zones can be identified along this coastal stretch and are shown in Fig.4.3.

(ii) Kottakkal - Kollam coastal stretch

Meladi - Payyoli area of the coastal stretch attains maximum width of 3.5 km and decreases gradually towards Kadalur. At Kadalur laterite hills are abutting to the sea and hard gneissic rocks are exposed in the west of Iringal hills. Depth to water levels are found deeper at Kadalur in well No.KQ 37 and also at well No.KQ 2 at Kottakkal near Iringal. Generally shallow water levels are noted along the coast. Average groundwater fluctuations vary from 0.75 to 2.00m (Appendix -3). Four Groundwater fluctuation zones have been identified in this coastal stretch and are shown in Fig.4.3

(iii) Kollam - Korapuzha coastal stretch

Average fluctuation varies from 0.75 to 2.00 m and shown in Fig 4.3 (also see Appendix-4). This also indicates that along coast, water levels of wells are found deeper towards Chemancherry in the laterite area.

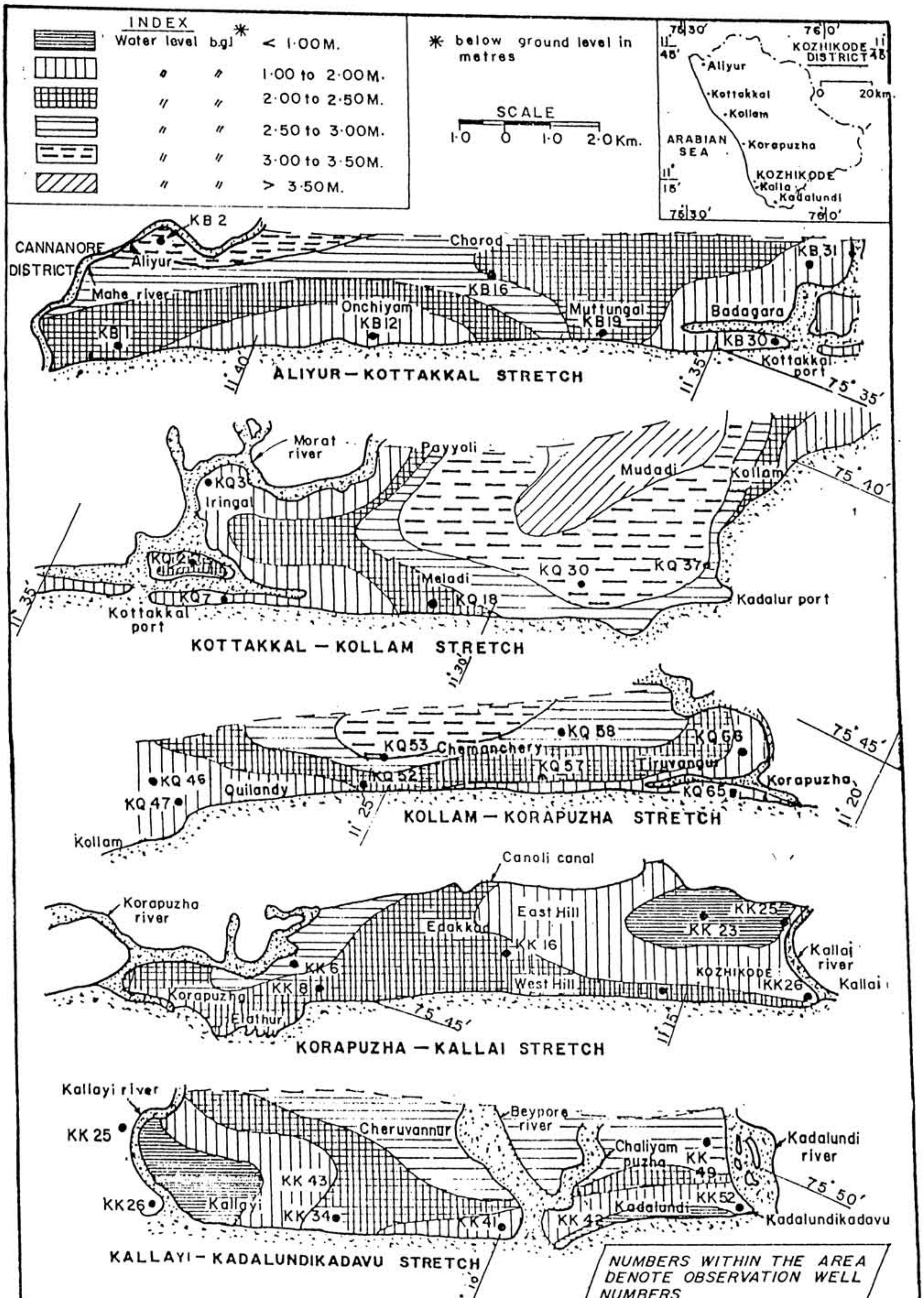


Fig. 4.2 DEPTH TO WATER LEVEL VARIATION ALONG KOZHIKODE COAST (Premonsoon 1982)

(iv) Korapuzha - Kallayi coastal stretch

Several patches of the land areas at east Kallayi, part of west Kallayi and KSRTC bus stand near Mavoor road junction are marshy during rainly season and water logging is common. These areas are covered by impervious clay. It is possible that the near - surface clay bed is separating the underlying sandy zone, giving rise to perched water table conditions. The depth-to-water level distribution of this stretch varies from 0.11 to 3.60m (Appendix-5). Three groundwater fluctuation zones are identified along this coastal stretch as shown in Fig.4.3. Average groundwater fluctuation varies between 0.75 to 1.50 m.

(v) Kallayi - Kadalundikadavu Stretch

The depth-to-water level along Kallayi - Kadalundikadavu stretch varies from 0.05 to 5.05m (Appendix-6). At Naduvattom, the wells located on the sand bar/high mounds of sand shows deeper levels (eg. well no. KK 39). In other parts of the coastal plain, shallow water levels are observed. Depending on the magnitude of fluctuation, 6 zones have been identified along this stretch as shown in Fig.4.3.

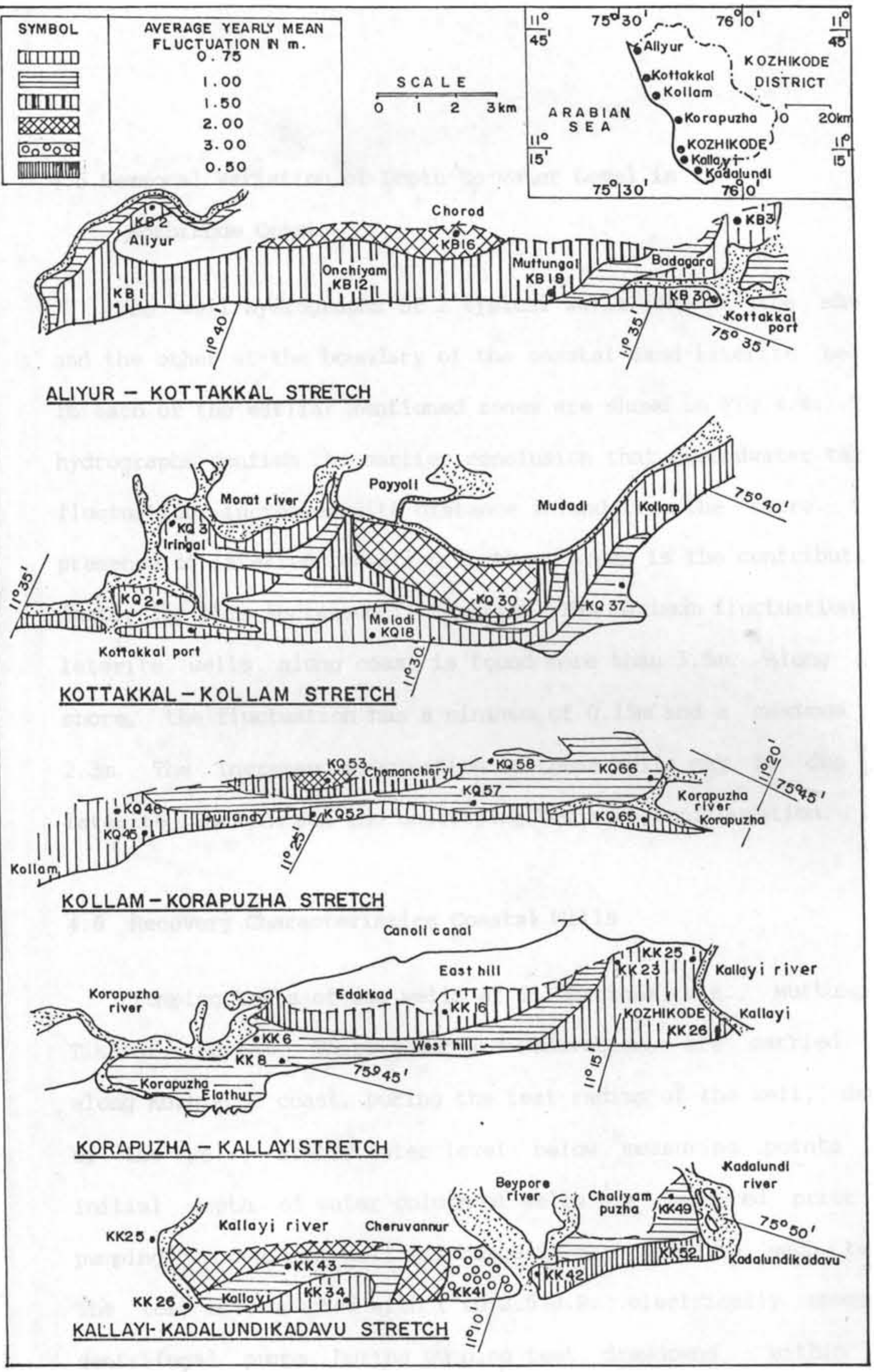


Fig. 4.3 GROUNDWATER FLUCTUATION IN VARIOUS STRETCHES OF KOZHIKODE COAST.

4.5 Seasonal Variation of Depth-to-water Level in Kozhikode Coast

The well hydrographs of 2 typical wells (one at the shore and the other at the boundary of the coastal sand-laterite belt) in each of the earliar mentioned zones are shown in Fig.4.4. The hydrographs confirm the earlier conclusion that groundwater table fluctuation increases with distance inland from the shore. The presence of laterite formation in these areas is the contributing factor for this increased fluctuation. The maximum fluctuation of laterite wells along coast is found more than 3.5m. Along the shore, the fluctuation has a minimum of 0.15m and a maximum of 2.3m. The increased fluctuation in these wells may be due to laterite landform and the underlying bed rock configuration.

4.6 Recovery Characteristics Coastal Wells

Pumping tests of dug wells of 5 locations, viz., Muttungal, Tikkodi, Kollam, Thiruvangur and Naduvattom, are carried out along Kozhikode coast. During the test radius of the well, depth of the well, static water level below measuring points and initial depth of water column of wells are measured prior to pumping. A constant well discharge is maintained in each test. The test is conducted with 1 to 2.5 H.P. electrically operated centrifugal pumps. During pumping test, drawdowns within the

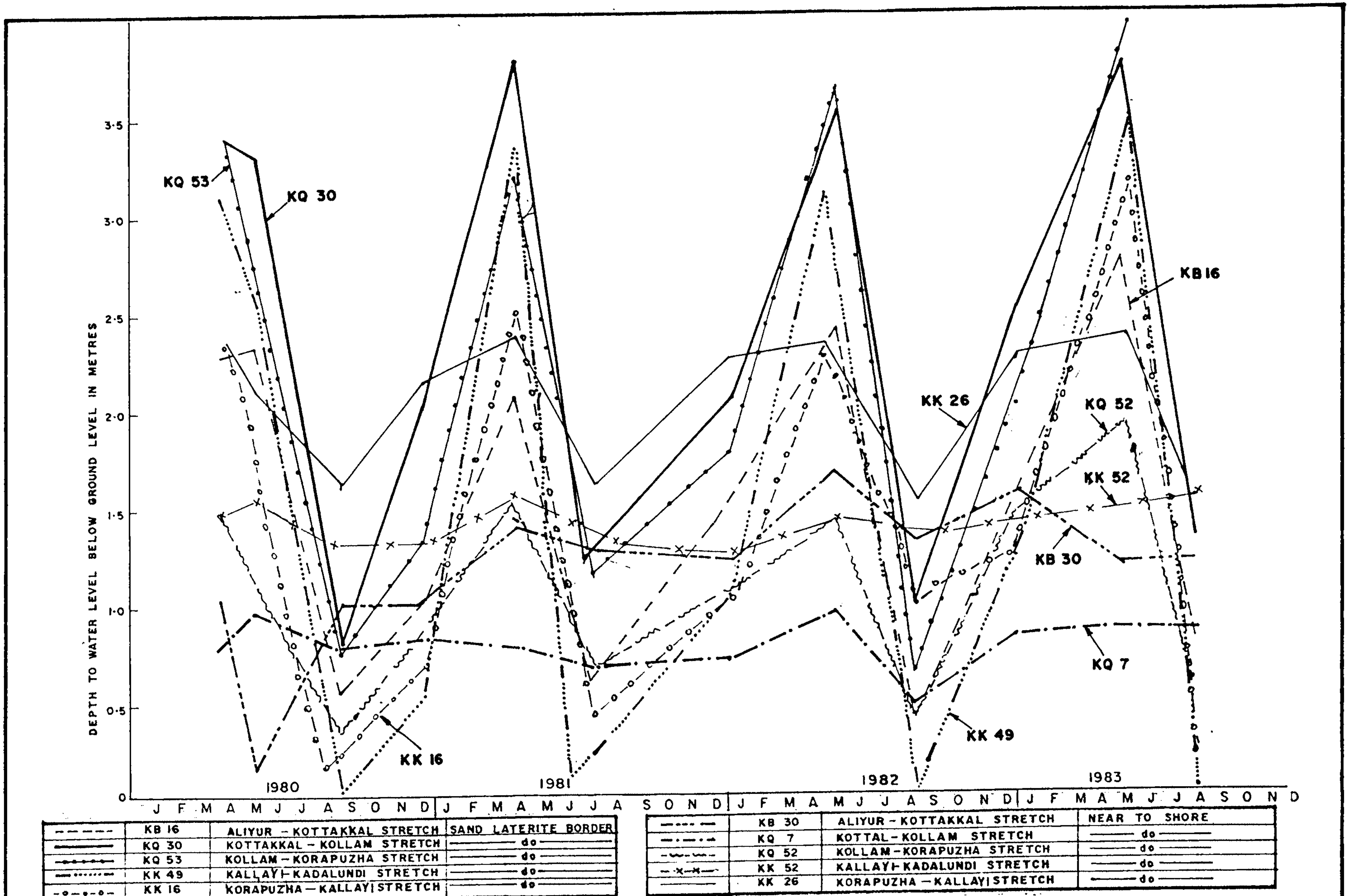


Fig. 4.4 WELL HYDROGRAPHS IN VARIOUS STRETCHES OF KOZHIKODE COAST

well during pumping phase are recorded in all well sites, since the pumping started. Once the pumping is stopped the wells are allowed to recover. During this recovery phase, data on the residual drawdown within the well diameter is recorded at discrete time intervals since recovery started. While selecting the duration of the tests, it is assumed that all the water that has been pumped is removed from the storage in the well itself and during the pumping period there has been very little contribution from the aquifer. Given the large diameter of the wells, the small column of the water available in the well, the short duration of pumping and the practical limitation of having very small discharge rate, such an assumption is fully justified. This being the case, a knowledge of specific capacity of the well is practically of no help in arriving at any conclusion on the discharge-drawdown relationship during pumping (Rajagopalan, etal., 1981; Rajagopalan, etal., 1983)

Only recovery data are used in the wells located in different geological formations for studying the rate of recouperation trends.

4.7 Pumping Tests and Results

The location of wells in which the pumping tests carried out are given below.

Location	Latitude	Longitude
Muttungal	N 11^{0} 38' 00"	E 75^{0} 34' 30"
Thikkodi	N 10^{0} 30' 00"	E 75^{0} 36' 00"
Kollam	N 11^{0} 25' 00"	E 75^{0} 39' 00"
Thiruvangur	N 11^{0} 23' 00"	E 75^{0} 44' 00"
Naduvattom	N 11^{0} 11' 00"	E 75^{0} 47' 00"

Table 4.2 presents the average depth of water column of open wells in different formation of the coast in different seasons. The results of the tests are presented in Table.4.3. Time-drawdown and residual drawdown vs time are given in Fig.4.5 and 4.6.

The Pumping test results indicate that the discharge of open wells tapping the sandy aquifer varies from 164 to 292 litres per minute (lpm). The wells tapping the sand - laterite border shows a low yield. The yield of the laterite well varies from 15 to 25 lpm. In coastal alluvial zone, the wells tapping the zone give

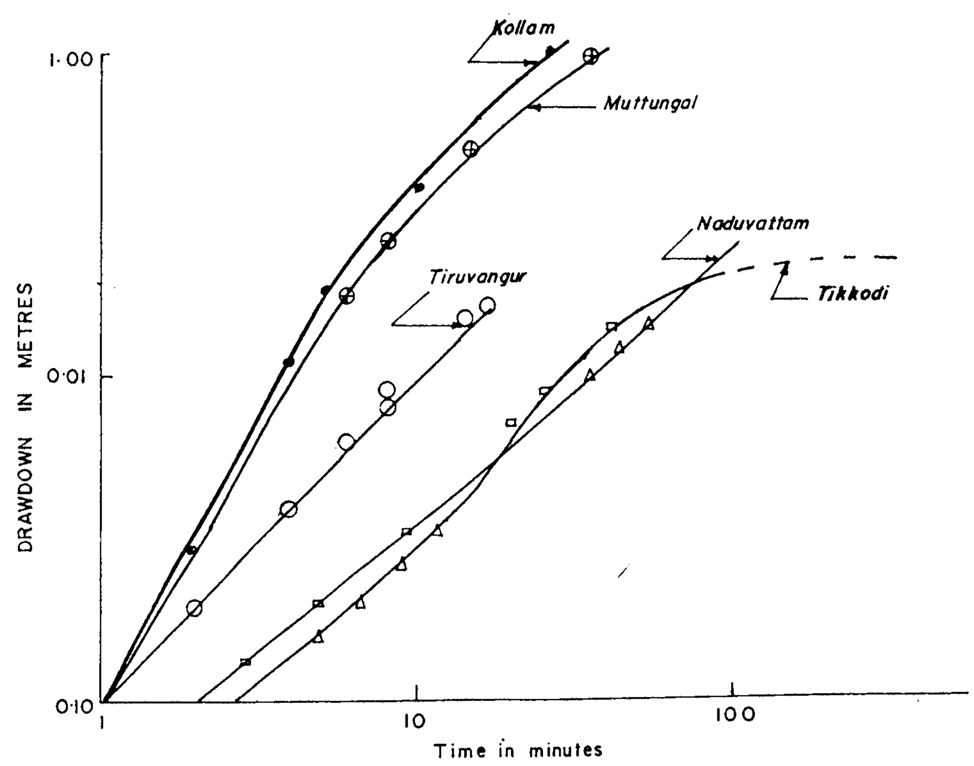


Fig. 4.5 TIME Vs DRAWDOWN PLOTS OF DUG WELLS ALONG KOZHIKODE COAST

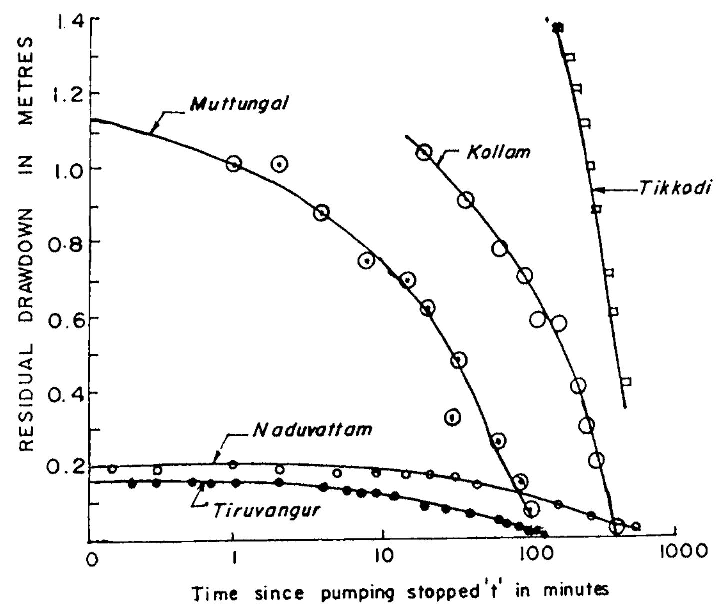


Fig. 4.6 RECOVERY PLOT OF DUG WELLS ALONG KOZHIKODE COAST

Table: 4.2 Average of (4 years 1980-83) depth of water columns and volume of water in open wells along the coast in different formations and in different seasons.

	Depth of water column in m					
Formation	Pre-monson in m	Volume in litres	Monsoon in m	Volume in litres	Post-monsoon in m	Volume in litres
(a) Coastal Sandy Zone	0.45	792	1.25	2207	0.65	1147
(b) Coastal alluvial Zone	0.65	1147	2.10	3709	1.15	2030
(c) Coastal alluvial laterite zone	0.75	1320	1.70	3091	1.05	2699
(d) Laterite Zone	1.00	1760	1.85	3267	1.65	2914

Table : 4.3 Recovery characteristics of open wells in the top unconfined coastal aquifer in Kozhikode

Sl. NO.	Location	Form ation (F)	Recoupe-ration rate of the well in lit-tes per minute (R)	Depth of water column in m (D)	S.W.L. in m b.g.l. (S.W.L)	Duration of pump-ing in minutes (D.P)	Radius of open wells in m (r)	Discharge of the wells dur-ing the test in litres per minute (Q)	Drawdown in the wells in m (S)
1.	Muttungal	C.A.	35.60	1.25	3.65	43	1.07	113	1.13
2.	Tiruvangur	C.L.	3.20	0.20	7.28	16	0.94	27	0.17
3.	Kollam	C.S.	17.95	1.47	5.00	26	1.53	292	1.03
4.	Thikkody	C.S.	20.00	2.65	5.12	102	1.25	164	2.17
5.	Naduvattom	C.L.	01.70	0.80	6.10	75	1.25	14	0.19

C.A. -- Coastal alluvial zone

C.L. -- Coastal sand laterite zone

C.S. -- Coastal sandy zone

b.g.l -- below ground level in metres

S.W.L -- Static Water level in metres

the discharge of 113 lpm and the rate of flow is found to be 15 lpm. In laterite wells, the rate of flow of aquifer varies from 1.7 to 3 lpm.

The wells tapping the coastal sandy zone and the coastal alluvial zones can be pumped safely twice in a day, because these wells take 2 to 7 hours to recoup fully before the next pumping. In the case of wells tapping the laterite formation the flow rates are found low as compared to other formation. Hence such wells can be pumped safely once in a day. These wells take one day for full recovery.

Based on the water column in the well, the quantity of water which can be pumped from the wells along the coast in different seasons is also examined. The depth of water column of wells in coastal sandy formation varies from, 0.45m to 1.00m for pre-monsoon season as we go from the shore to the laterite formation. Similarly the depth of water column of open wells shows an increase of 1.25m to 1.85m during monsoon. In post monsoon season the depth of water column increases towards inland with the shore recording 0.65m and the laterite lying in the sand-laterite boundary recording 1.85m. The volume of water which can be withdrawn from these wells (with 1.5m diameter) for different seasons are given in table 4.2.

4.8 Summary and Conclusions

Analysis of water level data indicate that 6 main groundwater fluctuation zones with mean annual fluctuction of 0.50, 0.75, 1.00, 1.50, 2.00 and 3.00 m. Nearer to the shore the groundwater table becomes shallowover. Depth-to-water level in the coast varies between 0.21 and 4.5m below ground level. Temporal Variations of depth to water level is minimum along the shore, whereas away from the shore, the temporal variations are appreciable.

The pump test results indicate that open wells tapping the aquifer varies from 14 lpm to 292 lpm. The wells tapping the laterite formation show low discharge. Wells tapping the coastal sandy alluvial formation can be pumped safely twice in a day. These wells take 2 to 7 hours to recoupe. But the wells tapping leterite formation take longer time for recovery. Laterites wells can be pumped once in a day.

CHAPTER 5

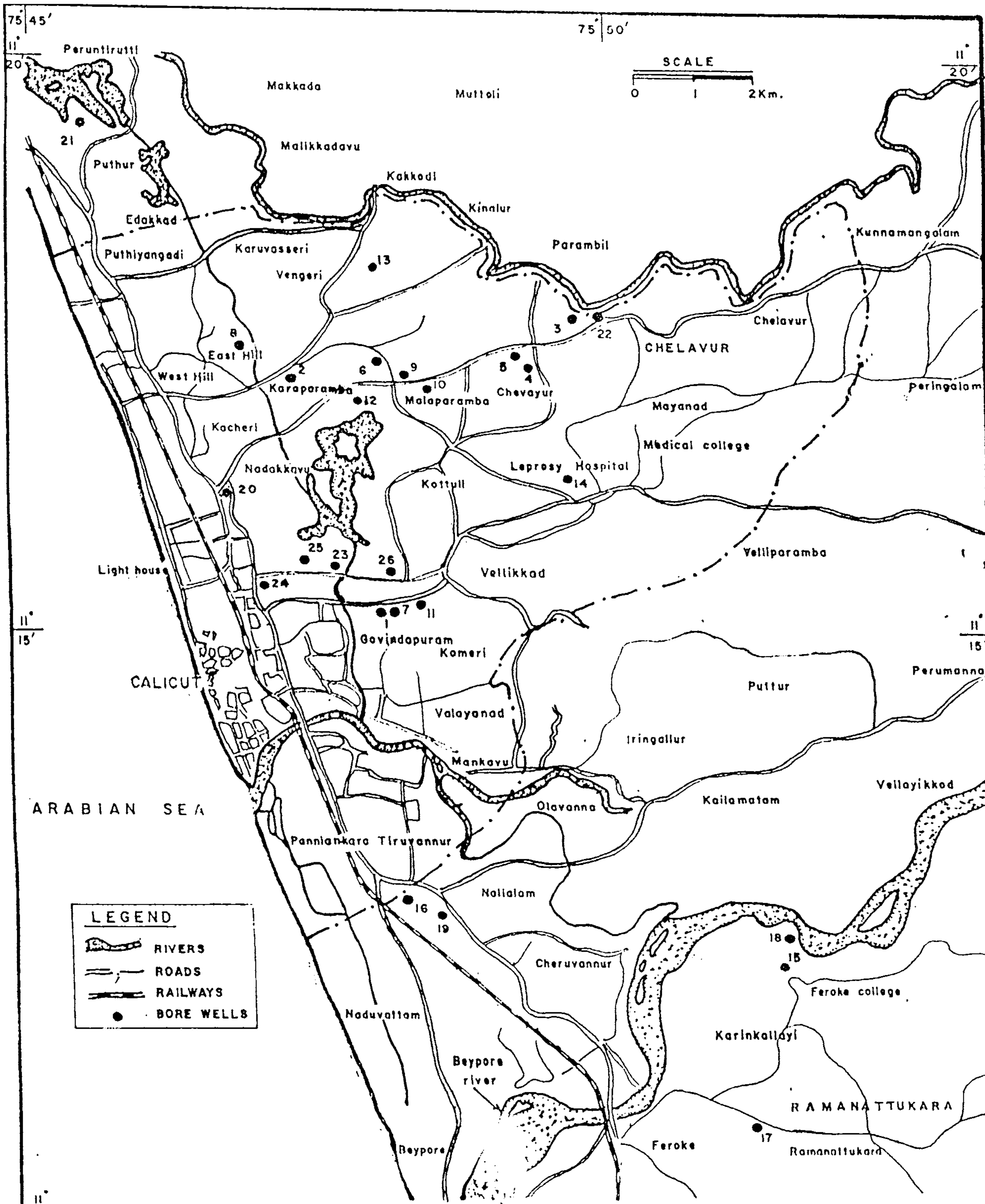
HYDROGEOLOGY OF COASTAL CRYSTALLINE AQUIFER

5.1 Introduction

Crystalline rock aquifers are the other alternate source of groundwater along the coast. Bore wells are the main groundwater extraction structures of this aquifer system. Crystalline rock aquifers are identified along the coast based on bore hole data. Twentysix boreholes are examined for the present study (Fig. 5.1). The bore wells are mostly of 152 mm in diameter. The depth of the bore well vary from 50m to more than 80m along the coast. The piezometric surface of the crystalline aquifer ranges from 2.67 m to 19.00m. The overburden thickness of these wells along coast is presented in Table 3.2 (Ref. Ch. 3). Maximum overburden thickness is found in the bore well at Marykunnu and minimum thickness rocorded at Elathur and Baby Hospital in Kozhikode city.

5.2 Types of Crystalline Rock Aquifers Along the Kozhikode Coast

Crystalline rock aquifers along the coast are classified based on the depth of fractures and the position of weathered



1. PARAYANCHERRY
2. Govt. HOMOEO COLLEGE
3. POOLAKADAVU CORPORATION TANK
4. LADIES HOSTAL, VELLIMADUKUNNU
5. Govt. SERVANT'S HOSTEL, VELLIMADUKUNNU
6. WOMEN'S POLYTECHNIC, MALAPARAMBA
7. KUTHIRAVATTAM
8. EAST HILL
9. A.D.M QUARTERS, MALAPARAMBA
10. HOUSING COLONY, MALAPARAMBA
11. PUTHIYARA WATER TANK
12. CIVIL STATION
13. VENGERI
14. LEPROSY HOSPITAL, CHEVAYUR
15. FEROKE COLLEGE
16. MEENCHANDA
17. FEROK CHUNGAM
18. RAMANATTUKARA
19. NALLALAM
20. NADAKKAVU
21. ELATHUR
22. MARIKUNNU
23. MANAPPAD HOSPITAL
24. HOTEL FOURA
25. BLUE DIAMOND THEATRE
26. ARAYADATH BRIDGE

Fig. 5.1 LOCATION MAP OF BORE WELLS IN KOZHIKODE COAST rock layer. Three types of crystalline rock aquifers can be identified along the coast:

(i) weathered rock aquifer above the crystalline rock;

(ii) a combination of weathered and fractured rock aquifer and

(iii) fractured crystalline aquifers at depth between 50 and 80m depth where the fractures are horizontal to sub-horizontal.

The depth horizon of fractures are shown in Table 3.2. (Ref. Ch. 3) Lateral and vertical variations of these fractured aquifers are also presented in the same section in Fig. 3.4, 3.5, 3.6, and 3.7 (Ref. Ch. 3). The yield rates of the weathered and fractured aquifers vary from 2500 to 31000 litres per hour and are shown in Table 5.1.

Table 5.1

Yield rates of weathered and fractured aquifers

Location	Water Level in meters B.M.P.	Discharge of Borewell in L.P.H.
Civil station	8.00	12000
Malaparamba	19.00	13600
Vellimadukunnu	15.33	5400
Marykunnu	11.48	2700
Feroke	12.50	5400
Nallalam	3.70	27270
Meenchantha	2.67	31765
Nadakkavu	Data not available	-
Blue diamond theatre	-	3000
Baby Hospital	-	3500
Kottuli	-	5000

5.3 Hydraulic Parameters of the Crystalline Rock Aquifers

Bore wells tapping the fractured aquifers below the bed rock along Kozhikode coast are a recent phenomena. The thickness of sediments or overburden over the bed rock is found to vary from 20 to 35 m depth below ground level. All the borewells tapping the coast are found below the bed rock. Long duration aquifer performance tests are done at five sites in Namenkulam, Parayanchery, Ferok, Vadakara and Puthiyappa. The aquifer tests are conducted at these sites using a 8.5 H.P. electrically operated submersible pump. In all the tests the wells are pumped at constant well discharge. Drawdown and residual drawdown data for all the wells are recorded and processed for both pumping and recovery periods. All the data are analysed by standard type-curve fitting methods of Boulton(1963) and Theis(1935). Theis(1935) recovery and Jacob(1940, 1944,1946) methods are the other methods used for computation of aquifer parameters such as permeability and transmissibility. Due to lack of piezometer in the site, the storage of the aquifer is not determined.

Theis type curve is drawn on logrithmic co-ordinate paper for the values of well functions W(u) versus 1/u. Values of drawdown measured in the well are plotted on logrithmic paper of the same scale as the type curve against the values of time after pumping started. This plot describes a time-drawdown field data curve which is superimposed on the type curve keeping W(u) axis parallel to drawdown axis and 1/u axis parallel to time axis. In the matched position a point at the intersection of the major axis of the type curve is selected and marked on the time drawdown field data curve. The co-ordinate of the match point W(u), 1/u, s and t are substituted in the following equations to obtain values of transmissibility and storativity (Fig. 5.2):

$$T = \frac{Q\,W(u)}{4 \times 3.14 \times s}$$

$$S = \frac{4Tu}{r^2}$$

where T - transmissibility, m^2/day

S - storativity

Q - discharge in m^3/day

t - time since pumping started in days

r - distance from the pumped well to piezometer/observation well.

Solution is found by using Jacob's modified formula by plotting the drawdown versus time on semilogarithmic paper. Here the drawdown is plotted on the linear scale and time since

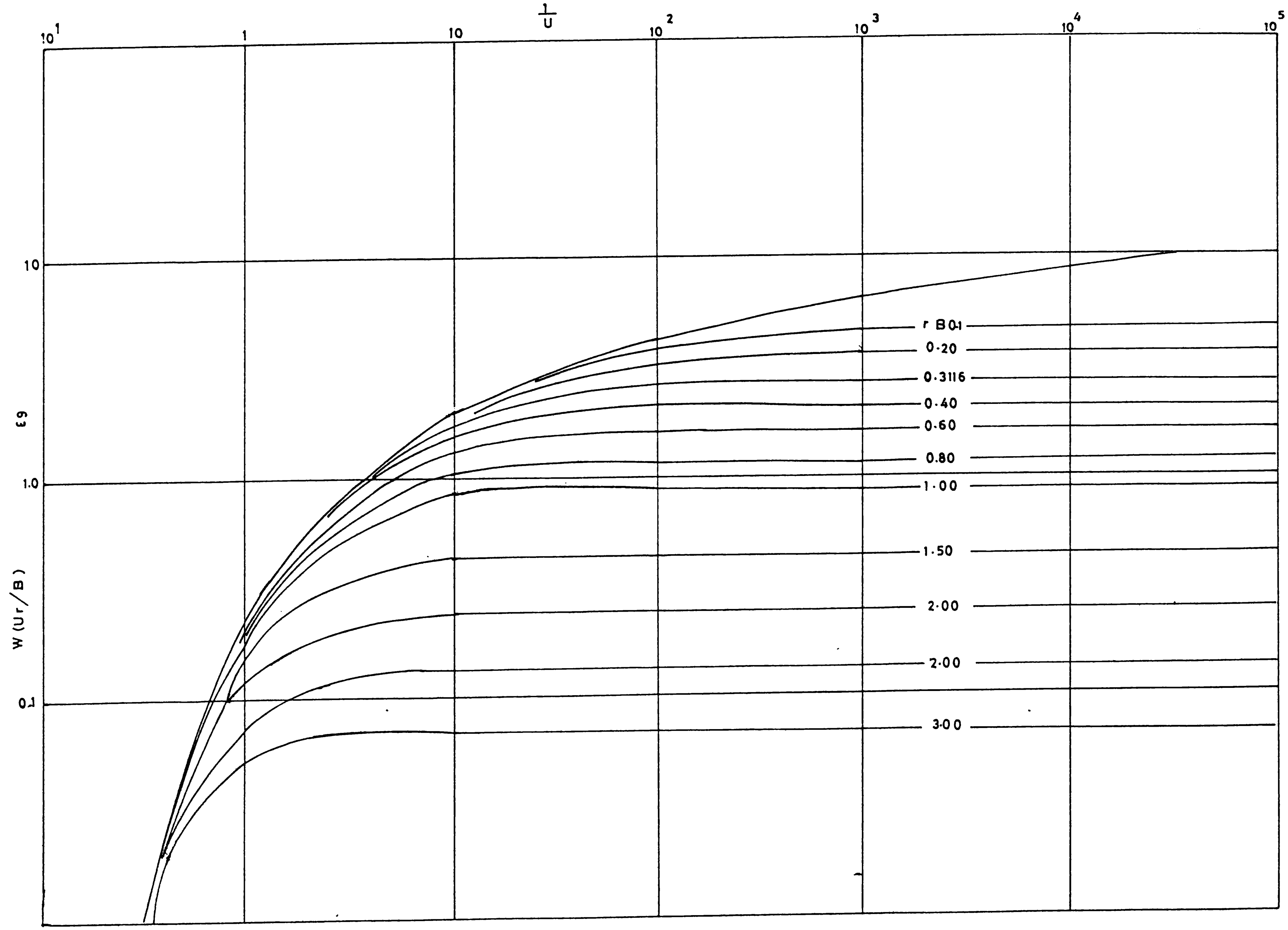


FIG.5.2 LEAKY ARTESTAIN, TIME-DRAWDOWN TYPE CURVES (AFTER WALTON 1962)

pumping started on the logarithmic scale. The field data points should describe a straight line and if not this method cannot be applied. For a log cycle of time $\log(t_2/t_1)$ the equation is

$$T = \frac{2.30\,Q}{4\pi\Delta s}$$

Where Δs is the difference in drawdown per log cycle of time.

The residual drawdown at various time intervals after the pumping stopped can also be analysed in a similar way. Here the residual drawdown is plotted on the linear scale against the ratio between the time since pumping started and time since pumping stopped on the logarithmic scale. This method is known as `Theis recovery method' and can be used to analyse the recovery data obtained from the observation well as well as from the pumped well. However solution for storativity cannot be obtained by this method.

In Kozhikode coast most of the borewells tapping the weathered coastal aquifer are hydraulically connected to the deep fractured rock aquifer and hence the latter one also shows unconfined or phreatic conditions. During pumping, water is released from the storage in the aquifer by gravity drainage due to compaction of the aquifer and expansion of water. Release of water by gravity drainage is not instantaneous but starts only after a short period of pumping. When the water released from storage by gravity drainage reaches the cone of depression, the rate of expansion of the curve tends to slow down for some time till all the water within that portion of the aquifer gets drained by gravity drainage. Finally the rate of expansion of the cone of depression increases and the cone continues to expand as gravity drainage keeps pace with declining water levels.

The transmissiblity and specific yield of such watertable aquifer is determined by using type curve graphical method devised by Boulton (1963). Values of W(Uay,r/Dt) are plotted against values of l/Ua and l/Uy on logarithmic paper and two families of type curves are constructed. The left hand part of the type curves are called type A curves and the right hand side are called Y curves. Type A curves are used for early drawdown data and type Y curves for late drawdown data (Fig. 5.3).

Observed values of drawdown from the pumped well is plotted against values of time t on logarithmic paper of the same scale as the type curves. The plotted values describe a time-drawdown field data curve analogous to one of the family type of curve partly in type A Curves and partly in type Y curves (Fig.5.3).

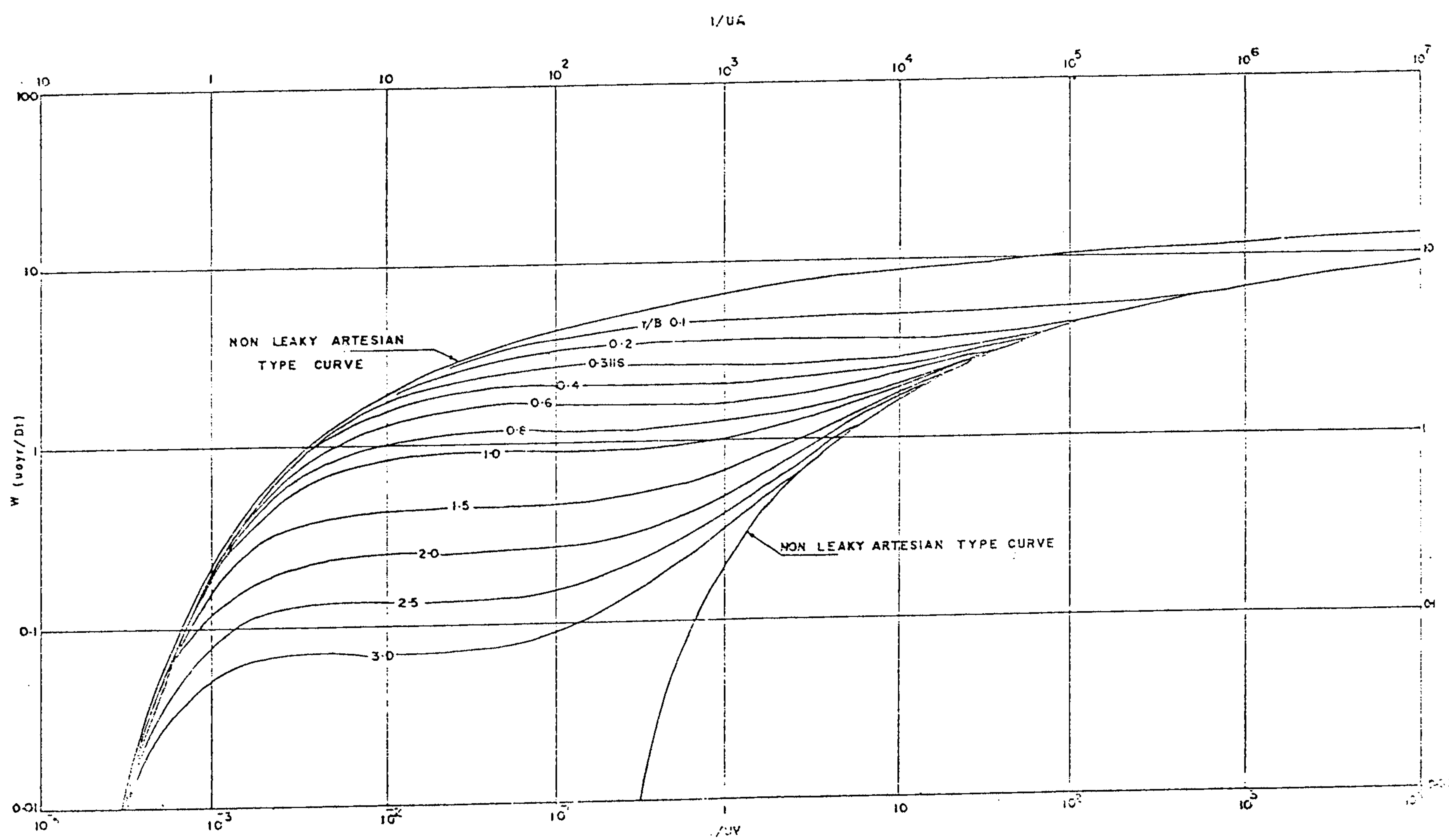


FIG. 5.3 WATER TABLE, FULLY PENETRATING DRAWDOWN TYPECURVES (FROM PRICKETT, 1965)

The field data curve is first superimposed on the type A curves, Keeping the W(Uy, r/Dt) axis parellel to the drawdown axis and 1/Ua axis parallel to the time axis. As far as possible the early time-drawdown field data curve is matched to any one of the type A curves. The r/Dt value of the type curve which is matched is noted. In the matched position a point at the intersection of the major axis of the type A curve is selected and marked on the time drawdown fielf data curve. The co-ordinates of the match point s 1/Ua, W(Uay, r/Dt) and t are substituted in the following equations:

$$T = \frac{Q}{4 \times 3.14 \times s} W(Uay, r/Dt)$$

$$S = \frac{4\ T\ t\ Ua}{r^2}$$

The time drawdown field data curve is moved horizontally and is superposed as type `Y' curve. The selected type Y curve, should have the same value of r/Dt as that used in matching the early time drawdown data. In the second match position a point is selected as done earlier and the co-ordinates s, 1/Uy, W(Uay r/Dt) and t are substituted in the following equations:

$$T = \frac{Q}{4 \times 3.14 \times s} W(U_{ay}, r/D_t)$$

$$S_y = \frac{T t \, U_y}{r^2}$$

where Sy is the specific yield and other notations are as described earlier.

Transmissibility calculated by second match (late match) should have approximately the same value as the one obtained from early drawdown data. If the difference is very high it indicates either dewatering of the aquifer or boundary conditions.

5.3.1. Performance tests of crystalline aquifer

For evaluating aquifer parameters along coastal borewells, five aquifer performance tests are carried out. A 5 HP diesel driven submersible pump is used for the pumping test. The duration of each test of borewell is 1000 minutes. All the test data both in the pumping and recovery phases are recorded during the test.

The data obtained from the tests are analysed by using standard methods based on the non-equilibrium formula derived by Theis (1935), Jacob (1946) and Boulton (1963) depending upon the hydraulic condition of the aquifer. Eventhough the fractured rock aquifer do not satisfy all requirements for the application of various formulae derived for the granular and unconsolidated aquifer, the test results and plots seem to fit into the type curves derived by various workers. The solution derived for granular aquifers can be applied also to calculate the aquifer parameters of fractured rock aquifers on the basis of "continuum approach" (Braester, 1981). The impervious blocks of the hard rock and the fractures play the role of solid grains in a granular aquifer. The fractures also play the role of inter granular voids or pores.

The results of the aquifer performance test of the borewells of Kozhikode coast are given in table 5.2. Aquifer parameters computed by various methods are compiled in table 5.3.

Table 5.2 Results of aquifer performance tests of borewells along Kozhikode coast

Sl. No.	Location	Static water level in m b.m.p.*	Measuring point(MP) in m	Date of test	Discharge (Q) in m^3/day	Duration of pumping in minutes	Maximum drawdown in m	Specific capacity in m/day
1.	Namenkulam	17.4	0.40	18-03-83	181.03	1000	18.51	09.78
2.	Parayan-chery	10.52	0.40	27-03-83	273.60	1000	23.88	11.45
3.	Govt. Hospital Vadakara	17.15	0.15	15-03-83	731.07	1000	19.15	38.17
4.	Feroke Coollege	12.59	0.15	15-05-83	129.30	1000	25.35	05.10
5.	Puthiyappa	19.12	0.15	22-01-83	432.00	1000	25.44	16.98

Table - 5.3 Computed Aquifer Parameters of borewells from test data along Kozhikode coast

Sl. No.	Location	Discharge in m^3/day	Methods used for Computation		Transmissibility in m^2/day	Average T in m^2/day	Remarks
1	Puthiyappa Borewell	432	Boulton's type curve method		13.75	9.23	unconfined condition
			Jacob's method		5.93		
			Theis Recovery		8.33		
2	Vadakara Govt. Hospital	731.02	Jacob's method		16.70		
			Theis recovery		26.70		
			Boulton's method	early match	23.26	19.69	unconfined condition
				late match	12.12		
3	Mamenkulam	181.03	Theis type curve method		6.32		
			Theis recovery		6.14	6.77	confined condition
			Jacob's method		7.85		
4	Parayanchery	273.6	Jacob's method		12.52		
			Theis recovery		9.54		
			Boulton's method	early match	4.36	7.71	unconfined condfined
				late match	4.44		
5	Farok College	129.30	Theis recovery		2.23		
			Jacob's method		2.75		
			Boulton's method	early match	0.82	1.63	unconfined
				late match	0.71		
6	Average thickness of fractures = 10 m						
7	Average Transmissibility = 9m^2/day						
8	Average permeability = 1.10m/day						

5.4 Discussion

From the test data, plots of time versus drawdown and recovery plots of borewells are drawn. Fig. 5.4 shows the time vs drawdown plot of various borewells along the coast. Fig. 5.5 shows recovery plots of borewells. Among the test results, except at Namenkulam, all the sites of bore wells tapping the fractured aquifers occur under phreatic conditions. The field data plotted are matching with Boulton type curve and hence confirms the unconfined conditions of the aquifer. The transmissivity of these aquifers vary from 1.60 to 19.69m^2/day. The permeability of the aquifer range from 0.18m/day to more than a 1.00m/day. The fractured zones tapping the borewell at Namenkulam is of confined nature, because the field data is fully fitting with Theis type curve. The transmissivity computed from the well is 6.70m^2/day.

Pumping test results of borewells indicate that there are two types of hydraulic conditions. They are unconfined and confined fractured aquifers. The fractured zones tapped from the borewells at Puthiyappa, Parayenchery, Vadakara and Feroke college occur under unconfined condition. Typical Boulton type curve obtained from the test data of various borewells are shown in Fig. 5.4 b,c,d and e.

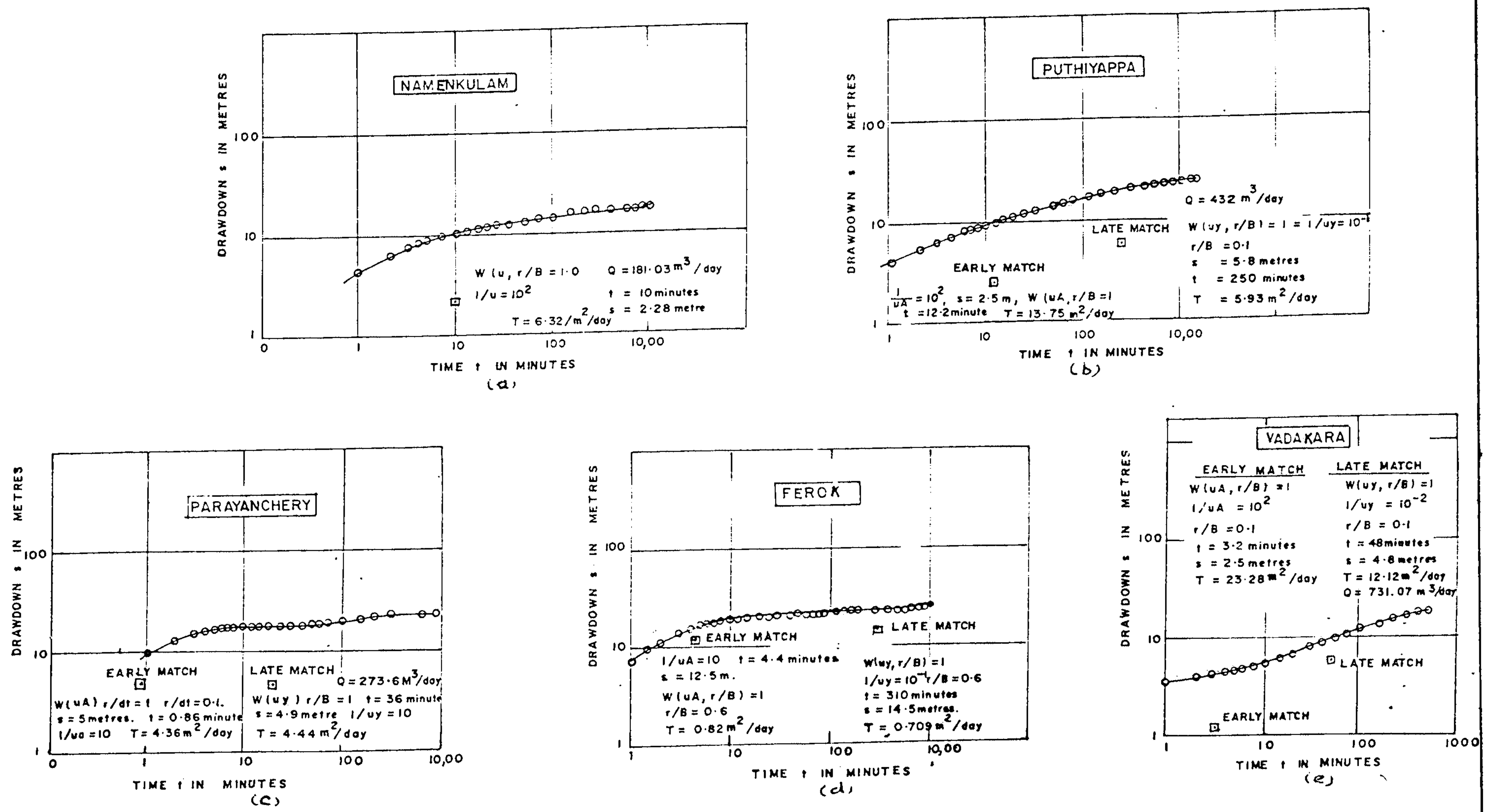


FIG 5.4 TIME Vs DRAWDOWN PLOTS OF BOREWELLS ALONG KOZHIKODE COAST

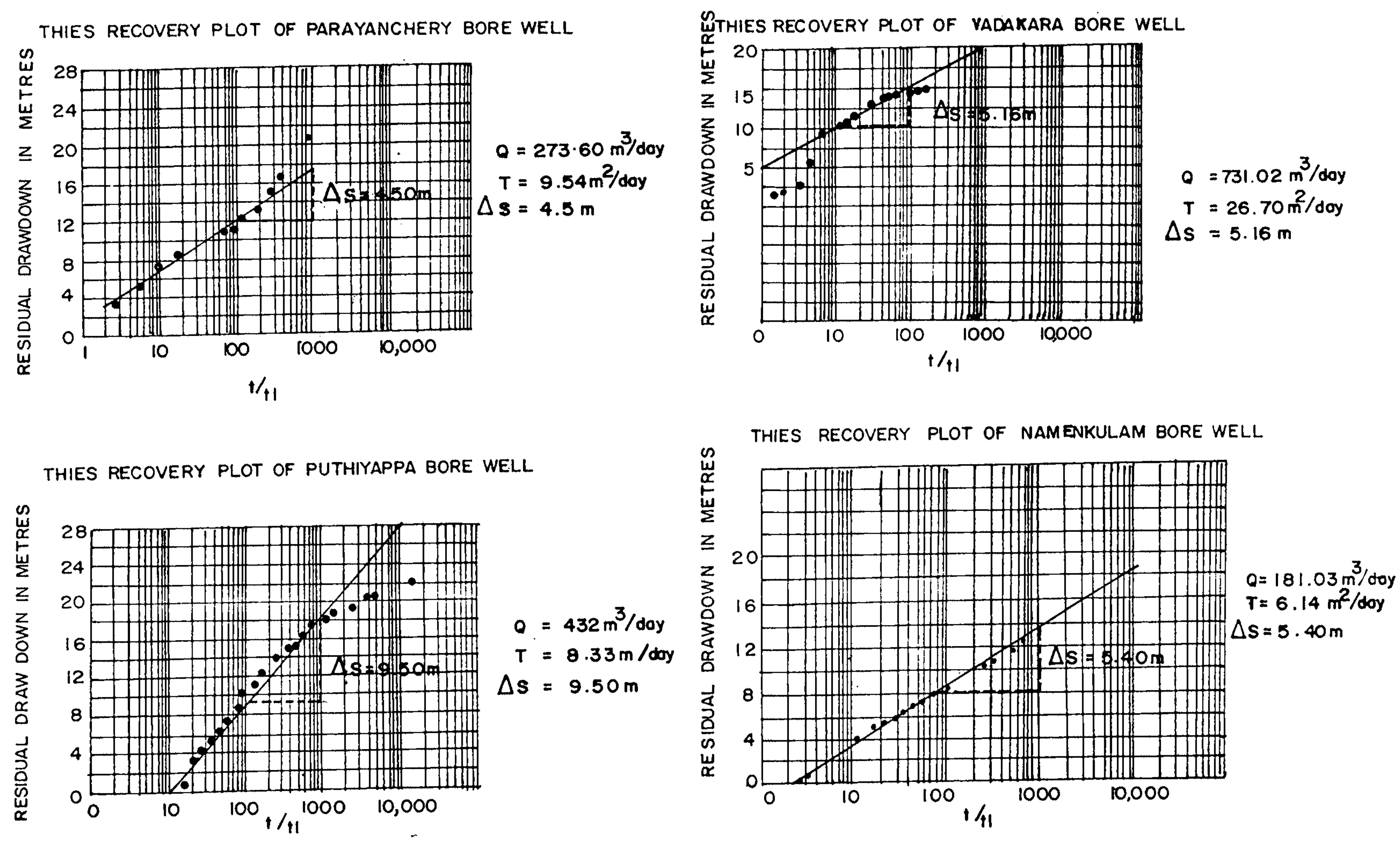


Fig. 5.5 THIES RECOVERY PLOTS OF BORE WELLS ALONG KOZHIKODE COAST

The pumping test analysed at Namenkulam shows that aquifer tapped in the borewell is of confined nature. The horizontal and subhorizontal fracture zones which are often separated from one another as well as from the top shallow aquifer by thick layers of massive rocks often form confined aquifer (Fig. 5.4a).

Pump test data indicate that the borewells tapped from these fractured and weathered aquifer can supply large quantities of water. The discharge rate of borewells range from 126.30 to 731.07m^3/day. Most of the borewells tapped from these aquifers occur under unconfined condition. Hence heavy pumping from such borewells may cause decline of water level from the dug wells in the top layer along the coast.

Borewells drilled at Baby Hospital, Arayadathu bridge, Kottuli, Pachakilpalam and Elathur indicate that the fractured aquifer encountered in such boreholes are saline and hence abandoned.

5.5 Summary and Conclusions

Tests conducted on the bore wells along Kozhikode indicate that there are two types of conditions viz. unconfined and confined. Most of the bore wells developed at Puthiyappa, Vadakara, Parayanchery, and Ferok College are found to be unconfined. The transmissibility of these aquifers vary from 1.63 to $9m^2$/day and the permeability is 1.10m/day. The specific capacity of these bore wells vary from 5.10m/day to 17m/day. Hence heavy pumping from such bore wells may cause decline of water levels in the top layer. The hard rock at aquifers tested at Namenkulam reveal that they are under confined conditions.

CHAPTER 6

GROUNDWATER ESTIMATION

6.1 Introduction

Major recharge to the groundwater in the area occurs as vertical leakage of water from precipitation through soil weathered-surface mantle or open fractures in the outcrop areas. The recharge in the area is during south west monsoon which occurs durig June to September. However, some recharge also takes place during north east monsoon (October - November) as well.

The recharge to coastal groundwater is evaluated in the present study by two independent methods: (a) analysis of water level fluctuation in key observation wells and (b) rainfall recharge method.

6.2 Groundwater zones along the coast

The groundwater availability along the coastal belt of Kozhikode can be estimated from the rocorded water level fluctuation data obtained from the observation well network spread all along the coast.

Analysis of water level data from the key wells set up along the coastal zone indicate that these coastal stretches can be subdivided into 6 distinct groundwater level fluctuation zones with average yearly mean fluctuation of 0.50, 0.75, 1.00, 1.50, 2.00 and 3.00 as shown in Fig. 6.1 to 6.5

Estimation of groundwater availability in the above zones can be made by multiplying the mean groundwater level fluctuation within the area over which these mean fluctuations occur and the assumed specific yield of 0.20 (Basak and Nazimuddin, 1983). The utilisation of groundwater in the mentioned 6 zones are found out by multiplying well density of 258 wells/km (more details are given in Ch.7) with an average draft of 800 l/day/well and the corresponding area of the zone calculated from the figures 6.1 to 6.5 by leaf area meter. A model calculation for the estimation of potential and utilisation is given below.

6.3 Estimation for Groundwater Potential in a Typical Zone

From the recorded groundwater table fluctuation data over the four years (1980-83) the Kottakkal - Kollam stretch can be divided into 4 fluctuation zones with average fluctuations of 0.75, 1.0, 1.5 and 2.0 m and is accordingly shown in Fig. 6.2. Take a typical zone with 2.0 m fluctuation in the stretch.

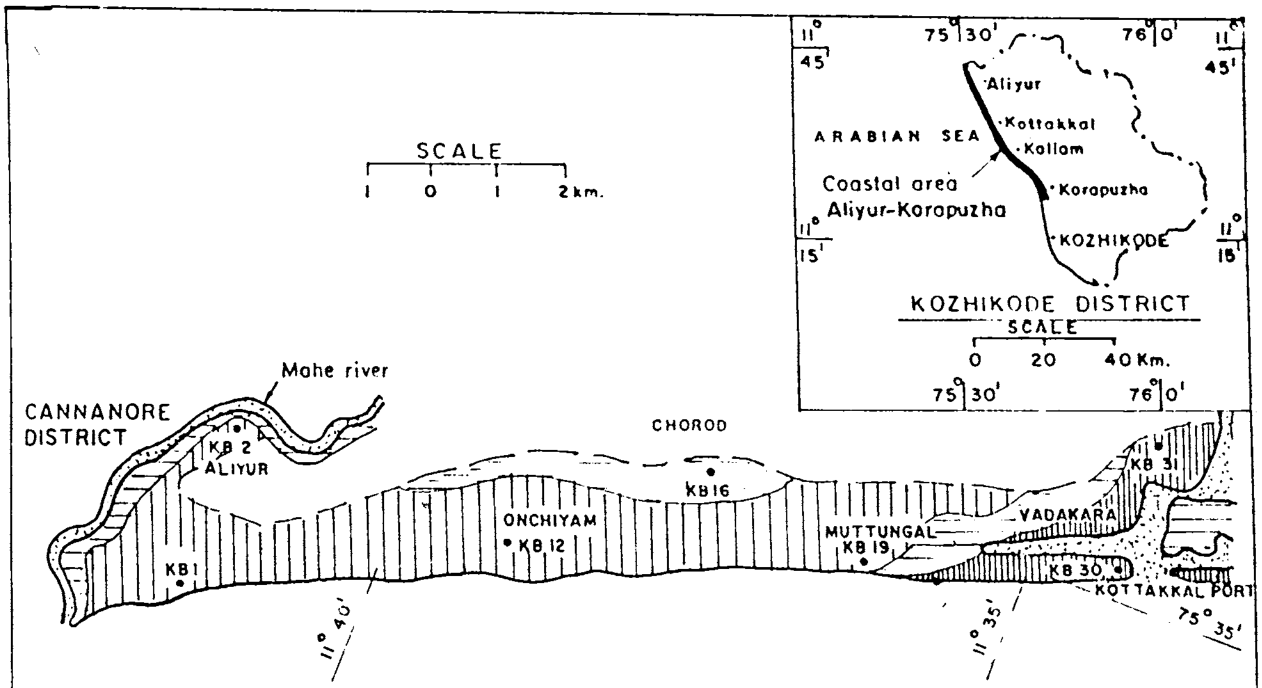


Fig. 6.1 GROUNDWATER AVAILABILITY AND UTILISATION ALONG ALIYUR–KOTTAKKAL STRETCH OF KOZHIKODE COAST

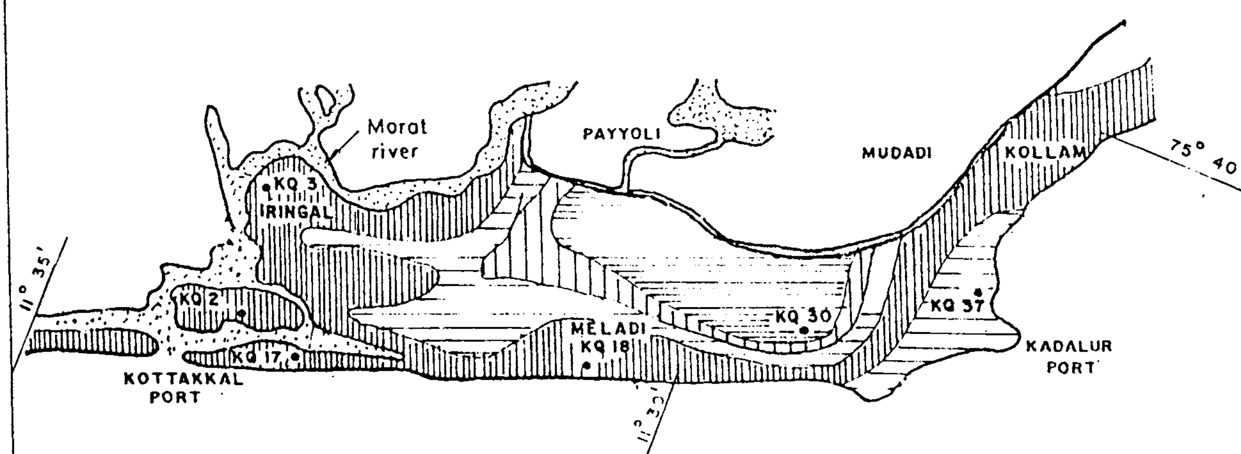


Fig. 6.2 GROUNDWATER AVAILABILITY AND UTILISATION ALONG KOTTAKKAL–KOLLAM STRETCH OF KOZHIKODE COAST

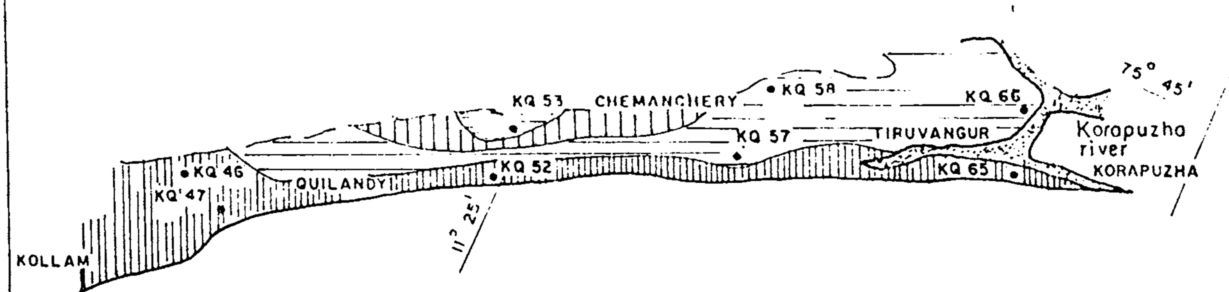


Fig. 6-3 GROUNDWATER AVAILABILITY AND UTILISATION ALONG KOLLAM–KORAPUZHA STRETCH OF KOZHIKODE COAST

SYMBOL	AVERAGE YEARLY MEAN FLUCTUATIONS IN M.	GROUNDWATER AVAILABILITY IN M.C.M			AREA IN Sq.km.			PERCENTAGE OF UTILISATION
		Fig.6.1	Fig 6.2	Fig 6.3	Fig.6.1	Fig 6.2	Fig 6.3	
	0·75	0·385	2·304	0·925	2·57	15·36	6·17	50 %
	1·00	0·518	1·954	1·694	2·59	9·77	8·47	37 %
	1·50	4·480	0·759	0·516	14·96	2·53	1·72	25 %
	2·00	0·752	2·204	0·192	1·88	5·51	0·46	19 %

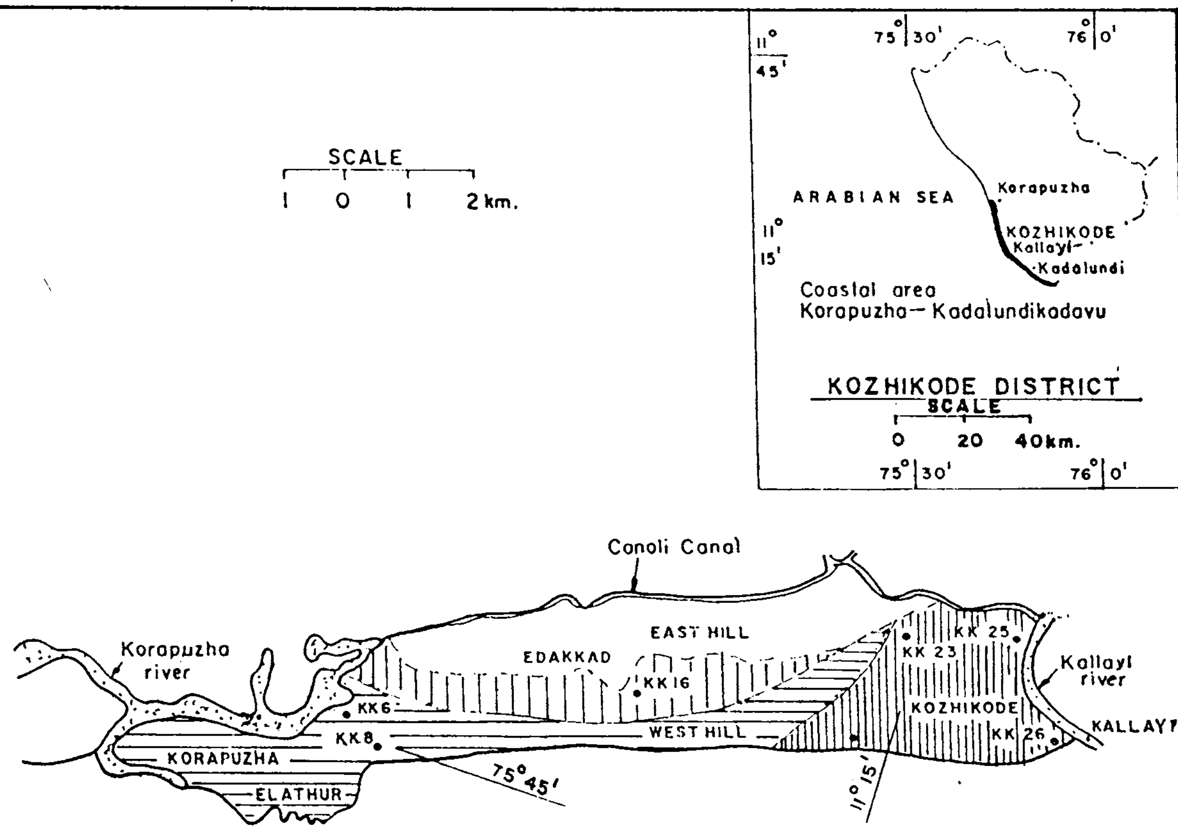


Fig. 6.4 GROUNDWATER AVAILABILITY AND UTILISATION ALONG KORAPUZHA – KALLAYI STRETCH OF KOZHIKODE COAST.

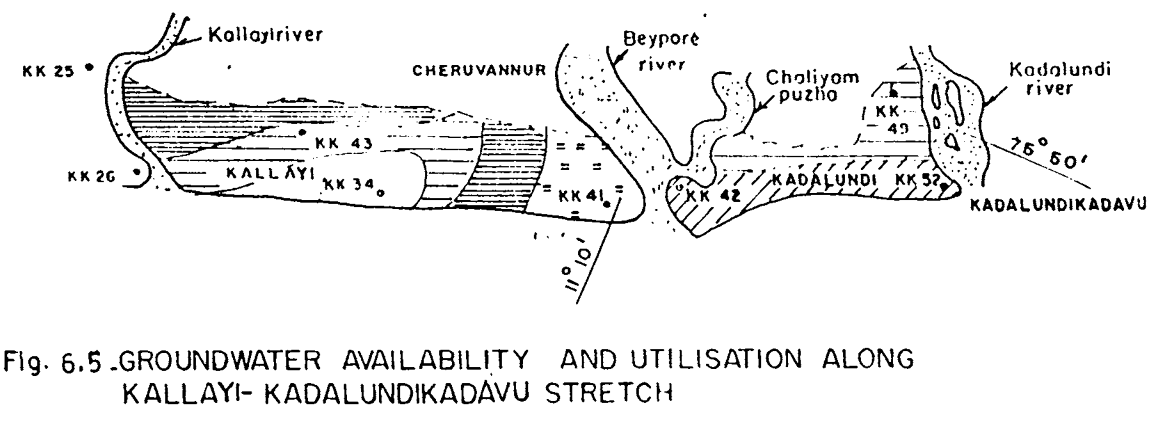


Fig. 6.5 GROUNDWATER AVAILABILITY AND UTILISATION ALONG KALLAYI- KADALUNDIKADAVU STRETCH

SYMBOL	AVERAGE YEARLY MEAN FLUCTUATIONS IN M.	GROUNDWATER AVAILABILITY IN M.C.M		AREA IN Sq.Km.		PERCENTAGE OF UTILISATION
		Fig. 6.4	Fig. 6.5	Fig. 6.4	Fig. 6.5	
(vertical lines)	0·75	0·994	0·268	6·63	1·79	60 %
(horizontal lines with dashes)	1·00	1·808	1·070	9·04	5·35	37 %
(widely spaced vertical lines)	1·50	3·525	N.A	11·75	N.A	25 %
(horizontal lines)	2·00	N.A	1·532	N.A	3·83	19 %
(dashes and dots)	3·00	N.A	0·990	N.A	1·65	12 %
(oblique lines)	0·50	N.A	0·206	N.A	2·06	75 %

N.A = NOT APPLICABLE

Area of the above zone (as found by leaf area meter)	=	$5.51 \times 10^6\ m^2$
Average yearly mean fluctuation in the zone	=	2.00 m
Assumed specific yield	=	0.20
Hence, estimated groundwater potential in the same zone	=	$(5.51 \times 10^6) \times 2.0 \times 0.20$
	=	$2204000\ m^3$
	=	2.204 MCM

6.4 Estimation of Groundwater Utilisation in a Typical Zone

For the Kottakkal - Kollam stretch (Fig. 6.2) used for availability estimation, the utization may be computed as follows:

Area of the zone	=	$5.51 \times 10^6\ m^2$
Assumed well density (Ref.Ch.7)	=	258 wells/sq.km
Assumed draft	=	800 l/day/well
Therefore, estimated annual draft	=	5.51 x 258 x 0.8 x 365
	=	$415101.36\ m^3$
	=	0.4151 MCM
Estimated availability (as found earlier)	=	2.204 MCM
Hence percentage utilisation	=	$\frac{0.4151}{2.204} \times 100$
	=	18.83 (say 19%)

6.5 Estimation of Groundwater Availability and Utilisation for Kozhikode Coast

As mentioned in the previous section the groundwater availability and the utilisation of the zones are estimated for the entire coast (Table 6.1)

Table 6.1 Distribution of Groundwater Availability and Utilisation

Name	Average annual fluctua ation in m	Ground water availa bility in MCM	Ground water withdrawal in MCM*	Percentage utilization
Aliyur	0.75	0.385	0.193	50%
Kottakkal	1.00	0.518	0.195	37%
Coastal	1.50	4.480	1.127	25%
Stretch	2.00	0.752	0.141	19%
Kottakkal	0.75	2.304	1.157	50%
Kollam	1.00	1.954	0.736	37%
Coastal	1.50	0.759	0.190	25%
Stretch	2.00	2.204	0.415	19%
Kollam	0.75	0.925	0.464	50%
Korapuzha	1.00	1.694	0.638	37%
Coastal	1.50	0.516	0.129	25%
Stretch	2.00	0.192	0.036	19%
Korapuzha	0.75	0.994	0.499	50%
Kallayi	1.00	1.808	0.681	37%
Coastal	1.50	3.525	0.885	25%
Stretch				
Kallayi	0.75	0.268	0.134	50%
Kadalundi	1.00	1.070	0.403	37%
Kadavu	1.50	Absent in the stretch		
Coastal	2.00	1.532	0.288	19%
Stretch	3.00	0.990	0.124	12%
	0.50	0.206	0.155	75%
Total		27.076	8.590	31%

Thus total groundwater availability in the top unconfined aquifer along the entire Kozhikode coast comes out to be 27 MCM and average utilisation is of the order of 31 per cent through an estimated twenty three thousand (23,478) open dug wells scattered all along the coastal stretch of the district.

6.6 Summary and Conclusions

Depending on the entire depth to water level variations the entire coast can be divided into 6 distinct groundwater level fluctuation zones with an average yearly mean fluctuation of 0.50, 0.75, 1.00, 1.50, 2.00 and 3.00m. The trend of groundwater utlization of the coast varies from 12 to 75 percent. The utlisation is found 50% towards the coast and showing a decrease in trend towards inland. Study also reveals that the average utilization of the groundwater is of the order of 31% through an estimated 23,478 wells scattered along the coastal stretch. The total groundwater availability in the top unconfined aquifer along the entire coastal belt of Kozhikode comes out to be 27 MCM.

CHAPTER 7

GROUNDWATER UTILISATION

7.1 Introduction

Vadakara, Quilandy and Kozhikode townships have protected drinking water supply facilities. There are rural water supply schemes along this coast at Naduvattom, Vengalam, Kollam, Quilandy and Thikkody, which satisfy only a small percentage of the water requirement of the coastal zone. The rest of the coastal zone depends entirely on the existing large number of family based dug wells.

The groundwater utilization for the Kozhikode coast has been estimated at 8.59 MCM in the earlier chapter (Ch. 6) using the `groundwater fluctuation method'. Another method normally used for this purpose is the `rainfall recharge method'. This chapter attempts to examine the groundwater utilization of this coast using the latter method.

7.2 Methodology

To find out the extent and pattern of groundwater use in the coastal zone using this method, two representative areas, ie Tiruvangur-Pookad and Meladi Payyoli are chosen and a cent-percent well inventory is made. These areas are representative as they are solely dependent on family based dug wells. The first sample area is 1.20 sq.km and the second is 1.40 sq.km.

Field survey's are conducted (format shown in Appendix-7) in these sample areas (Fig. 7.1) and the following parametres are estimated: the existing well distribution, well density, diameter, depth, age, number of pumps employed, average draft, use pattern and growth pattern.

7.3 Characteristics of Wells

The number of wells per sq.km is 285 in Tiruvangur Pookad area and 232 in Meladi Payyoli area (Table 7.1). All these are open dug wells. Since both these areas are solely dependent on family based open dug wells an average of 258 may be taken as the well density. Hence the total number of wells in the entire Kozhikode coastal zone having an area of 91 sq.km excluding the backwaters) may be estimated as 23,478.

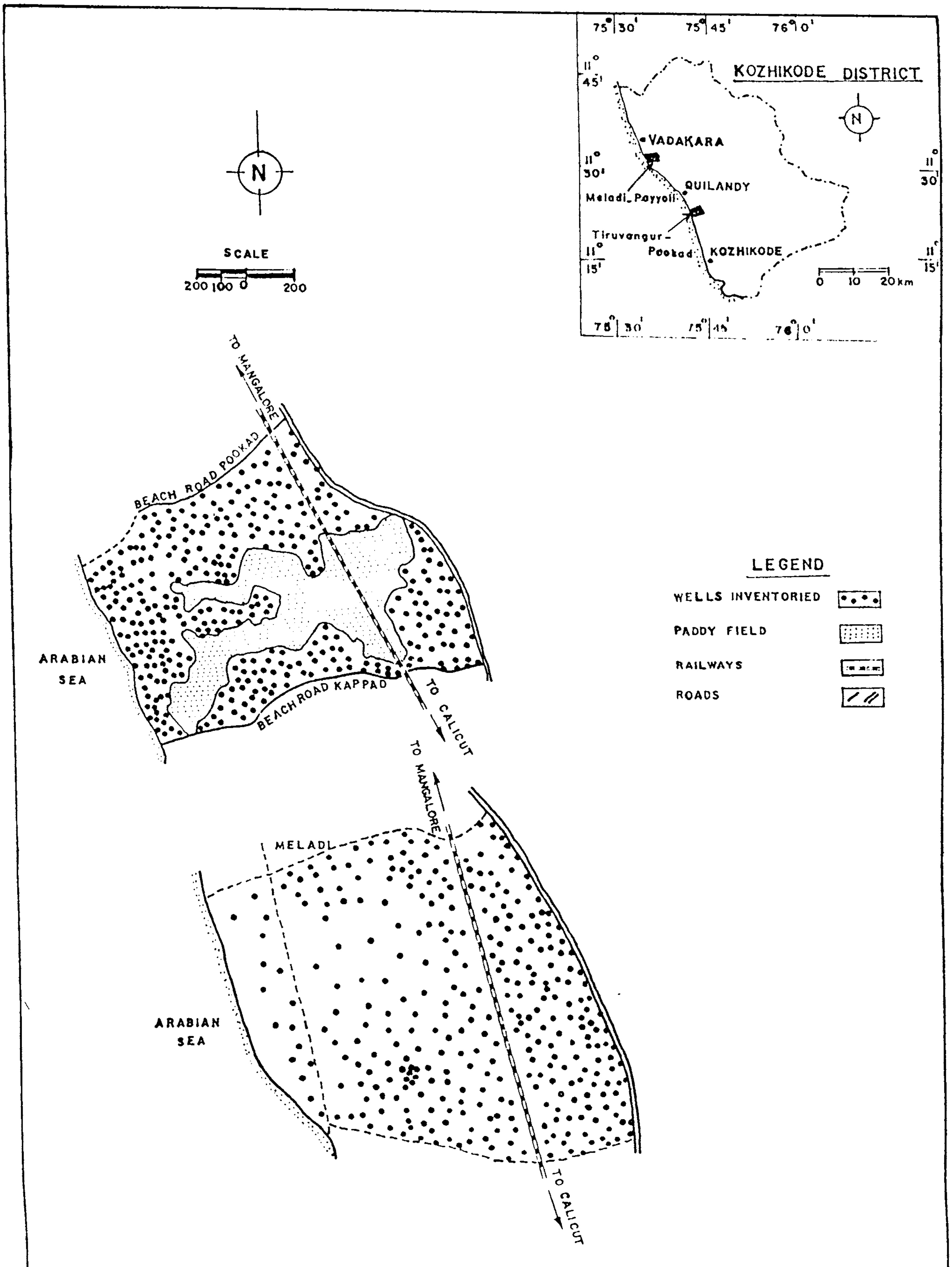


FIG. 7.1 WELL DISTRIBUTION IN SAMPLE AREAS AT TIRUVANGUR - POOKAD AND MELADI - PAYYOLI IN KOZHIKODE COAST

Table 7.1 Details of wells in sample areas

Sl.No.	Parameters	Thiruvangur-Pookad	Meladi-Payyoli
1	Area surveyed in sq.km	1.20	1.40
2	Number of open wells	342	325
3	Number of filter point wells	Nil	Nil
4	Total number of wells	342	325
5	Well density per Sq.km	285	232
6	Open well density per sq.km	285	232
7	Filter point well density per sq.km	Nil	Nil

Table 7.2 Physical details of the wells in sample areas

Sl.No.	Parametres	Thiruvangur-Pookad	Meladi-Payyoli
1	Average diameter (m) of the open well	Not available	1.76
2	Range of open well diameter (m) variation	do	1.12 to 2.81
3	Average depth (m) of open wells	do	2.43
4	Range of depth (m) variation	do	1.55 to 3.82
5	Age in years of the oldest well as on 1979	200	126
6	No. of open wells fitted with pumps	9	10
7	Percentage of open wells fitted with pumps	2.63	3.07

As seen from Table- 7.2 the average diameter of open well in Meladi Payyoli area is 1.76 m. The minimum and maximum diameters observed in the field are 1.12 m and 2.81 m. respectively. Corresponding depth variations are from 1.55 m to 3.82 m. The age of the oldest well (within the area surveyed) is about 200 years. The wells are generally lined either by concrete ring or be laterite bricks. Majority of the wells are open and have no platform around.

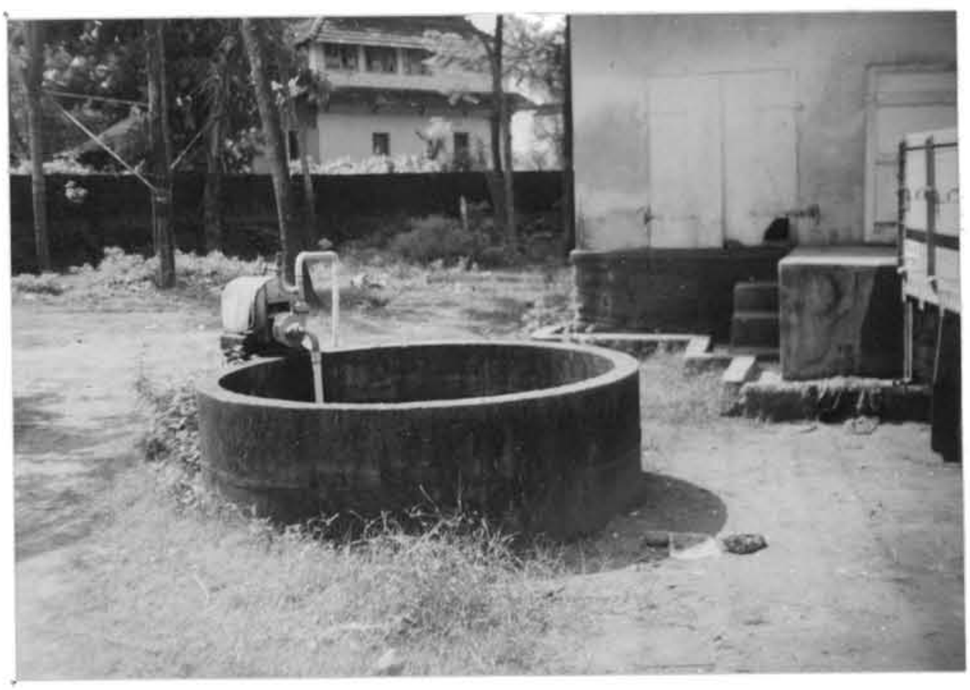
In 97 to 98% wells the water is lifted manually using bucket and rope and only 2 to 3 percent of the wells are fitted with pumps (photographs 5 & 6).

7.4 Estimation of Groundwater Draft

While doing physical survey in Tiruvangur-Pookad and Meladi-Payyoli areas, a rocord was kept about the average withdrawal from each of the wells. This average draft is calculated from the knowledge of persons using a particular well and by assuming that a person consumes 100 litres of water per day (Basak and Nazimuddin 1983).

Following this procedure, the average draft from various types of wells in the two sample areas are estimated (Table 7.3).

PHOTOGRAPH - 5 TYPICAL COASTAL WELL



PHOTOGRAPH - 6 TYPICAL COASTAL WELL FITTED WITH PUMPSET

Table 7.3 Estimated draft in sample areas

Sl.No.	Type of wells	Average draft in l/day/well	
		Thiruvangur-Pookad	Meladi-Payyoli
1	Domestic open wells	887.31	725.54
2	Irrigation open wells	2236.36	7257.14
3	Irrigation filter point wells	Nil	Nil

Notes : 1. Domestic open wells are defined as those wells which are either exclusively used for drinking or mainly used for drinking with occasional irrigation of crops in the well compound and are not fitted with any type of pump (Photograph - 5).

2. Irrigation open wells are those open wells which are fitted with pump and are mainly used for both (Photograph - 6).

It is seen that average draft from domestic open wells varied in between 723 to 887 l/day/well. Assuming conservative draft of 800 litres per day per well for estimation of the total draft from the entire coastal zone, the total amount of draft for domestic needs comes to be 800 x 23, 478 l/day or 18.8×10^{6} l/day. The irrigation wells in the coastal zone seem to be negligible in number, and hence draft from these wells can be neglected. So total estimated annual draft is $18.8 \times 10^{6} \times 365$ litres or of the order of 6.9×10^{9} litres/year. If 10% of rainfall is taken as recharge (Basak, 1983), the annual recharge in this coastal belt (91 sq.km area) is (for average annual rainfall of 300 cm) 27.3×10^{9} litres per year which means at present roughly 25% of available ground water resources are being utilised.

7.5 Groundwater Use Pattern

To get an idea about the pattern of groundwater use in the coastal zone relevant information from two sample areas are collected and presented in Table 7.4. It is seen that at Tiruvangur-Pookad 86% of open wells are used for drinking purposes and in Meladi-Payyoli it is 78% (Ref. Fig. 7.2). In

Table 7.4 Well use statistics in sample area

Sl.No.	Parameters	Thiruvangur-Pookad		Meladi-Payyoli	
		No.	% of total wells	No.	% of total wells
1	No. of open wells used for drinking alone	294	85.96	253	77.85
2	No. of open wells used for irrigation and drinking	8	2.34	49	15.08
3	No. of open wells used for irrigation alone	11	3.22	7	2.15
4	No. of abandoned open wells	19	5.56	10	3.08
5	No. of open wells used for washing and cleaning	10	2.92	3	0.92
6	No. of open wells used for both drinking and washing	NIL	NIL	3	0.92
	Total	342	100	325	100

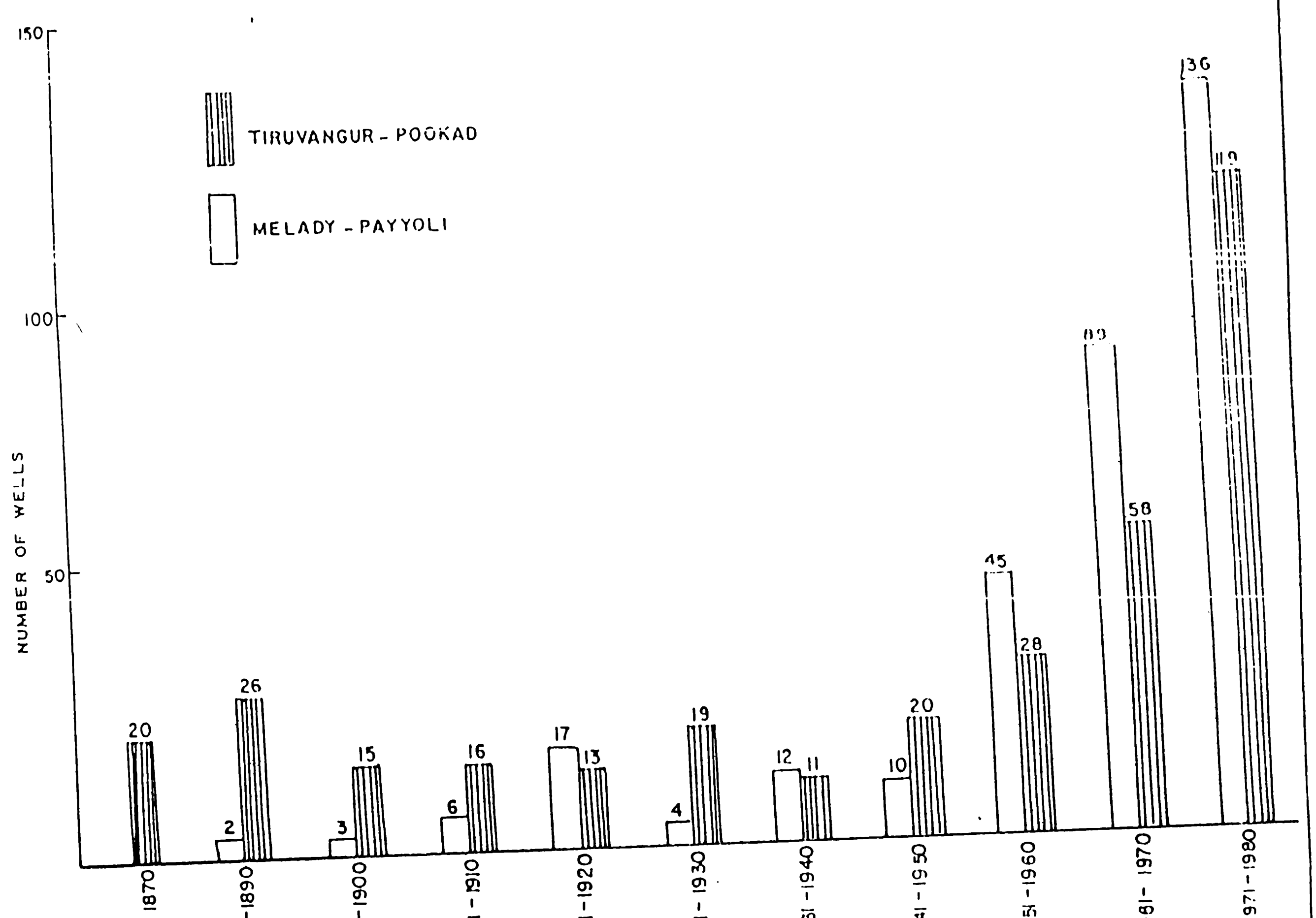


FIG. 7.2 GROWTH PATTERN OF OPEN WELLS IN TIRUVANGUR - POOKAD & MELADI - PAYYOLI AREA

Tiruvangur-Pookad areas 3% of the wells are used for kitchen gardening and irrigating cash crops while at Meladi-Payyoli area it is 2%. It is also seen that 3% of wells in Tiruvangur-Pookad area abandoned while in Meladi-Payyoli it is only 0.92%. Also no filter point wells are seen in both these areas.

7.6 Crystalline Rock Aquifer

Bore wells drilled in Kozhikode coast after the drought of 1983 is mostly fitted with pumps. These bore wells are used for supplying drinking water in Kozhikode. Hence adequate data is not collected in the case of peizometric surface of the aquifer and it's seasonal variations. This is because, most bore wells are fitted with pumps and are also covered with tin sheets. This has created difficulty in taking readings from the bore wells. Hence the availability of water from crystalline aquifer is not covered here.

7.7 Conclusions

The field investigations and analysis reported here broadly indicate the extent and pattern of ground water use in the coastal belt of Kozhikode. Out of estimated annual recharge of 27 billion litres, the annual groundwater draft is found to be only 6.4 billion litres which points towards a great untapped potential. The entire groundwater draft is being utilised through an estimated 23,500 open wells. These figures agree with the results obtained in Ch. 6 with the groundwater fluctuation method.

CHAPTER 8

GROUNDWATER QUALITY

8.1 Introduction

The quality of groundwater vary greatly in different parts of coastal areas. This variability is due to the complex geology, variable topography, climate, surface hydrological conditions proximity to sea water and other anthrapogenic factors. The lack of data on the quality of groundwater is considered to be one of the constraints in water resources management. Hence a detailed study has been made on the groundwater quality of Kozhikode coast.

8.2 Water Quality Problems

8.2.1 Population density

Kozhikode coast is a thickly populated region. The density of population varies between 1000 to 2000 per sq.km. The soil and aquifer is sandy, where the human waste and solid waste mix with it and reach groundwater very easily, polluting the system. This region like, western Kallayi, west of Korapuzha, west of Beypore, in parts of Moratupuzha and beach areas of Kozhikode are susceptible for epidemics of diarrhoea and cholera.

8.2.2 Coconut husk retting

Coir making is one of the major cottage and traditional industries of the coastal areas of Kozhikode. Coir fibre is made of the coconut husk by allowing the husk to ret in the water (Photograph - 7) for 4 to 6 months and then the fibre is removed manually by cushioning the husk. In the process of retting and retreaval of the fibre, lot of solid waste is produced. This gets mixed up with soil and gradually decomposes. It merges with the soil and the aquifer polluting the groundwater system. Decomposition of the organic matter produces large quantities of hydrogen sulphide which dissolves in the water system. This type of contamination of well water is observed in places of Kadalundikadavu, west of Thiruvangur, Korapuzha, Moratpuzha, in parts of Chaliyar and north east of Aliyur.

8.2.3 Industrial wastes

The major industries in the Kozhikode coast are concentrated along the banks of Chaliyar. Timber industries are along the banks of Kallayi (Photograph - 8) and the lime industries (Photograph - 9) are along the banks of Korapuzha and Moratpuzha. These industries discharge their effluents into the river system

PHOTOGRAPH - 7 COIR RETTING ZONES ALONG KOZHIKODE COAST (KORAPUZHA)

PHOTOGRAPH - 8 TIMBER INDUSTRY ALONG KOZHIKODE COAST

PHOTOGRAPH - 9 LIME INDUSTRY AT KORAPUZHA polluting them.

Apart from the major industries, there are a number of industrial estates, minor workshops, foundaries, etc. spread over the coast of Kozhikode, especially between Kallayi and West Hill area. Apparently their water requirements are limited and so they use groundwater sources and the effluents are discharged into the nearby soakpits. Even such minor pollution can develop into serious health hazards, if the polluted water is consumed over long periods of time.

Fishing (fish processing and canning) is one of the thriving industries along the coastal stretches of Kozhikode. The fish waste from most of these factories are not disposed properly. On the other hand it is disposed off into nearby surface water or soil itself, thereby allowing profuse growth of bacteria, which pollute the surface water and ground water.

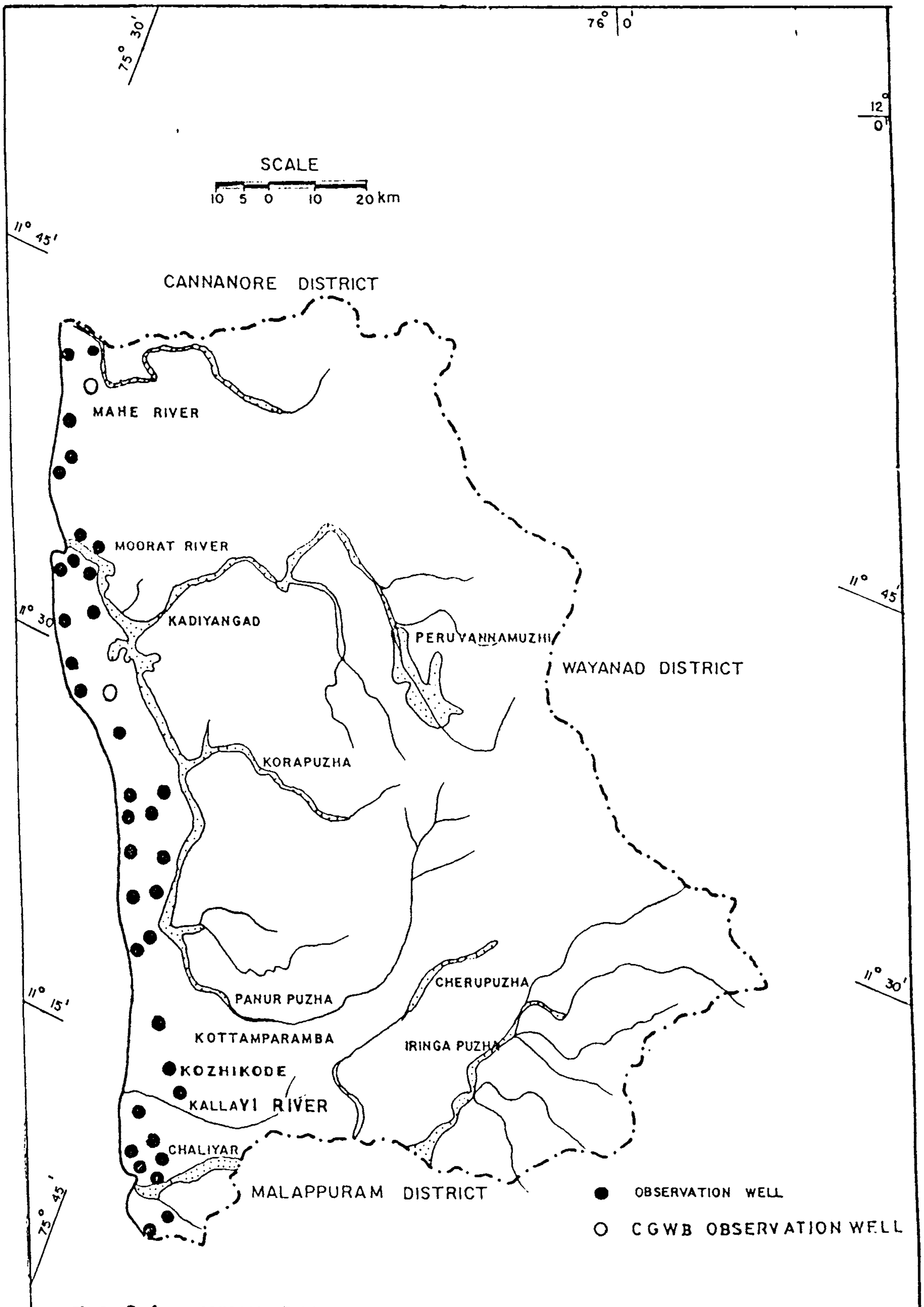
8.2.4 Agricultural practices

Agriculture is the main occupation of the people. Mainly cocunut, paddy, banana and vegetables are cultivated. These are raised on an intensive multicropping pattern using high dosages of fertilisers and pesticides. Residual concentration of these chemicals are likely to get into the groundwater system. However, there is a likelihood of these to get diluted and flushed from the aquifer system in the subsequent rainy season.

All these problems call for a detailed study of the groundwater quality for the proper management of the groundwater system.

8.3 Methodology

The general groundwater quality of open wells in Kozhikode coast are studied from a network of 36 open wells. The locations of these wells are given in Fig. 8.1. The criteria for fixing these wells are already explained in Chapter 4. Water samples of these wells are collected in premonsoon, monsoon and postmonsoon periods. They are subjected to chemical analysis. The chemical parameters such as calcium, magnesium, chloride, T.D.S, iron, pH, total hardness and conductivity are determined (Appendix 8, 9 and 10).



FIG·8.1 NETWORK OBSERVATION WELLS IN KOZHIKODE COAST

Table 8.1 presents summary of groundwater quality parameters for the Kozhikode coast.

Table 8.1 Summary of Groundwater quality parameters for Kozhikode coast

Elements	Range for Kozhikode coast	WHO Standards		
		Limit of general acceptability in ppm		Maximum allowable limit in ppm
Total dissolved solids	110 - 2600	550		1500
Chloride	8 - 5500	200		600
Iron	0.20 - 1.20	0.3		1
Hco_3	14 - 427			
Mangnesium	1.70 - 67.80	50		150
Calcium	8 - 153	75		200
pH	5.4 - 8.19	7.8	Min	6.5
			Max	9.2

8.4 Results and Discussions

The chemical parameters like pH, T.D.S, chloride, magnesium, calcium, iron, total hardness and conductivity of open well waters have been correlated with W.H.O. criteria on potability (Table 8.1) and general quality map of different stretches are prepared (Fig. 8.2 and 8.3).

Generally water quality of open wells along Kozhikode coast are found neutral in character during premonsoon season. The well water becomes alkaline in character in other seasons. Typical variation in different lithological units of each coastal stretch is given in Table 8.2.

Table 8.2 pH Variation of well water in various stretches along Kozhikode coast

Name of the Coastal Stretches	Geological Horizons								
	Coastal Sandy Zone			Coastal Alluvial Zone			Coastal Alluvial Laterite Zone		
	Premon-soon	Mon-soon	Post-monsoon	Premon-soon	Mon-soon	Post-monsoon	Premon-soon	Mon-soon	Post-monsoon
Aliyur-Kottakkal	6.58	7.76	7.10	-	-	-	6.20	7.61	6.88
Kottakkal-Kollam	6.42	7.64	6.97	6.05	7.46	6.90	7.75	7.86	7.45
Kollam-Korapuzha	6.52	7.23	7.10	6.20	7.50	7.63	-	-	-
Korapuzha-Kallayi	6.93	7.52	7.23	7.20	6.69	6.95	7.55	7.86	7.56
Kallayi-Kadalundikadvu	6.96	7.30	7.16	7.20	7.50	7.05	-	-	-

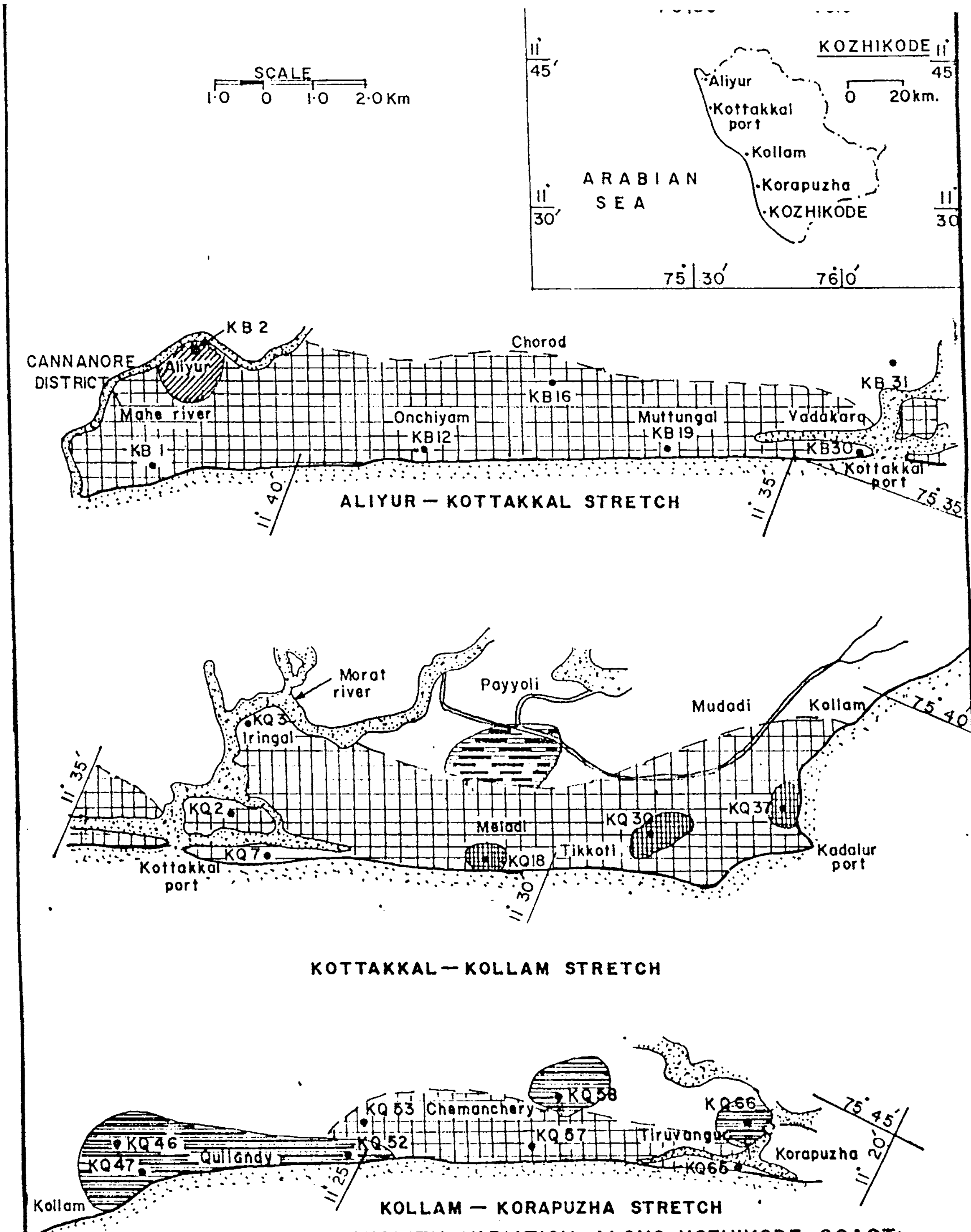


FIG.8.2 GROUNDWATER QUALITY VARIATION ALONG KOZHIKODE COAST: ALIYUR — KORAPUZHA STRETCH

INDEX

- POTABLE WATER THROUGHOUT THE YEAR
- UNPOTABLE DUE TO HIGH PH, Fe & TDS THROUGHOUT THE YEAR
- UNPOTABLE DUE TO HIGH ALKALINITY (P_H > 6·5) ALL OVER THE YEAR
- BECOMES UNPOTABLE IN SUMMER ONLY DUE TO HIGH P_H
- BECOMES UNPOTABLE IN SUMMER ONLY DUE TO HIGH P_H & Fe
- RIVERS & BACK WATERS

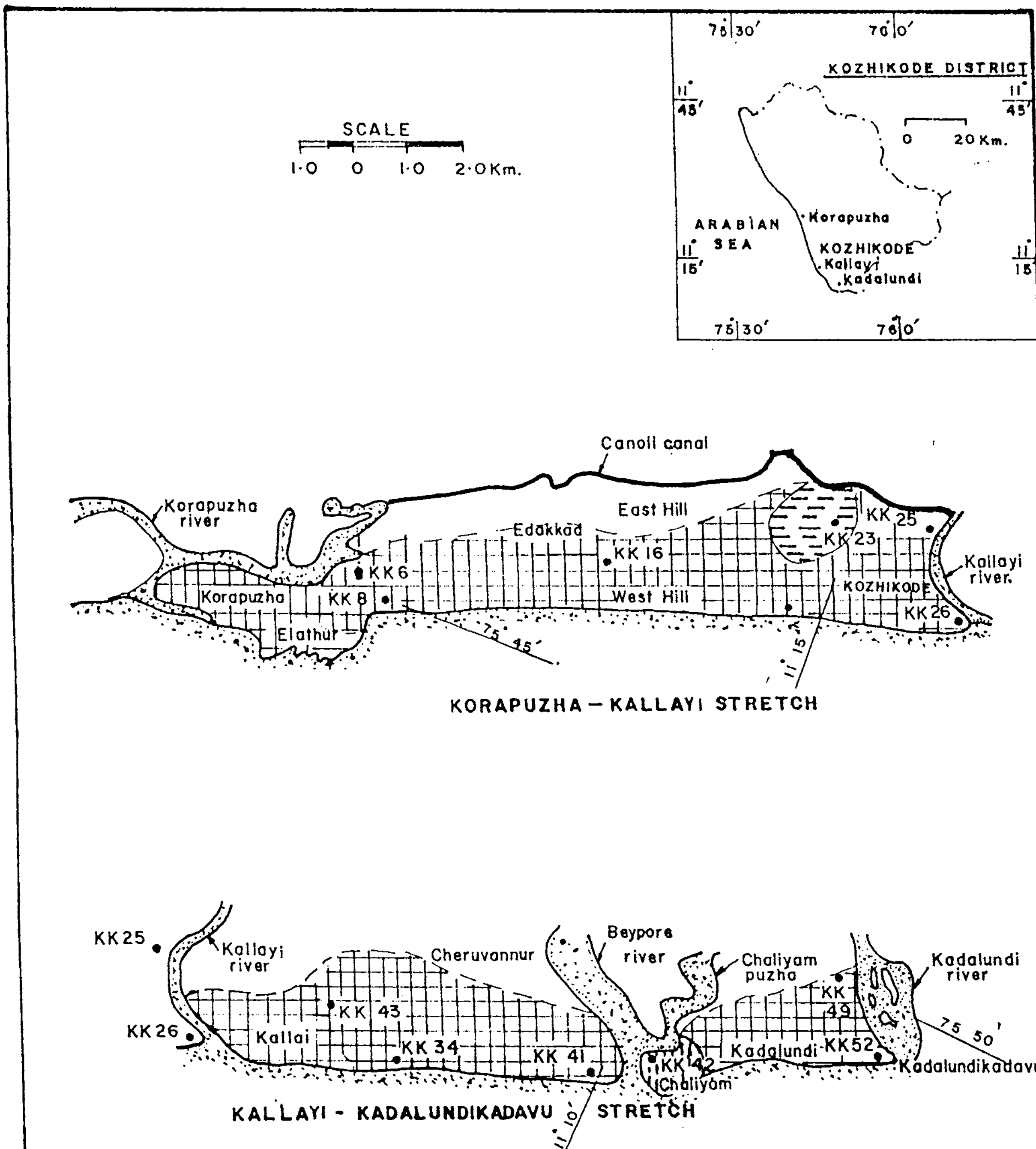
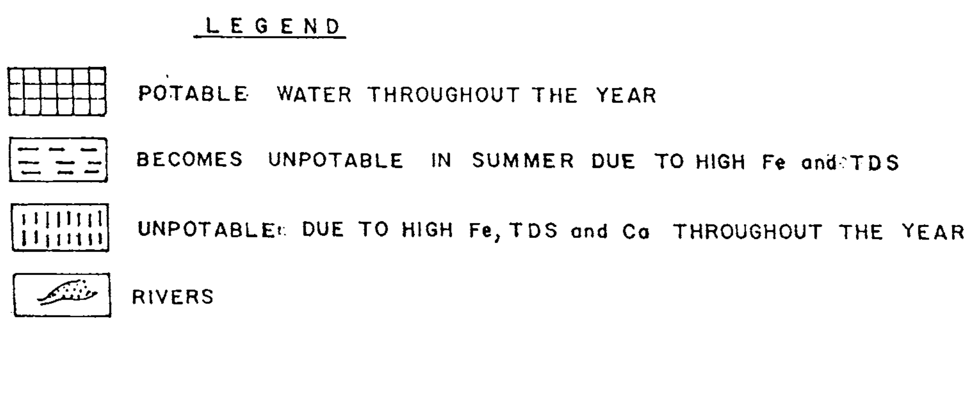


FIG.8·3 GROUNDWATER QUALITY VARIATION ALONG KOZHIKODE COAST: KORAPUZHA — KADADLUNDIKADAVU STRETCH



Different stretches show low pH and certain pockets show high pH condition. The details of location of wells showing low and high pH values are given in Table 8.3. Perched water table condition of the wells located in coastal alluvial zone and wells adjacent by coir retting industry may be the cause of low pH.

Table 8.3 Location and the geological horizons of low pH and high pH wells along the coast

Coastal stretch	Well No.	Location	Name of the zone	High/low pH
Aliyur-Kottakkal	KB30	Purakkara	Coastal sandy	Low pH < 6
Kollam-Korapuzha	KQ52	Edakulam Beach	Coastal sandy	Low pH < 7
Kallayi-Kadalundikadavu	KK34	Naduvattom	Coastal sandy	High pH < 8
Aliyur-Kottakkal	KB02	Aliyur	Coastal alluvial	Low pH < 4
Kottakkal-Kollam	KQ30	Tikkodi	Coastal alluvial	Low pH < 6
Kollam-Korapuzha	KQ46	Kollam	Coastal alluvial	Low pH < 6
Kallayi-Kadalundikadavu	KK39	Beypore	Coastal alluvial	Low pH < 6
Kottakkal-Kollam	KQ20	Payyoli	Coastal alluvial	Low pH < 6
Aliyur-Kottakkal	KQ37	Kadalur Beach	Laterite	Low pH < 6

Well water that has a hardness of less than 50 ppm. is considered soft. Typical variation of hardness of well waters in different geological horizons of the coastal stretches of Kozhikode in various seasons are given in Table 8.4.

Table 8.4 Hardness variation of wells along Kozhikode coast in different seasons

(a) **Coastal sandy zone**

		Total hardness in ppm.		
Well No.	Location	Pre-monsoon	Monsoon	Post-monsoon
KB01	Aliyur-Puzhithala	228	104	194
KQ07	Kottakkal	190	80	64
KB19	Kuriadi Beach	210	84	138
KR26	Kothiroad, Kallayi	418	248	230
KR65	Kannankadavu	350	138	170
KK08	Puthiyappa	305	179	189

(b) **Coastal alluvial zone**

Well No	Location			
KB02	Aliyur	2760	13	20
KQ66	Korapuzha	208	174	164
KK31	Meenchanda	105	72	110
KK41	Beypore	156	70	110

(c) **Coastal alluvial - laterite zone**

Well No.	Location			
KQ03	Iringal	300	140	270
KK25	East Kallayi	390	160	180
KK31	Puthupanam	220	46	96
KK23	Mavoor Road (KSRTC Bus stand)	390	166	180

Results indicate that certain pockets of wells in Kozhikode coastal stretch are found to contain hard water. These wells are concentrated in Aliyur, Kadalundi, east Kallayi, Iringal, and Korapuzha. Lime shells are found in Kozhikode backwaters, as stratified deposits. These shells are mined at Kadalundi, Korapuzha, Kannankadavu and Kuriyadi. Because of the concentration of lime industries wells mentioned in above locations are clogged with $CaCO_3$ causing hardness.

The Iron concentration of well waters in various coastal stretches vary between 0.20 to 0.80 ppm in different seasons. General variation of iron concentration in wells located in various lithological units of the coast is given in Table 8.5.

Table - 8.5 Iron Concentration of Well Water in different formations

	Pre-monsoon in ppm	Monsoon in ppm	Post-monsoon in ppm
Coastal sandy zone	0.30 to 0.43	0.25 to 0.55	0.25 to 0.55
Coastal alluvial zone	0.40 to 0.80	0.20 to 0.45	0.30 to 0.60
Coastal Alluvial laterite zone	0.30 to 0.50	0.30 to 0.40	0.30 to 0.60

Groundwater is found to contain excessive Iron (>1 ppm) in certain locations at Beypore port, Edakulam beach and near K.S.R.T.C bus stand in Kozhikode city.

The field investigations and chemical data on water samples from dug wells located at Aliyur (KB2) (near Mahi river), Payyoli (near to Morat river) and Chaliyam (near Beypore port) indicate that groundwater remain unpotable throughout the year. This unpotability is mainly due to high pH, Fe and T.D.S. Groundwater in places like Tikkodi, Meladi and Kadalur becomes alkaline in summer, whereas places around Tiruvangur and Korapuzha, become alkaline as well as ferric (Fe > 1ppm) during summer.

Barring the pockets explained above, groundwater along the coast of Kozhikode is found to remain potable throughout the year.

8.5 Summary and Conclusions

Water quality of wells along Kozhikode coast are found to be neutral in character during pre-monsoon season. However there are pockets in Kozhikode coast, where well water is found to be acidic which is due to coir retting industry. This is along the coast at Korapuzha and Kadalundi. Beacuse of lime industry, the well water is found hard in places like Korapuzha, Kadalundi, Kallayi and Iringal. Ground water is found to contain excessive iron at Beypore, Edakulam beach and near K.S.R.T.C bus stand in Kozhikode city. Chemical data on well water samples from Aliyuar, Payyoli, and Chaliyam reveal that groundwater remain unpotable throughout the year and this is due to high pH, iron and T.D.S. Groundwater along the coast of Kozhikode is found to remain potable throughout the year except in the above mentioned places.

CHAPTER 9

SALINITY PROBLEMS OF KOZHIKODE COAST

9.1 Introduction

Salt water intrusion into the confined and unconfined aquifers along various coastal belts of India is being increasingly reported (Basak, and Vasudev 1983). The problem is particularly severe in the coastal tracts of Tamil Nadu and Gujarat. Due to the increasing demand for potable water resources the limited groundwater resources of these sensitive zones are being more extensively utilized compared to the last decade. In many places particularly in Tamil Nadu coast, this has resulted in a gradual lowering of water table causing the sea water wedge to intrude further into the land (Basak, and Vasudev 1983). Withdrawal of such fresh water from the shallow unconfined aquifer adjacent to shore, particularly in the absense of appropriate recharge in the non-monsoonal season, cause lowering of the freshwater table. This lowering of water table is met with the landward advancement of the seawater interface and thus reducing fresh water storage space and also partially increasing the salt content of the potable water due to transverse or lateral diffusion from sea water.

In Kozhikode coast the salt water intrusion takes place from the sea, which is hydraulically connected to the coastal aquifer. This chapter presents the study on groundwater quality deterioration caused by salt water instrusion along different coastal stretches of Kozhikode. For this two year's observations (See Ch. 8) on the wells are analysed and correlated with depth-to-water level and distance of the well from the sea shore using a simple conceptual model. The possible impact of predicted sea level due to greenhouse effect is also discussed.

9.2 The Ghyben - Herzberg Model

The basic concept of sea water intrusion in coastal aquifers is provided by Ghyben - Herzberg (Todd, 1959) and is shown in Fig.(9.1).

According to this the quantitative relation between the freshwater table and the position of seawater interface (Fig.9.1 and 9.2).
is expressed as

$$\frac{h}{H} = \frac{D_f}{D_s - D_f}$$

h - depth of freshwater in the aquifer

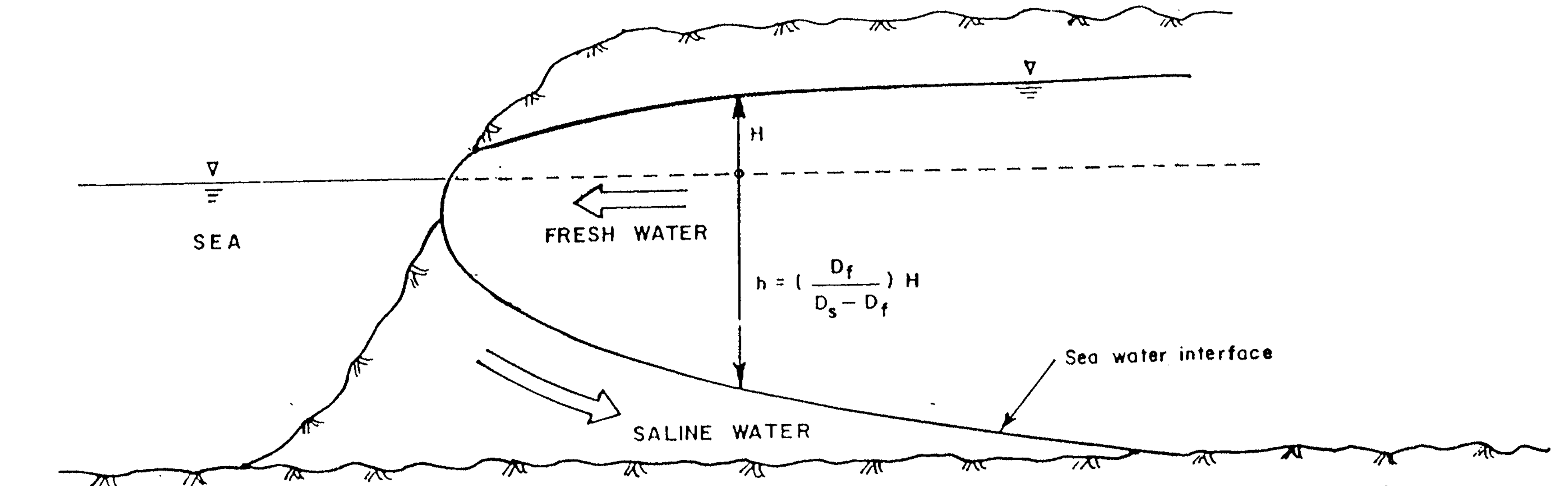


Fig.9.1 SEA WATER INTRUSION IN THE COASTAL UNCONFINED AQUIFER AND GHYBEN HERZBERG'S RELATION

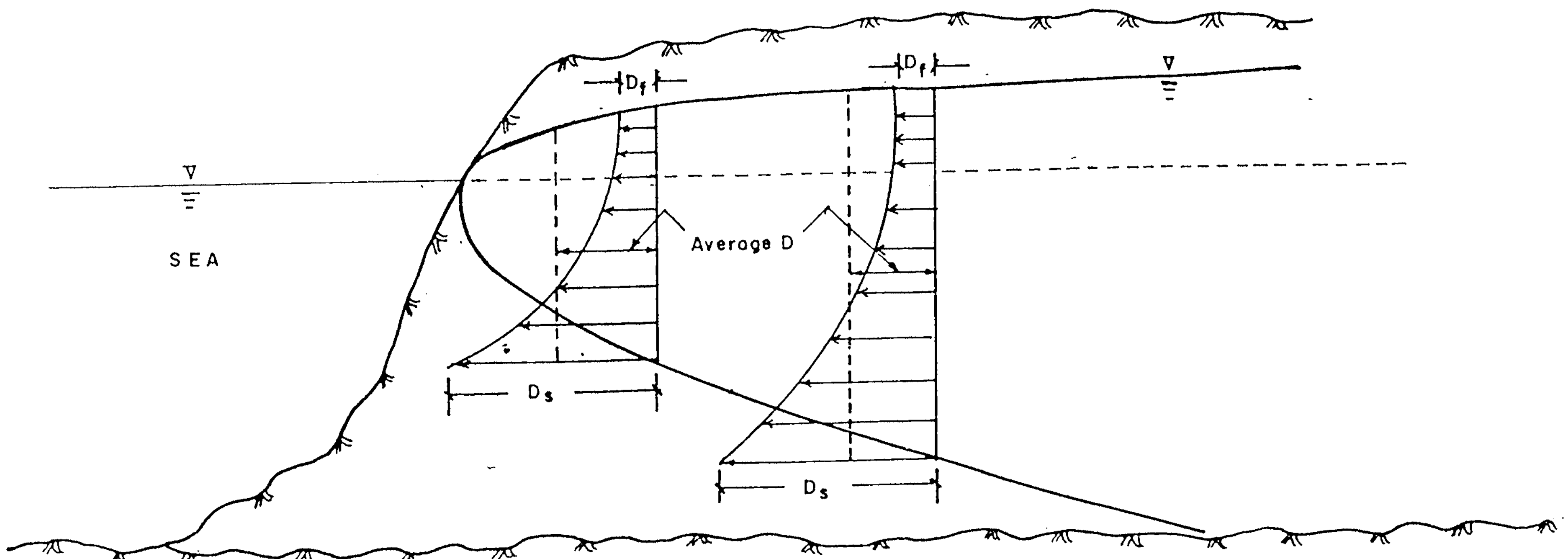


Fig 9.2 PROBABLE DENSITY DISTRIBUTIONS IN THE FRESH WATER LENSE ABOVE THE SEA WATER INTERFACE

H - depth of freshwater above the sea level

D_f - density of fresh water (gm/cc)

D_s - density of sea water (typically 1.025 gm/cc).

Physically, this equation signifies that for every unit drop of fresh water table there is $(D_f/D_s - D_f)$ times rise of sea water interface, thus severely restricting the available quantum of fresh water. The typical value of the factor $D_f/(D_s - D_f)$ is of the order of 40. What happens to the quality of fresh water consequent to this rise of sea water interface is not adequately studied.

The sharp interface between fresh and saline water as depicted is only simplification of the actual situation. In reality there exists a transition zone of certain width where the density varies between that of seawater to fresh water. The density distribution will be similar to what is shown in Fig. 9.2. The density of water is proportional to the dissolved salt content in it. This means TDS (Total Dissolved Solids), chloride and other salt content distribution across the freshwater lens (Fig.9.2) will also be of the same nature of that of density distribution. Hence, it is obvious that the average density (D) and consequently average TDS, chloride and salt content of the floating freshwater lens will be dependent on the thickness of freshwater lens available at that point. Fig. 9.2 is self explanatory in this respect. Keeping this in mind, it is perhaps logical to expect the following:

(a) at any point of time average salt content of the freshwater lens should increase as one approaches the shore,

(b) at all points in the coastal aquifer salt content should increase with the lowering of freshwater table,

(c) the rate of increase of salt content with the lowering of fresh water table should increase as one goes nearer to the shore and

(d) beyond a certain critical distance from the shore, salt content of the freshwater lens should be independent of the depth-to-water table and it's temporal fluctuations.

9.3 Salinity Intrusion in Kozhikode Coast

In Kozhikode coast the low-lying areas are mostly threatened by seawater intrusion problem. These low-lying areas found in

Aliyur near Mahi river, Kottakkal near Kottakkal port, Puthiyanirathukadavu near Elathur, Kothi near east Kallayi and Kadalundikadavu in the southern part of the coast. Seasonal variation has been observed in salinity in wells located in the above mentioned areas.

9.3.1 Ways of salt water intrusion

Salt water intrusion in the fresh water lens can occur in a number of ways. Firstly, according to the Ghyben-Herzberg principle the position of the interface depends upon the flow of groundwater and the outflow of water from the edge of the lagoon or island. Fluctuations in the size of the lens occur with saline intrusion at the lens margin when the lenses contract. The coastal wells located at Kadalundikadavu and Kottakkal are partly influenced by lagoon and partly by seawater as they have sea on one side and lagoon/backwater on the other.

More localised saline intrusion can occur as a result of over-pumping and also due to effect of tides. The well no. KB2 situated at Aliyur near Mahi river is affected by salinity due to tidal water from the sea and also over-pumping from nearby well. Again assuming the Ghyben-Herzberg relationship, the effect of over-pumping in a shallow well is to drawdown the water table. If the water table is drawn by 0.03 m, this will result in upconing of the interface at the base of lens by 1.2 m (i. e. 40 times the amount of drawdown).

The third way in which salt can intrude the coastal aquifer is by overwash also called freeboard washover (Roy and Connell, 1989). If storm water overtops the seaward beach ridge the sea water will flood the coast and shallow wells existing on the shore will become saline. Frequent outwash may result in increase in salinity.

9.3.2 Seasonal salinity variation

To understand the variation of salinity levels, in the coastal wells chloride variation map of different coastal stretches are prepared based on the chemical analysis data obtained for the permanent observation wells for pre-monsoon, monsoon, and post-monsoon periods.

Fig.9.3 shows the chloride variation along Aliyur - Kottakkal stretch. The chloride level is found to be >5000 ppm in well no. KB2 which shows intrusion of sea water in wells in the area during summer. In other seasons the chloride variations are

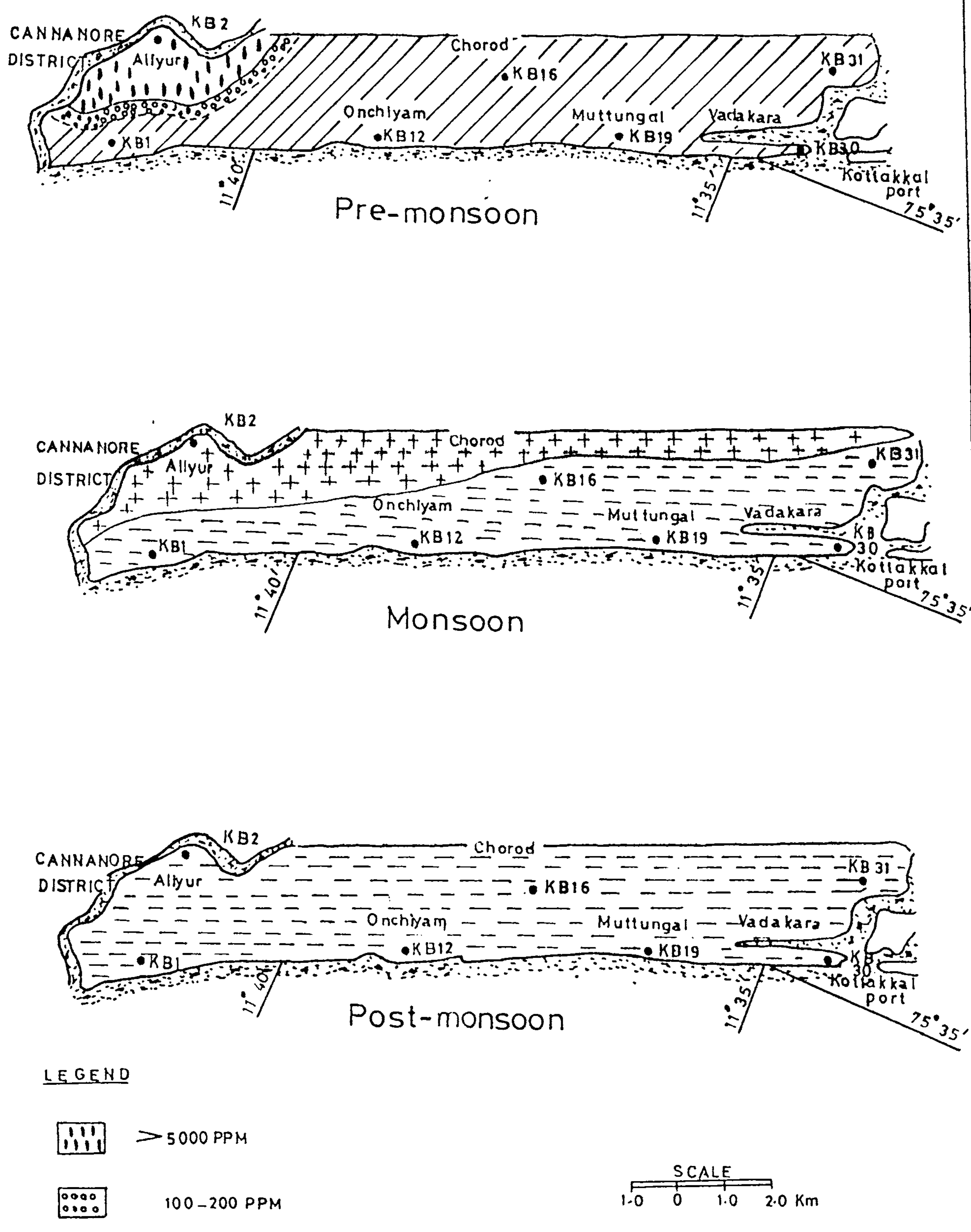


FIG.9.3 CHLORIDE VARIATIONS OF WELLS ALONG KOZHIKODE - COAST (Aliyur –Kottakkal Stretch)

found to vary between 25 and 50 ppm.

Fig 9.4 indicates the chloride levels of wells in ppm in Kottakkal - Kollam stretch. In this stretch at Kottakkal coast at well no. KQ7 indicates more than 150 ppm of chloride during pre-monsoon. In other season in general chloride variation of well is found to vary from 10 to 30 ppm. At Kadalur, laterite hills are abutting the coast hence the salinity of wells are found to be minimum. Increase in chloride variation is noticed towards the Morat river and also towards the sea during summer season.

Chloride variation map of Kollam - Korapuzha stretch in different seasons are presented in Fig. 9.5. Analysis of the data indicates that in this stretch also wells adjacent to Korapuzha and towards sea shore an increase of chloride (more than 50 ppm) during pre-monsoon. In other seasons, the general chloride level in this stretch is found to vary between 10 ppm and 20 ppm.

At Korapuzha - Kallayi coastal stretch, the high content of chloride is recorded near Elathur which lies close to the Korapuzha estuary, Canoli canal and sea. In pre-monsoon season the wells located at this stretch indicate a variation of more than 300 ppm in chloride levels which is noticed towards sea and near Korapuzha at Elathur. In other wells the chloride level

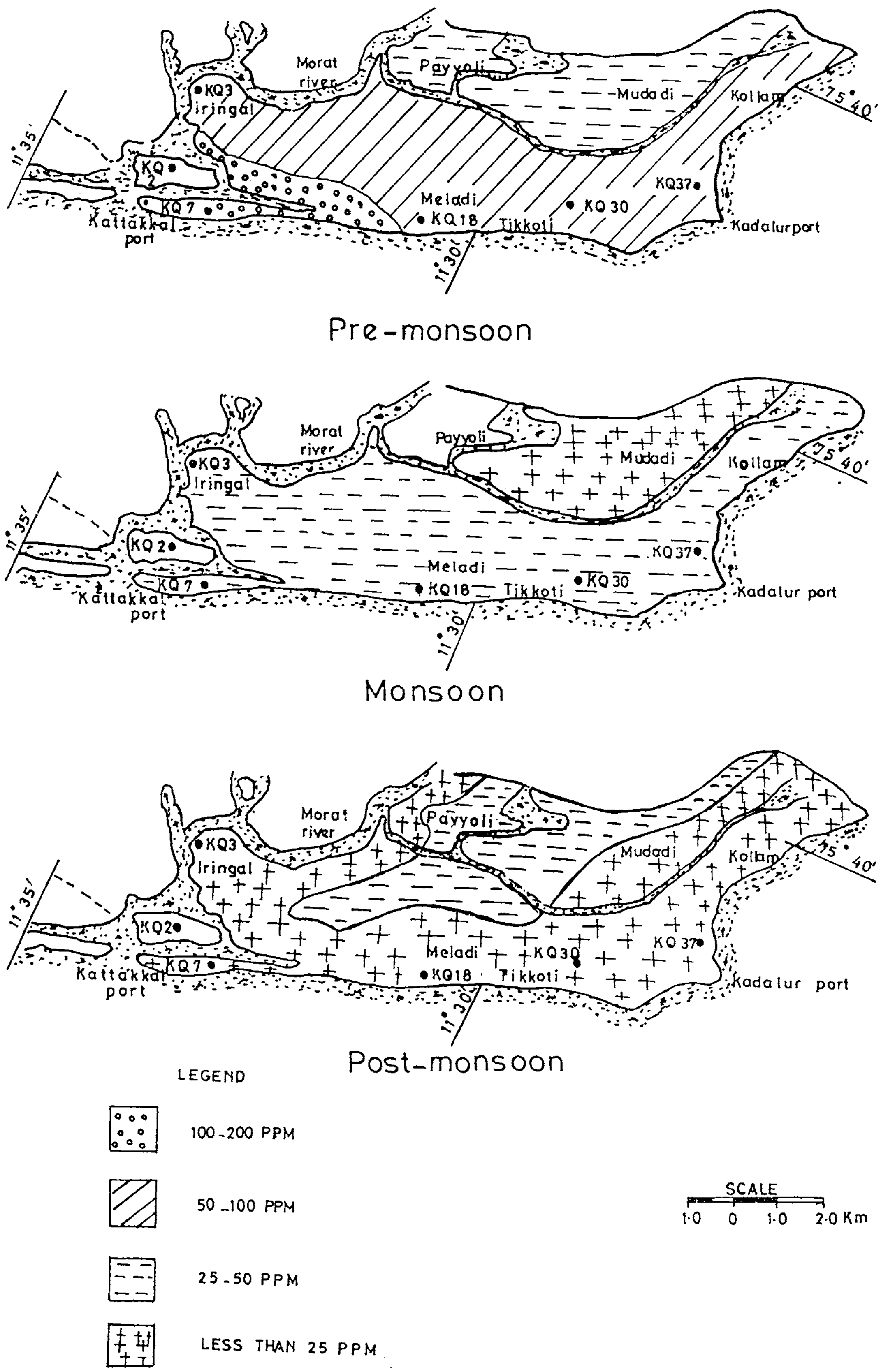


Fig9.4 CHLORIDE VARIATION OF WELLS ALONG KOZHIKODE COAST (Kottakal-Kollam Stretch)

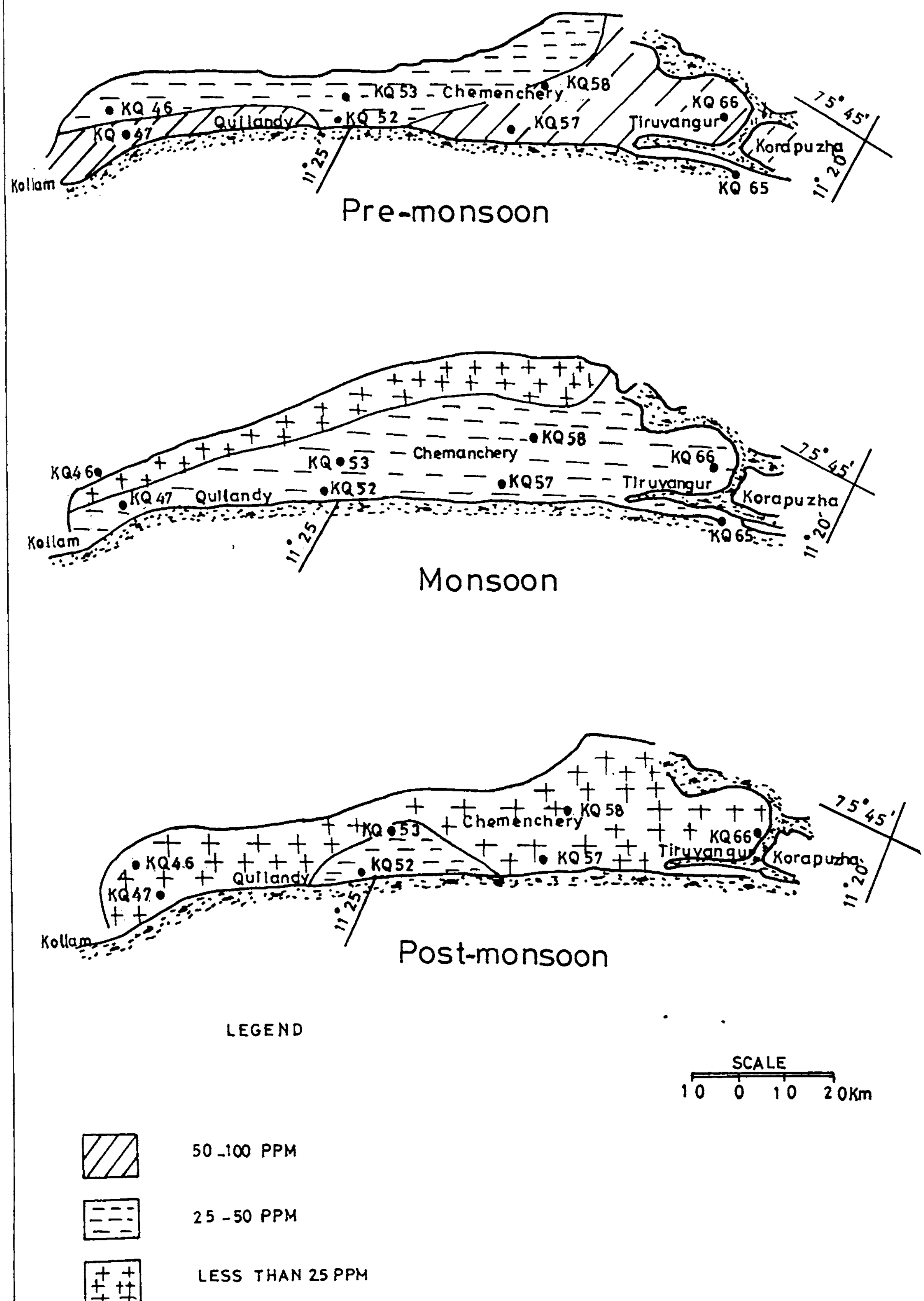


Fig 9.5 CHLORIDE VARIATION OF WELLS ALONG KOZHIKODE COAST (Kollam - Korapuzha Stretch)

varies from 200 to 300 ppm in pre-monsoon, 50 to 200 ppm in monsoon and 50 to 150 ppm in post-monsoon period. Fig. 9.6 shows the general variation of chloride levels along Korapuzha - Kallayi coastal stretch.

Kallayi - Kadalundikadavu forms southernmost part of Kozhikode coast. The chloride level variation of open wells along this stretch is presented in Fig 9.7. The variation of chloride is found to vary from 50 to 200 ppm in pre-monsoon and in other seasons the chloride levels vary from 20 to 50 ppm.

9.3.3 Estimation of seawater length

Spatial and temporal variations of groundwater salinity are also studied in the open wells selected for quality studies. The study is significant as the fresh water lens in the shallow unconfined aquifer is floating over the sea water wedge of the type described in Fig 9.2. General direction of fresh water flow is from the eastern uplands to the sea in the west.

For studying seawater intrusion studies 6 wells are chosen as experimental wells from among the 36 permanent observation wells along the coast. The distance of the these wells from the shore is measured. In the wells the T.D.S., chloride and

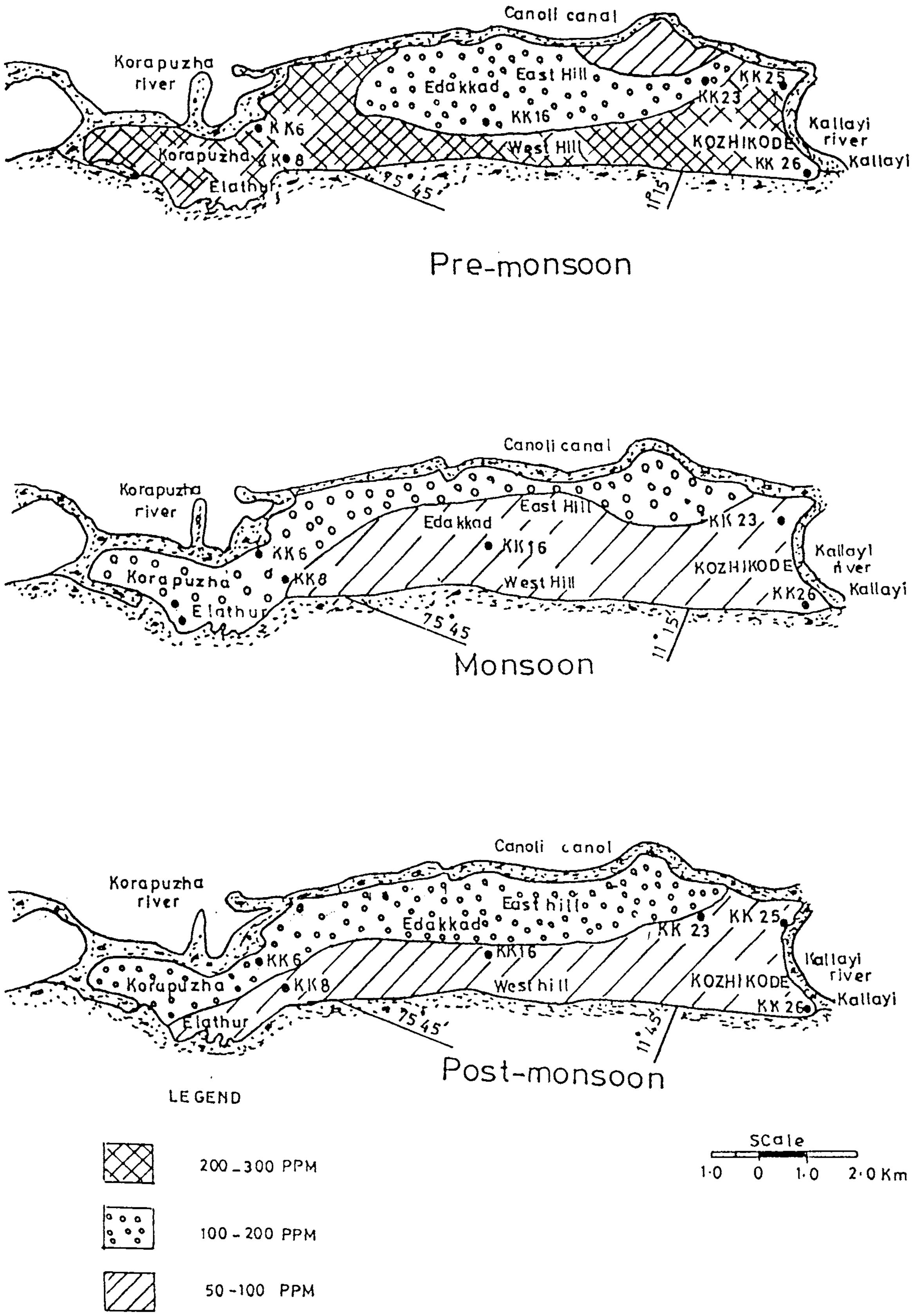


Fig 9.6 CHLORIDE VARIATION OF WELLS ALONG KOZHIKODE COAST (Korapuzha-Kallayi Stretch)

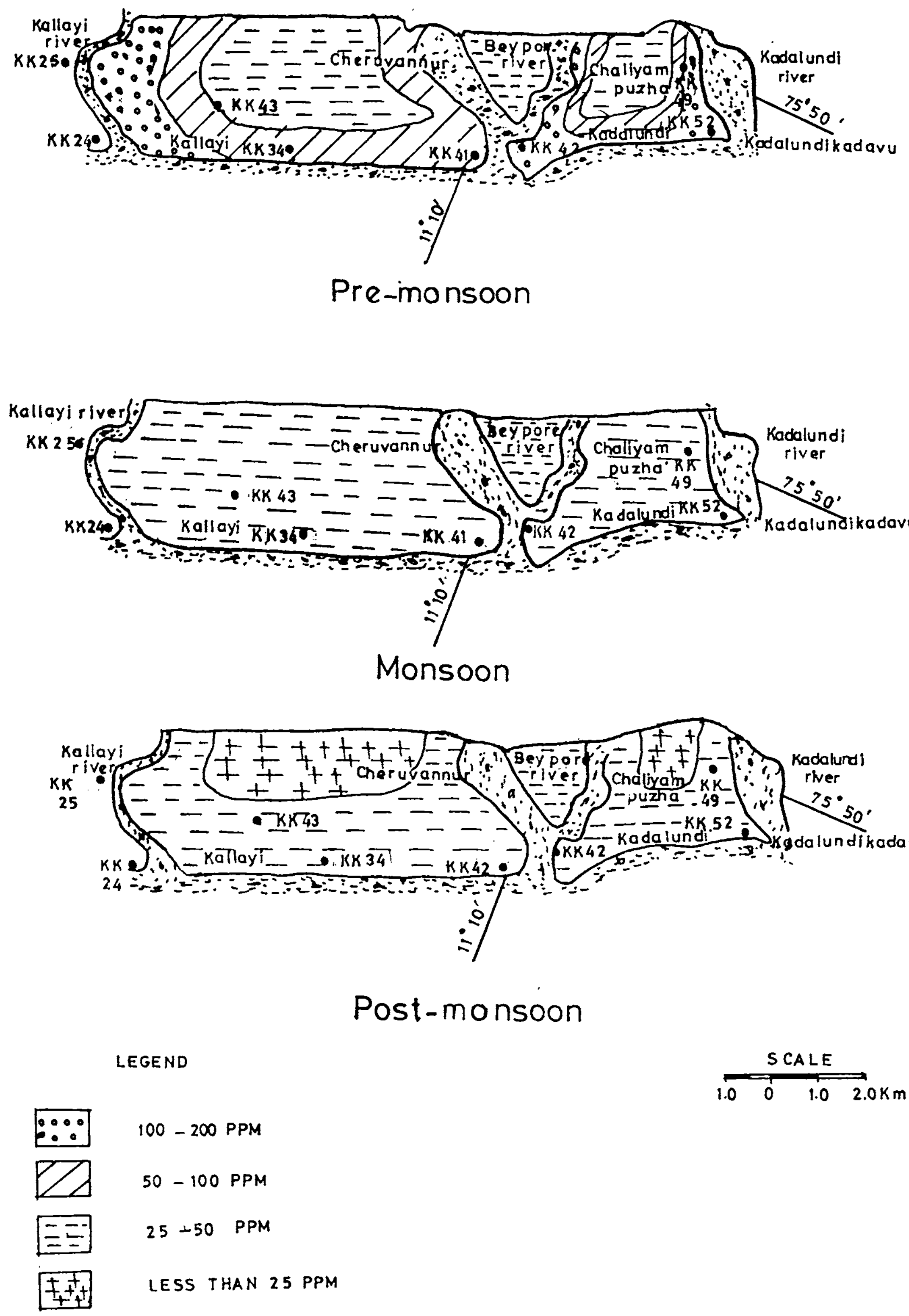


Fig.9.7 CHLORIDE VARIATION OF WELLS ALONG KOZHIKODE COAST(Kallayi-Kadalundikadavu)

conductivity are measured for two years. For each depth-to-water level corresponding T.D.S and chloride values are plotted. From these plots width of sensitive zone lying the Kozhikode coast is estimated.

The depth-to-groundwater table and the two salinity parameters (TDS and Cl_2) were measured during April - May, July - August and December - January, representing the pre-monsoon and post-monsoon seasons. Table 9.1 presents the season-wise average values for TDS, chloride and water levels of coastal wells for two years.

For each depth-to-water level measurement corresponding TDS and Cl_2 values are plotted for different coastal wells, (Fig. 9.8 and 9.9). The slopes of these plots indicate rate of salinity ((TDS or Cl_2) change with change of depth of fresh water table and are termed here as "Quality - Depth Index (QDI)". These indices tell the well user, the likely amount of rise or drop of salinity per unit lowering or rise of depth-to-water level. Higher QDI indicates higher sensitivity of the freshwater towards the change in depth-to-water table. The distance of the observation wells from the sea shore are plotted against the QDI for TDS and Cl_2 in Table 9.1 and Fig 9.10.

SL NO:	SYMBOL	WELL NO:	DISTANCE FROM SHORE	QDI IN ppm/m
1	⊙	KK 52	60	2000
2	⊕	KQ 7	70	1428
3	Δ	KB 19	100	338
4	●	KK 26	200	297
5	○	KK 6	600	118
6	□	KB 2	150	59

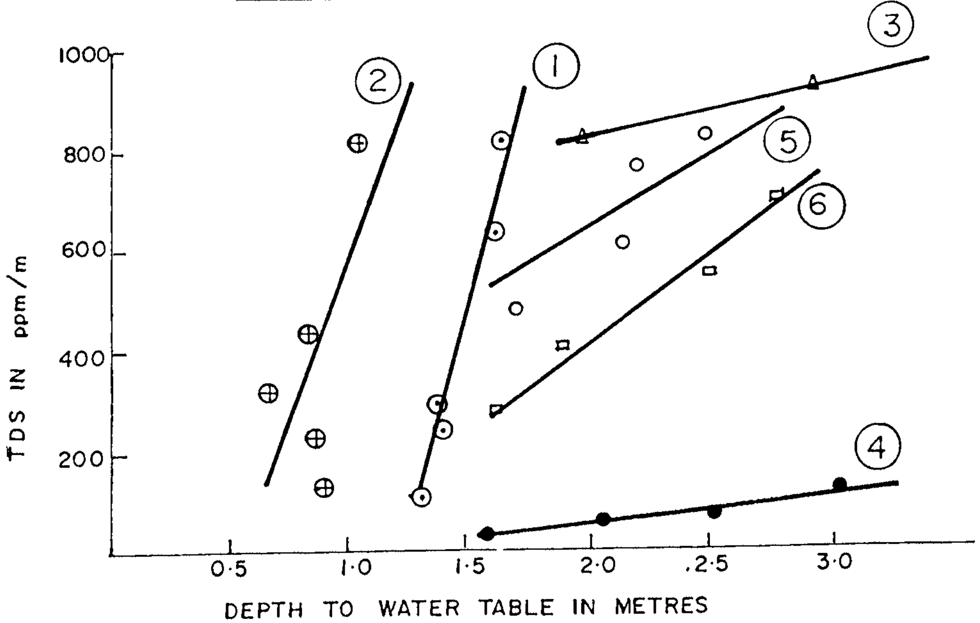


Fig. 9.8 VARIATION OF TDS WITH WATER TABLE ALONG KOZHIKODE COAST

SL NO:	SYMBOL	WELL NO:	DISTANCE FROM SHORE	QDI IN ppm/m
1	⊙	KK 52	60	800
2	⊕	KQ 7	70	475
3	Δ	KB 19	100	95
4	●	KK 26	200	75
5	○	KK 6	600	58
6	□	KB 2	1500	14

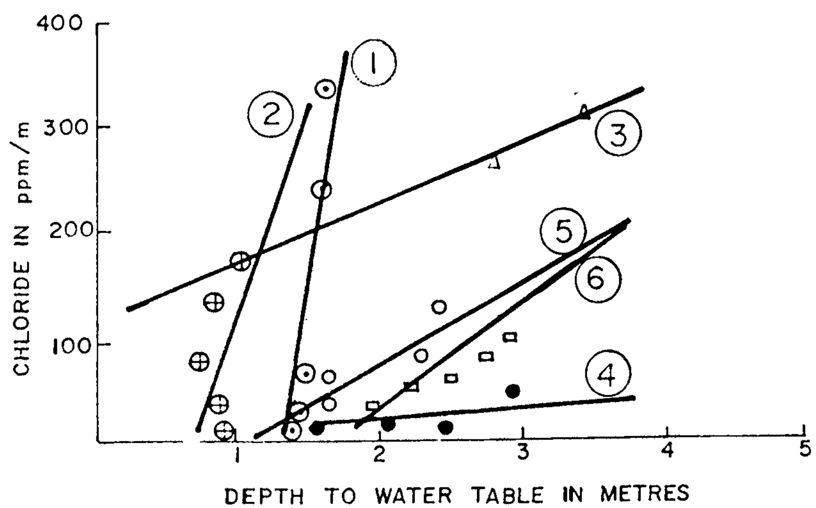


Fig. 9.9 VARIATION OF CHLORIDE WITH DEPTH TO WATER TABLE ALONG KOZHIKODE COAST

Table - 9.1 **Season-wise average values for TDS, chloride, and water levelS of wells along Kozhikode coast**

Sl.No.& Well No	Distance from Sea in m	Season	Average depth to water level in m.	Average TDS in ppm.	Average Chloride in ppm.
1		Pre-monsoon	2.72	114.18	2523.00
KB-02	2400	Monsoon	1.52	35.00	155.00
		Post-monsoon	2.37	76.90	9.00
2		Pre-monsoon	2.73	578.00	85.00
KB-19	80	Monsoon	1.67	332.00	58.00
		Post-monsoon	2.36	602.00	62.00
3		Pre-monsoon	0.88	651.00	150.00
KQ-07	70	Monsoon	0.83	287.00	50.00
		Post-monsoon	0.80	144.00	10.00
6		Pre-monsoon	3.44	966.00	167.00
KK-06	100	Monsoon	2.08	1273.00	571.00
		Post-monsoon	2.80	986.00	160.00
7		Pre-monsoon	0.95	1033.00	188.00
KK-25	200	Monsoon	0.23	455.00	50.00
		Post-monsoon	0.80	702.00	35.00
10		Pre-monsoon	1.56	759.00	282.00
KK-52	70	Monsoon	1.33	198.00	43.00
		Post-monsoon	1.28	317.00	26.00

Earlier (Fig. 9.8 and 9.9) it was seen that salinity parameters (TDS and Cl_2) in the coastal aquifers vary linearly with the depth-to-water table. As expected, lowering of freshwater table is associated with the deterioration of quality. Experimental areas show that the QDI variation is between 2000.

and 60 ppm/m for TDS and between 800 and 15 ppm/m for Cl_2. Nearer the well to the coast higher the value of QDI. At larger distance from the shore, it is seen that QDI is insensitive to the change in depth- to-water level. This is in conformity with the basic concepts mentioned earlier.

The plots of QDI vs well distance (from the shoreline) indicate an exponential decrease. Based on this analysis, coastal aquifers may be divided into two zones:

(a) Sensitive zone : zone adjacent to shore which is extremely sensitive to the fluctuation of water table. Even a slight variation in depth-to-water table will cause a marked change in the ground water salinity in this zone (Fig. 9.10).

(b) Insensitive zone : Depth-to-water table variation in this zone has only marginal effect on water quality parameters.

The suggested model would be of help to the well users to find out the maximum quantity of water, he can withdraw without adversely affecting the quality of this water as well as it will also be of direct help in forecasting the likely level of

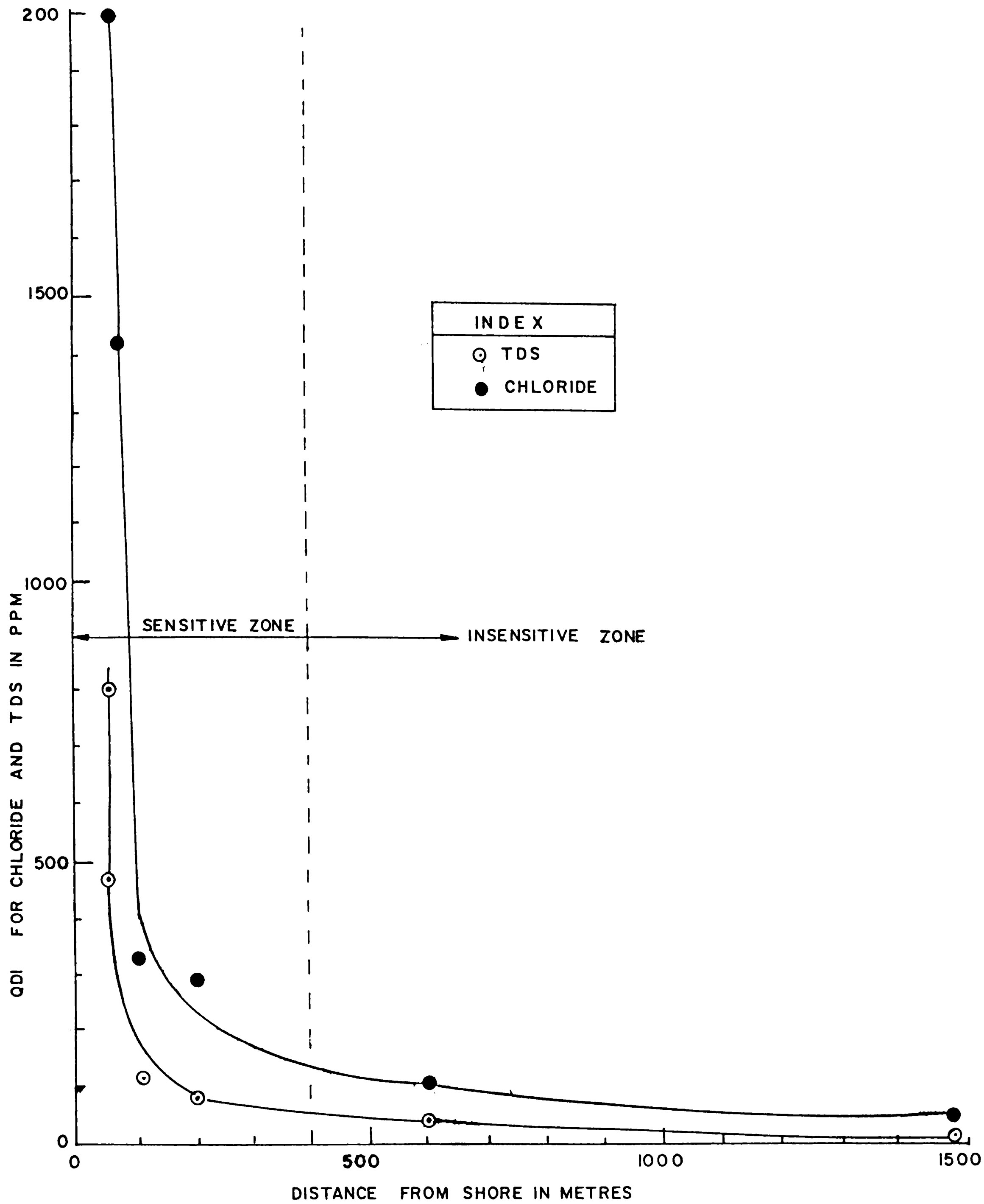


Fig.9.10 VARIATION OF QDI ACROSS THE COASTAL AQUIFER OF KOZHIKODE COAST

salinity intrusion into the coastal aquifers and device possible remedial measures for the same.

9.3.4 Indiscriminate drilling and associated problems.

After the drought of 1983, there is a tremendous increase in borewell drilling by private agencies in Kozhikode. These activities are mostly concentrated along the coastal stretches of Kozhikode and the adjoining lateritic areas. Most of the private agencies drill borewells in the coast and leave the same without sealing off the saline zones. As a result, there is contamination due to sea water intrusion from the bottom aquifer to the top aquifer.

The location of borewells in and around Kozhikode is given in Fig. 5.1 (ref. Ch.5). Among the studied borehole logs, few borewells tapped in the fractured zones are found saline. The depth horizons of these saline fractured zones encountered in the borewell sites are given below.

Location	Fractured zones in m below ground level
(i) Elathur	70 - 73
(ii) Arayadathu Bridge	15 - 21
(Baby hospital)	22 - 30
(iii) Puthiyara water tank	99 - 105
(iv) Pachakil Palam	38 - 75

The salinity in these fractured zones may be due to the following reasons:

(a) Canoli canal passes through these areas in the above mentioned borewell sites and is ending in a small lagoon near Elathur. During summer the tidal water comes from the lagoon through the canal and spreads to the Paddy fields. This saline water trapped in the clay and soil may be percolating down and causing the salinity in these fractures;

(b) These fractured aquifers tapped from the borewells may be extending towards the sea which may be another cause of salinity in the deeper fractured aquifers in the study area.

Similar saline problems are found at Vadakara, Thiruvangur Beypore, Kozhikode beach, etc. Groundwater contamination can be sealed off by putting concrete blocks inside the bore and gradually the hole can be plugged with cement, thus reducing/ arresting the salinity permanently.

Identification of sensitive zone is extremely important, because much care has to be taken to maintain minimum possible depth for groundwater table. This can be achieved by a combination of restricted groundwater withdrawal and appropriate recharging in this zone, which will be dealt in detail in the next chapter.

9.4 Sea Level Rise due to Greenhouse Effect and the Coastal Groundwater System.

9.4.1 Sea level rise due to greenhouse effect.

Sea level changes can be broadly divided into eustatic and isostatic. A variety of processes can bring in changes in Sea level. During the last few million years the more obvious and rapid cause of eustatic change has been the glaciation.

Sea level was close to the present between about 35,000 to 25,000 years ago. It then began to recede as the last full glacial episode began. The maximum drop in sea level was during Wisconsin glaciation. The drop was estimated to be in the order of 75 to 130 m about 18,000 years before present.

Holocene transgression is represented by an extremely rapid rise about 8mm/year. During the deglaciation period from 10,000 to 7,000 years ago, sea level rose at the rate of 10 mm/year. Since the Holocene transgression, which lasted up to 7000 years ago, the sea level continued to rise at the rate of 1 to 2 mm/year.

Long term tide guage records demonstrate that the global rise in sea level is continuing (Hicks, 1978; Wyrtki, 1990). Published values for global sea level rise for the last 50-100 years vary from about 1 to 3 mm/year (Douglas, 1991).

The increased emission of `greenhouse gases' during the last century has brought in dramatic changes in the global climate. It is now expected that the global warming will be of the order of 1.5 ^{o}C to 4.5 ^{o}C during the next century (IPCC, 1990)

An accelerated rise in global sea level is generally considered to be the most important impact of global climate change in coastal areas. One of the widely accepted estimates

(IPCC, 1990) of rise in global sea level is 31 to 110 cm by the year 2100, for the low and high scenarios respectively (Fig. 9.11). This is mainly due to thermal expansion of the oceans and melting of glaciers. Such a rate of rise would be 3 to 10 times faster than the current rate.

As a result of present population growth and development, coastal areas are under tremendous pressure. Consequently populated coastal areas are becoming more and more vulnerable to sea level rise and other impacts of climate change. A rise in sea level could increase shoreline erosion, accelerate coastal flooding, inundate coastal wetlands, and other lowlands, increase the salinity of estuaries and aquifers, alter tidal ranges in rivers and bays, etc. Sea level rise could also increase the severity of storm related flooding and consequent salinity intrusion.

It is difficult to predict the effect of sea level rise on the groundwater resources of coast because of uncertainity on three issues:

(a) It is not conclusively estimated at what rate the sea level will rise at a regional level (say, at Kozhikode),

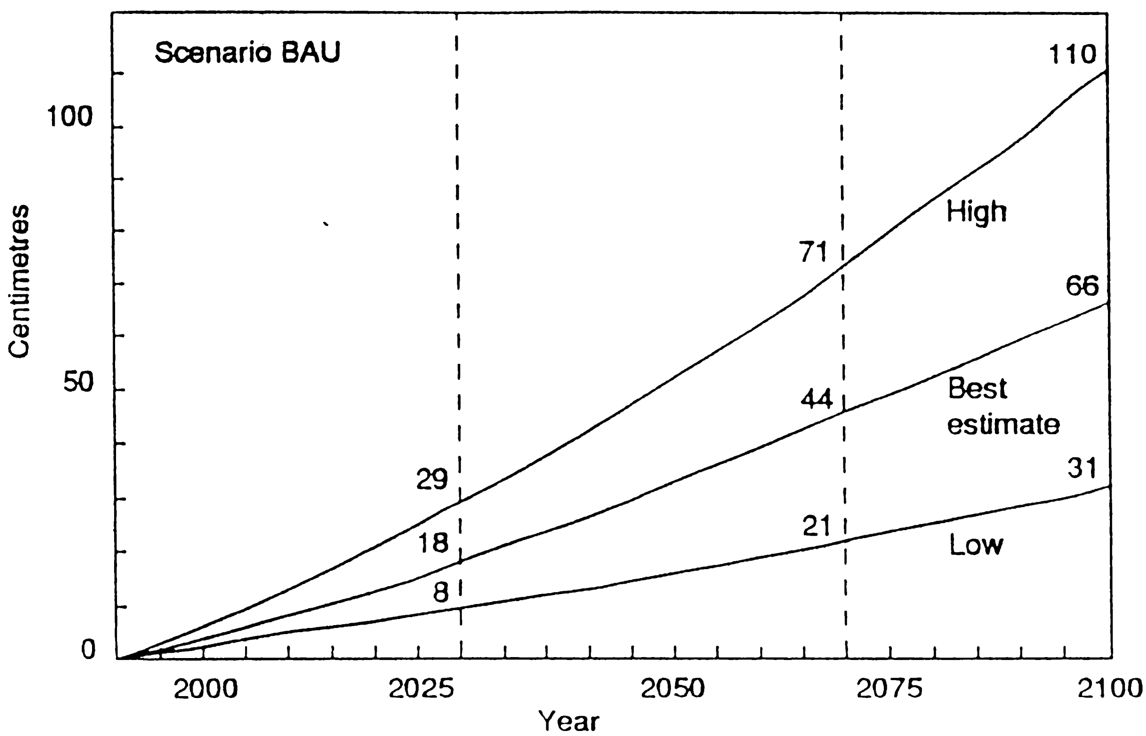


Fig.9.11 Global sea level rise, 1990-2100, for Policy Scenario Business-as-Usual (no limitation of greenhouse gases) (IPCC, 1990).

(b) It is still unclear how freshwater lenses behave especially in terms of patterns of flow and

(c) Thirdly, it is unclear what the response of coast will be to sea level rise (Komar etal, 1991).

9.4.2. Saline intrusion in coastal aquifer due to sea level rise

Saline intrusion in coastal stretches of Kozhikode have been described in Section 9.3. Here the same problem is examined in the light of the predicted sea level rise.

If we assume a rise in sea level at the above mentioned rate, let us examine what are its likely effects in various stretches of Kozhikode coast.

(a) Aliyur - Kottakkal stretch

The bed rock topography along the coastal strip is highly undulated. The configuration of the aquifer follows the bed rock topography with crests and troughs as in a wave. Wells located on the crests of the undulations in which the aquifer taps will not be affected. Wells situated on the sloping side (trough side) already have salinity problems, during summer. This is because of considerable decrease in flow in the river during this period there is salinity intrusion from the high tide waters. This tidal water trapped in the aquifer might have been causing salinity during summer. In future with the sea level rise the tidal impact may encroach into the upper reaches of the Mahi river. This may affect the higher reaches of the aquifer. But as it is observed now this saline water may be washed off during monsoon.

(b) Kottakkal - Kollam stretch

The most important feature of this coastal strip is the presence of rocky hills at Iringal which is a barrier between the lagoon and the sea. The other notable feature is the abutment of laterite hills along the coast. Because of the raised topography of the rock, the wells of this stretch are not saline and in future also there won't be any threat of salinity due to sea level rise in this area.

(c) Kollam - Korapuzha and Korapuzha - Kallayi stretches

In these coastal stretches there are areas prone to saline intrusion. They are found at Elathur and at low lying areas adjacent to Korapuzha. Elathur is connected by a canal called Canoli canal which is connected to Kallayi river.

During high tide seawater is pushed into Canoli canal and the saline water entrapped in the clay cause salinity in the study area. Bore hole data reveals that deeper fractured hard aquifer is also saline. Sea level rise can furthur increase the salinity and hence drilling bore wells should be banned in this stretch.

(d) Kallayi - Kadalundikadavu stretch

In this coastal stretch three main rivers are influencing the ground water system. They are Kallayi, Chaliyar and Kadalundi. All these rivers are influenced by tides. James (1983) indicates that salinity intrusion in the rivers of Kozhikode is limited to about 1 km in monsoon, whereas in summer it propogates upto 15 to 28 km upstream. In the Beypure estuary of Chaliyar a salinity of 5,500 ppm was reported 28 km upstream (Nataraj, 1983). Saline intrusions in coastal aquifers are observed generally in the river bank pockets and along the man made canals connecting these rivers. Sea level rise can induce more salinity in these pockets.

9.5 Summary and Conclusions

Sea water intrusion studies along the coastal belt of Kozhikode region shows the qualitative response of change of depth-to-water table to the change of water quality parameters (TDS and chloride) in the coastal unconfined aquifer. Pattern of variation of quality parameters with depth-to-water level is similar to other coastal aquifers. An exponential decrease of QDI (Quality Depth Index) with well distance (from the sea shore) is observed. The coastal aquifers of Kozhikode can be divided into sensitive and insensitive. The QDI variation is between 2000 and 60 ppm/m for TDS and in 800 ppm/m and 15 ppm/m for chloride. Nearer the well to the coast, higher is the value of QDI. At greater distances from the shore, it is found that QDI is insensitive to the change in depth-to-water level. This is in conformity with the basic concepts mentioned earlier.

The estimated width of sensitive zone in Kozhikode coast extends upto 400 metres from the shore. This zone should be avoided while drilling any deep tube wells or bore wells along the coast. Identification of sensitive zone is extremely important, because much care has to be taken to maintain minimum possible depth for groundwater table. This can be achieved by combination of restricted groundwater withdrawal and appropriate recharging in this zone. The predicted sea level rise can cause saline intrusion in Aliyur-Kottakkal and Kollam Kallayi stretches. Kottakkal-Kollam stretch will not be affected by sea level rise problems.

CHAPTER 10

GROUNDWATER MANAGEMENT

10.1 Introduction

Increasing population density and everchanging coastal environment calls for an integrated coastal zone managemment programme, where the groundwater is a major component. Groundwater management envisages the (i) evaluation needs for preservation of groundwater along the coast, (ii) examination of the techniques in vogue to satisfy the needs, (iii) formulation and implementation of plans and (iv) monitoring of the system regularly.

10.2 Problems of Groundwater Management of Kozhikode Coast

10.2.1 Natural problems

The natural problems of groundwater management are related to coastal erosion, wave-tidal influx and sea level rise.

Coastal erosion causes erosion of the sandy aquifer. In this process the aquifer gets exposed to seawater. In Kozhikode in the southernmost stretch between Kadalundikadavu and Chaliyam the coastal erosion is more and it is less towards Naduvattom. Erosion is also observed at the inlets of Beypore, Korapuzha, and Moratpuzha. This also leads to salinity intrusion into coastal aquifer.

High storm waves and spring tides can inundate the coastal areas, as observed at Naduvattom. Groundwater system in this area can be protected from salinity intrusion, utilising suitable engineering structures.

Sea level rise can accelerate the above processes and cause salinity problems to the coastal and crystalline aquifers along the coast. Sea level rise and the likely effects on the groundwater system in various zones of Kozhikode coast has already been explained in Ch. 9.

10.2.2. Man-made problems

The different man-made groundwater management problems along Kozhikode coast are due to coir retting, lime and timber industries, fishing industry,seawater intrusion, modern agricultural practices, indiscriminate drilling and associated activities, over pumping, mining, etc.

In Kozhikode coast as compared to other parts of Kerala coast, the overlying formation over the basement rocks is found in limited thickness.The thickness varies from 20 to 35m from north to south.The quarrying of rock and removal of sand are common in parts of Iringal and Payyoli areas. The loss of sand material may result in decrease of storage of water in the aquifer and may attract saline intrusion problems. For managing the groundwater system, such mining activities of the coast may have to be curtailed.

Constraints for exploration is another problem of groundwater management in the coastal stretches of Kozhikode.(Jacob, 1991a) Surface geophysical studies are confronted with the limitations caused by high density of population and cultivation which restricts the spreading of the cable, blasting, etc. The power cable (overhead / underground) hinders the electrical measurements.

Pumping test results of borewells along Kozhikode coast indicate that the top and bottom aquifers are interconnected. Large scale pumping in these borewells may lead to drying up of dugwells in the top aquifer. Such cases are reported in Malaparamba colony of Kozhikode (Basak, etal., 1988). Pumping test results of borewells at Vadakara and Puthiyappa also show unconfined conditions. Heavy pumping in these wells may lead to the same problems as discussed earlier. Basak, etal (1988) suggested that drying up of these wells can be minimised by reducing the pumping rate to four to eight hours in a day during summer months.

10.3 Management of Groundwater Availlability and Utilisation

Human wellbeing is the primary motivation for water resources development and management. The total groundwater availability of Kozhikode is of the order of 27 MCM (see Ch. 6 and 7). This means that at present with a consumption of 8.48 MCM only 31% of the groundwater is being used through about 23,578 open wells scatttered along the coast.

Growth pattern of wells indicate that there is a continuous growth in the number of wells at an average rate of 125 wells per year since 1980. If the same rate of growth of wells continue there will be 26,000 wells in the year 2000. If the growth rate of bore wells and shallow tube wells continue to increase at the rate of 30 wells per year the estimated draft for all types of wells in Kozhikode coast is estimated at 11.31 MCM per year. Fig. 10.1 presents the extrapolated groundwater draft of Kozhikode coast in 2058 A.D. It is seen from the projection that the entire coastal groundwater will be used up in 2058 A.D. This is a pointer to the need for regulated use of groundwater.

As already mentioned in Ch. 6 the Kozhikode coast has been divided into 6 groundwater fluctuation zones. The utilisation trend indicates that consumption of groundwater is found more towards the shore and less towards the inland. The utilistion varies from 75% to 19% from the shore to the inland area. It is therefore suggested that any groundwater development in future along the coast may be thought of by taking care of the above zones.

Fig. 10.2 presents the groundwater developmental plans for the entire coast. These suggestions on the development plan is based on all the inferenes derived from Ch. 3 to 9. Based on this Kozhikode coast is divided into six type areas for the groundwater development through wells:

(a) Preservation zone: This zone lies between the shore and 500m inland. Any development in this area may be regulated.

(b) Areas suitable for filter point wells/ shallow tubewells:

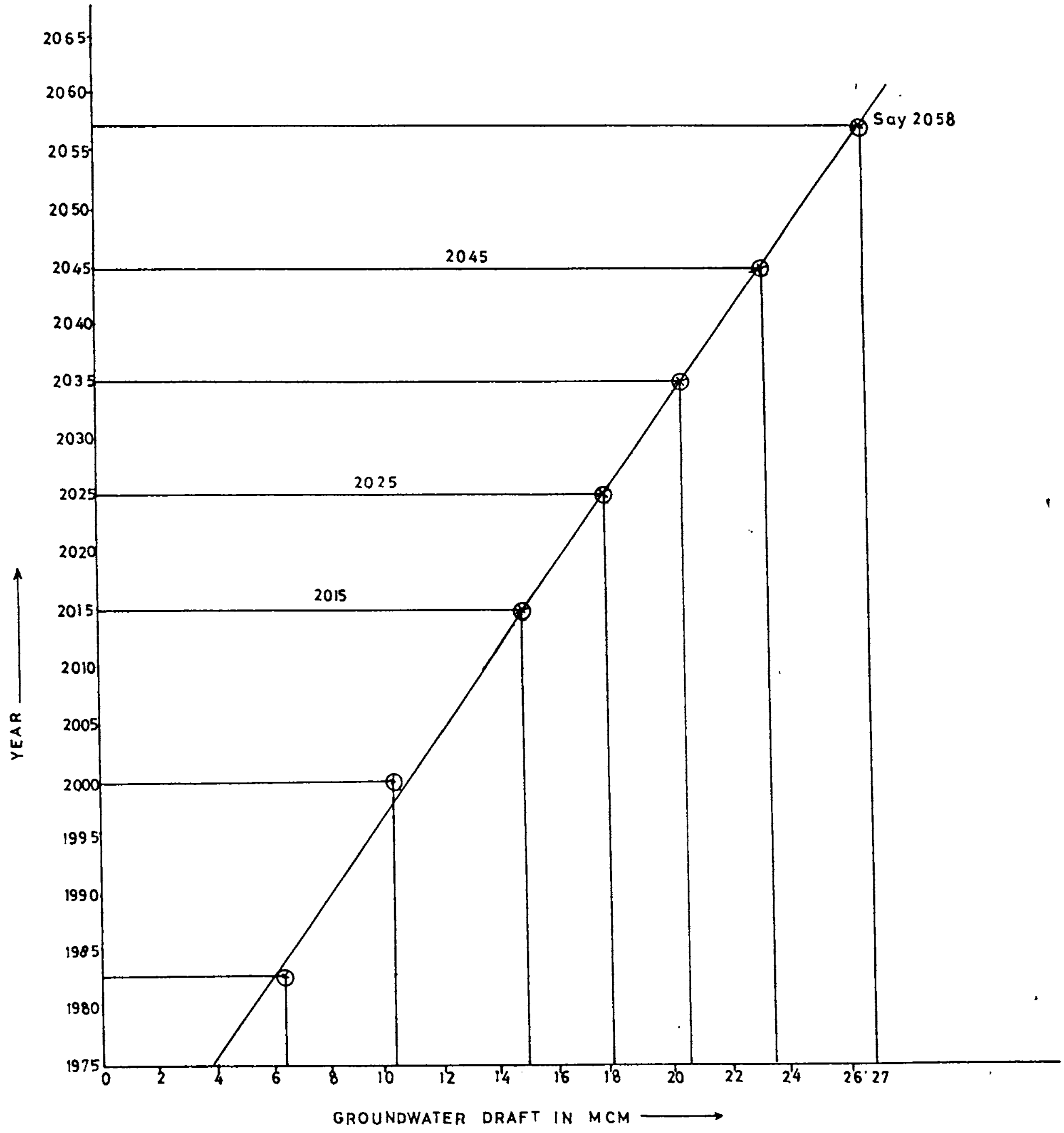


FIG.10.1 ESTIMATED GROUNDWATER DRAFT IN KOZHIKODE COAST

Fig 10.2 shows the areas suitable for shallow tubewells/filter point wells. The depth of the wells in this area is 10 to 20m.

(c) Areas suitable for medium to small diameter ordinary wells: The diameter of these type of wells can be 0.75m to 1.50m and the depth of well will be of the order of 3 to 6.00m.

(d) Areas suitable for medium to large diameter wells: Alluvial, laterite, alluvial-laterite formations are falling under this catagory. Large diameter wells of 2 to 4m can be dug in this area. The depth of the wells range from 6 to 12m depending on the overburden thickness.

(e) Areas suitable for borewells: There are valley areas in the sand-laterite border. These valley-fill areas are found suitable for drilling bore wells based on geophysical surveys. This may be based on geophysical surveys.

(f) Areas unsuitable for development: Unsuitable areas for groundwater development are given in Fig. 10.2. These areas have to be abandoned due to poor quality of water.

10.4 Suggestions for Management of Groundwater along Kozhikode Coast

In a thickly populated region, the problems affecting the

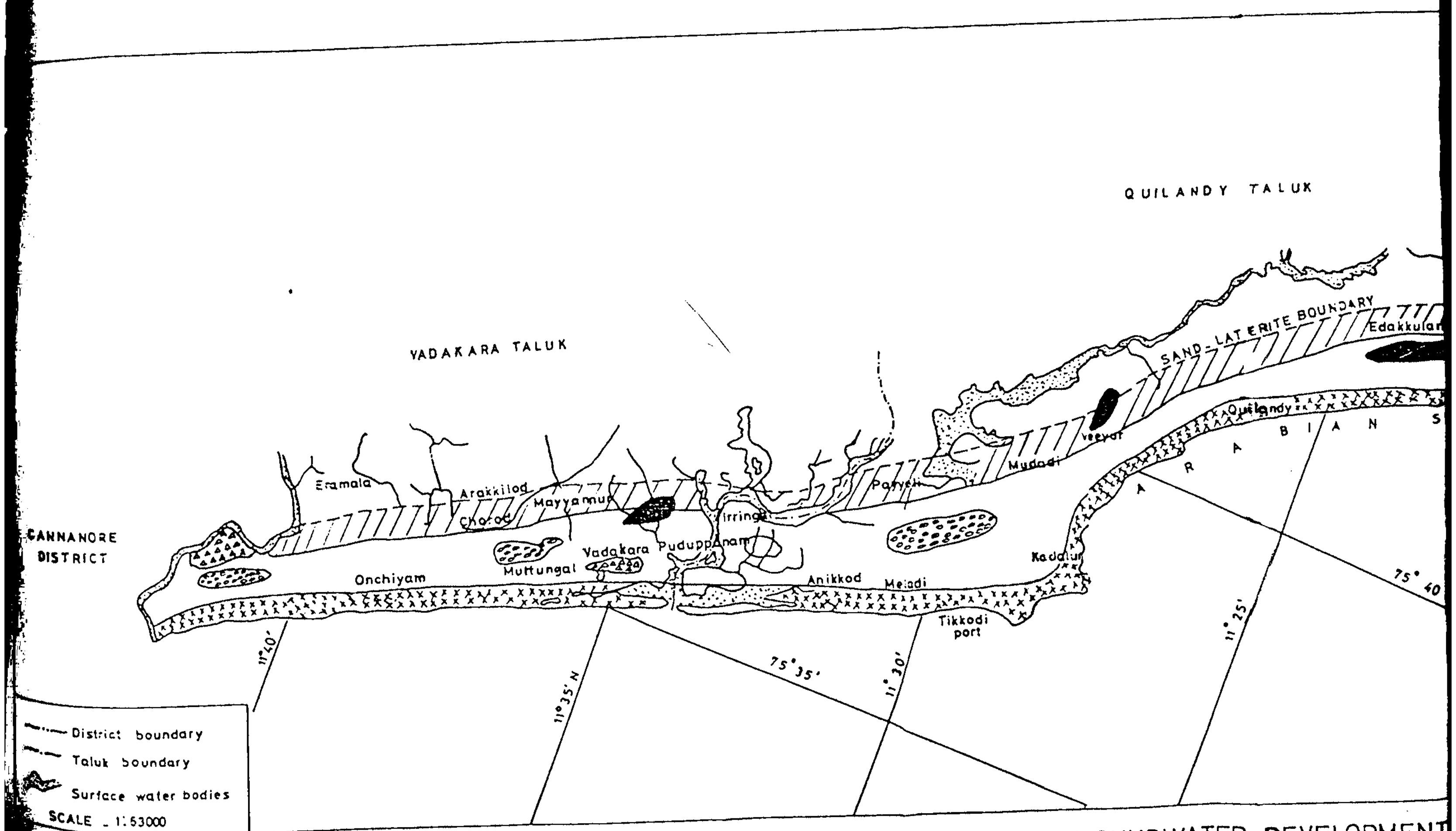
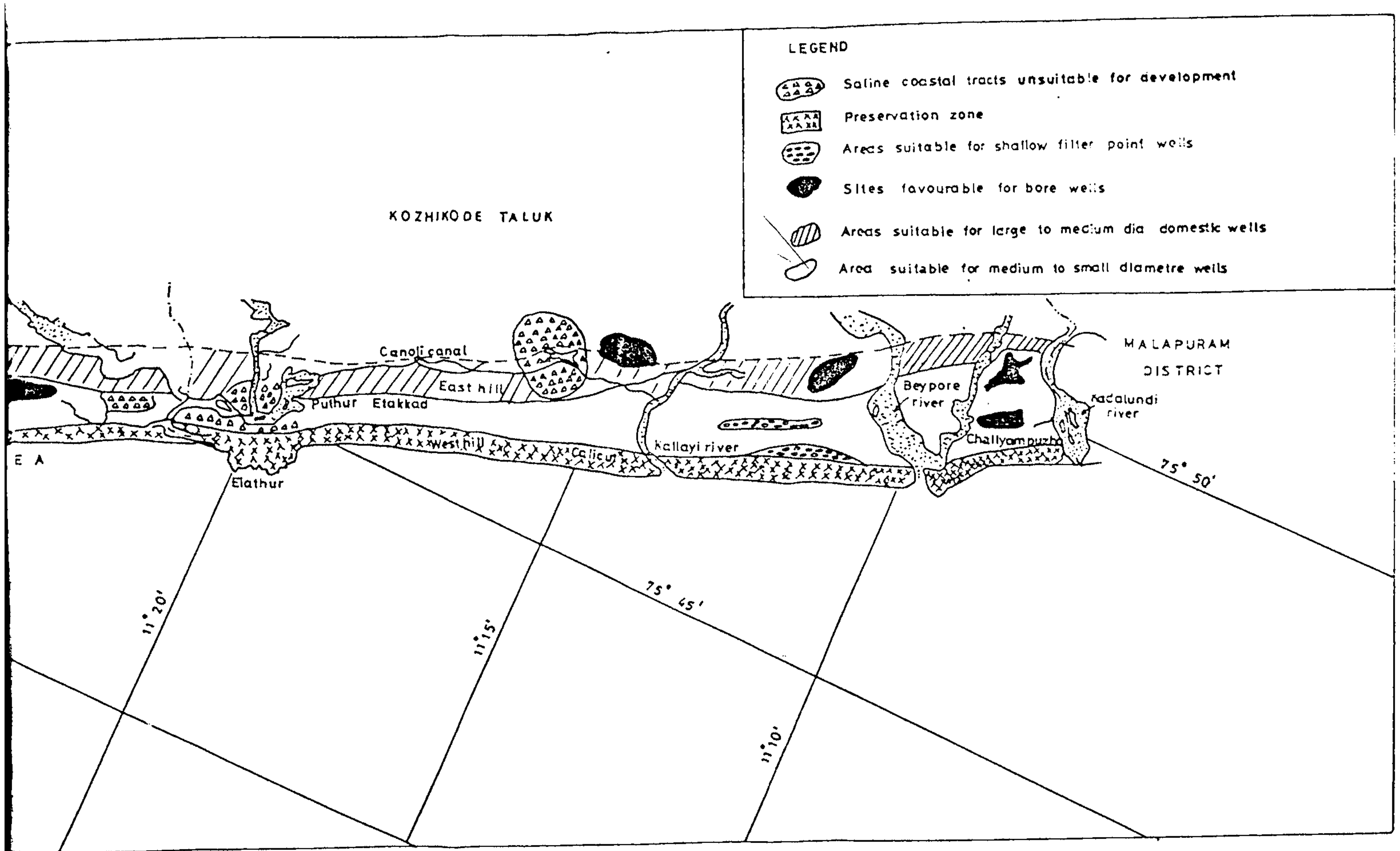


FIG.NO.10.2AREAS SUGGESTED FOR GROUNDWATER DEVELOPMENT



ALONG KOZHIKODE COAST

groundwater, if allowed to go unchecked, they can be detrimental to the future generations. In this context few suggestions for groundwater management are proposed.

Coastal groundwater can be managed in different ways. During monsoon season large quantities of water goes to the sea as run off. The run off water can be stored and the run off reduced by constructing check dams/weirs across the rivers like Chaliyar, Kuttiyadi and Moratupuzha. To intensify the groundwater development through wells first priority area is between the laterite and alluvial formation. The development wells in these zones may be thought for future use. Feasibility of small sub-surface dams in small valleys between the laterite hills may be examined in detail for preserving water in the sand-laterite border.

People may be allowed to dig shallow open wells along the coast. They may be allowed to withdraw water only manually. The withdrawal of water through energised pumps in coastal wells may be restricted and if possible prohibited. Excess withdrawal of water in these wells can be controlled in this way. Sufficient spacing between wells will also help in controlling the excess withdrawal.

There is considerable growth of shallow tubewells with depths ranging from 25 to 35m between Kallayi and West Hill area. Such wells are concentrated near the shore at Poilakada marine fisheries in West Hill area. The pumping of shallow tube wells may be regulated to four hours in a day. The present drawdown beyond 10m may invite salinity intrusion and hence drilling of shallow tubewells are to be controlled in this area.

The excess pressure on coastal groundwater in Kozhikode may be reduced by the use of surface water resources wherever possible under an integrated water resources management programme. Misuse of water and wastage of water are to be controlled effectively for the preservation of water in the coastal regions of Kozhikode.

There are few unlined canal systems running from the inland area to the shore (eg. canal passing through St.Michael School near the beach side and the Canoli canal passing through the area between Kallayi and Elathur). These canals may be lined and the silt in the canal may be frequently removed, which will improve the groundwater quality of wells adjacent to the canals.

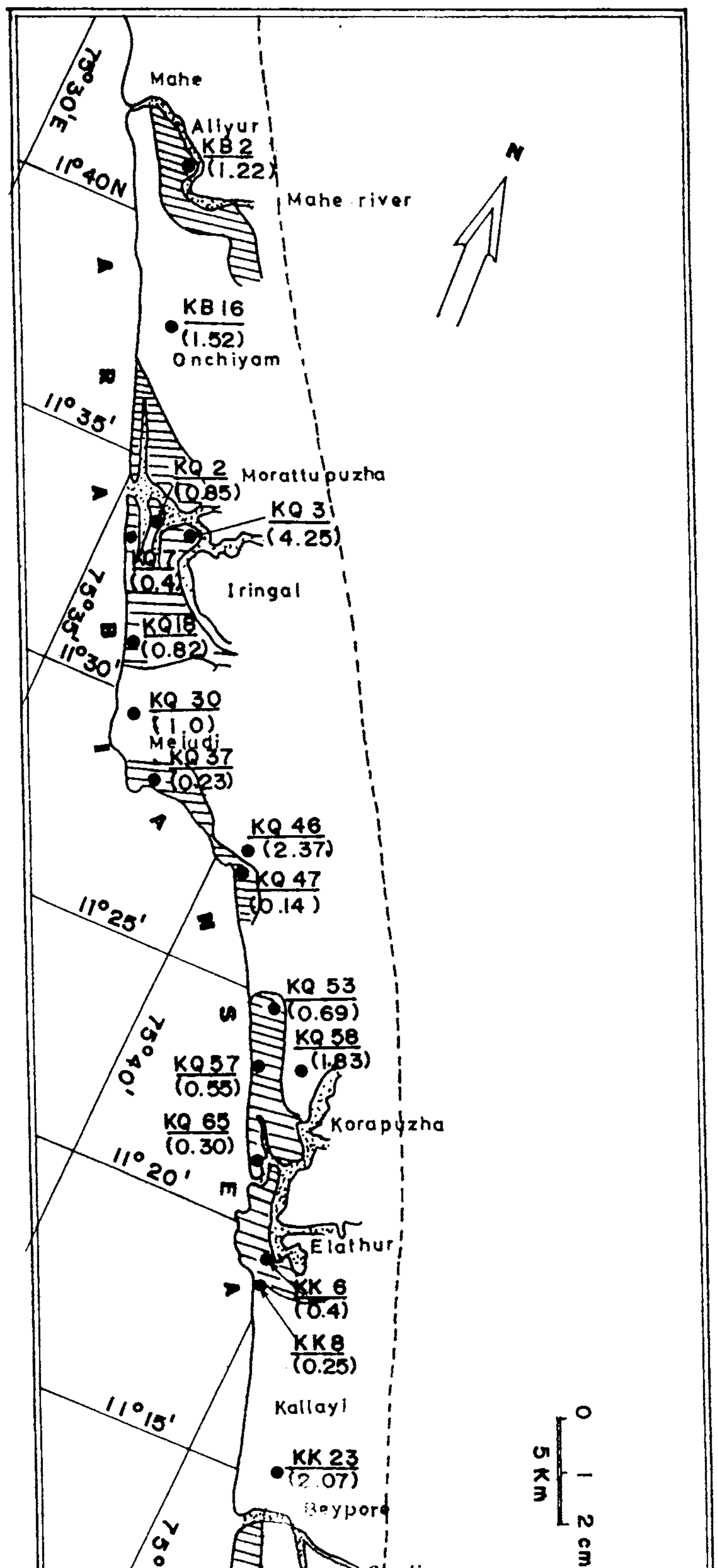
For the protection of groundwater resources avoid setting up of new industries, dumping of ash or any wastes for the purpose of land filling and dumping of city waste or any other type of waste along the coastal areas of Kozhikode as envisaged in the Govt. of India Notification for regulating the coastal zone, (Dept. of Environment, 1991).

Among the problems of groundwater management of Kozhikode coast, pollution plays an important role (see Ch. 8). To tide over this it is suggested that the polluted water may be subjected to filtration using activated carbon and the filtered water may be subjected to ozone treatment to get rid of the bacteria (Jacob, 1991[b]). Restrictions may be imposed on coir retting.

For managing the quality of groundwater system along the coast there is a need to set up and strengthen the environmental, geological and hydrogeological monitoring network .This will help to draw up the environmental quality standards for groundwater and make periodical trend forecast so as to prevent contamination of groundwater.

In the long range plans for shore stabilisation, besides structural protection, non-structural methods like creation of artificial beaches have to be examined. Loss of sand, and mining of rock may attract salinity problems. Withdrawal of sand, rocks and other strata materials may be banned along the coastal stretches of Kozhikode from the shore to 500 m towards inland. Crystalline aquifer tapped from the borewell at Elathur, Pachakilpalam, Arayadathu Bridge and Kottamparamba hospital of Kozhikode city indicate the saline water below the basement rocks. Some of the wells are still used for cleaning and other domestic purposes. These saline borewells may be closed permenently by putting small concrete cement blocks inside the bore well and by cementing. Thus the salinity of water from the bottom aquifer below the basement rocks can be controlled. The groundwater tapping from borewells within the coastal regulation zone has already been prohibited by Govt. of India (Dept. of Environment, 1991).

Areas likely to be inundated due to rise in sea level in Kozhikode coastal belts are shown in Fig. 10.3. For this GTS maps are referred. Based on these reduced levels of wells are arrived at and the areas likely to be inundated are demarcated. These areas may be declared as prohibited areas for any developmental activity including groundwater exploitation in Kozhikode. Any drinking water supply scheme located adjacent to the above



LEGEND

- - - - - SAND LATERITE BOUNDARY

● OBSERVATION WELLS [Along with well number the elevation is given in brackets]

▤ AREA THREATENED TO INUNDATION DUE TO SEA-LEVEL RISE

FIG.10.3 COASTAL AREAS THREATENED TO INUNDATION DUE TO SEA LEVEL RISE mentioned areas may be shifted from this point of view.

Public awareness is also another tool for managing the groundwater system in the coastal areas. The common man seems to be ignorant or indifferent to the problems of the coast and its groundwater resources. There is a need to create awareness among common people about the use / abuse of water, water pollution and the other health hazards.

CHAPTER 11

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary of the work carried out along with the conclusions drawn is presented in this Chapter. On the basis of the observations made in the different Chapters recommendations for the management of the groundwater resources and further studies are given.

11.1 Summary and Conclusions

The Kozhikode coast is 72.5 km long and it extends from Kadalundikadavu in south and Aliyur in the north near Mahi river covering an area of 91 sq.km. The coastal area is thickly populated and also have a humid tropical climate with an average rain fall of 3000 mm. Kuttiyadi, Kallayi, Chaliyar and Kadalundi are the major rivers draining the coastal belt. The coast has a large backwater body and is formed by the confluence of Agalapuzha with Panurpuzha and it meets the sea at Elathur.

The coastal alluvial soil is distributed all along the coast. The riverine alluvium composed of moderately well-drained soil is distributed mainly on the banks of rivers and their tributories. The various geomorphic units identified from the coastal area of Kozhikode include beach, sandbars, shore platforms, lateritic hills and valleys. Two major types of shorelines are identified in Kozhikode coast, namely cliffed and neutral.

The Kozhikode coast is mainly underlain by hardrocks of Archaean age forming part of peninsular shield. Archean rocks include charnockites and gneisses. Laterite is also found in Kozhikode region. Based on the lithological units present the coast can be grouped into coastal sandy formation, coastal alluvial formation, coastal alluvial-laterite formation and laterite formation underlain by crystalline rocks.

The sub-surface geology of the coast has been studied using bore hole data. The coastal stretches of Kozhikode comprises of four types of aquifer zones namely sandy, lateritic, weathered rock, and fractured rock. The bed rock depth of the coast varies from 20 to 35 m. The bed rock encountered in all the bore holes are quartz-feldspathic and granitic gneisses. The thickness of various aquifers tapped from the bore holes are given in Ch. 3. Analysis of bore holes show that there are three types of fractured aquifers along and across the coast. They are (a) weathered rock aquifer above the basement rock (b) weathered and fractured aquifer and (c) fractured rock aquifer below the basement. They are low to moderately permeable, sub-horizontal to horizontal fractures between the massive gneissic rocks.

Hydrogeological observations are made in from 150 wells along the coast. Based on this information 36 permanent observation wells are identified for regular monitoring of water levels and water quality parameters for four years. Study shows that small diameter wells of 0.70 to 0.80 m are found in abundance in sandy formation. More than 1.00 m. diameter wells are found distributed towards coastal alluvium and laterite formation. The coastal open wells along Kozhikode coast can be grouped based on depth of penetration, cross-sectional area and formation are given in Ch. 4.

A close look at the depth-to-waterlevel data through the observation network all along the coasal belt of Kozhikode coast indicate that that there are 6 main groundwater fluctuation zones with mean annual fluctuation of 0.50, 0.75,1.00,1.50, 2.00 and 3.00m. Near the shore the groundwater is found shallow. Depth to water along the coast and across the coast vary from 0.21 to 4.5m below the groundlevel. Wells near the backwater bodies also show high water level. Coastal wells near the shore, but situated at high grounds of sand bar, show low ground water level. Naduvattom beach is one of the examples of such phenomena. Temporal variations of depth-to-water level is minimum along the shore, whereas they are maximum away from the shore. Perched water table conditions are noted in the coastal areas of east Kallayi, part of west Kallayi and KSRTC bus stand near Mavur road. The above mentioned places are marshy during rainy season and water logging is also common. In this area near the surface clay-bed separates the underlying sandy zone giving rise to perched water table conditions.

The analysis of the pumping test data of open wells show that the discharge of the wells vary from 15 lpm to 292 lpm. The rate of inflow of the well depends on the type of geological formation and the diameter of well. The recouperation rate is found to vary from 15 lpm to 20 lpm in coastal sandy formation, but it is found 3.5 lpm in alluvial formations. The inflow of laterite wells show 2 to 3 lpm indicating low recuperation rate. Hence laterite wells can be pumped once in a day. These wells take one full day for recovery. Other wells show that they can be pumped twice in a day. These wells take 2 to 7 hours to obtain full recovery. Depth of water columns in different wells in different seasons are mentioned. The estimated availability of water from wells of 1.5 diameter are given in Ch. 4.

The peizometric surface of the crystalline rock aquifer varies from 2.67m to 19.00m The discharge of the bore wells vary from 129m^3 to 731 m^3 per day. For evaluating aquifer parameters five pumping tests are carried out. The test results indicate that there are two types of hydraulic conditions. Test data analysed is fitting with Boulton curve as these aquifers are unconfined. The transmissivity of these aquifers range from 1.60 to 19.69 m^2/day. The permeability of the aquifer varies from 0.16 m/day to more than a 1.00 m/day. The fractured zones tapping the borewell at Namenkulam is of confined nature, as the field data is fitting the Theis type curve. The transmissivity of the well is found to be 6.70 m^3/day.

The recharge to coastal groundwater is evaluated by analysis of water level fluctuation in observation wells and by rainfall-recharge method. Thus the groundwater availability in the top unconfined aquifer along the entire Kozhikode coast comes out to be 27 MCM and an average utilisation is of the order of 31% through an estimated 23,478 open dug wells along the coast. The distribution of groundwater availability and utilisation in the above mentioned coastal stretches are presented in table 6.1.

Utilization is found to vary from 50% to 75% towards the coast from inland in that order.

For arriving at the groundwater utilisation and use pattern field surveys are conducted at two representative areas, ie Tiruvangur-Pookad and Meladi-Payyoli areas. In the estimated 23,478 wells, 97 to 98% are operated manually and only 2 to 3 % of wells are fitted with pumps. The result also shows that the wells are lined either by concrete ring or by laterite bricks. Most of the wells are found open and have no platform around. The average draft from domestic wells along Kozhikode is found to be 800 litres/day . Assuming a conservative draft of 800 litres/day per well estimation for the total draft for domestic needs comes to 18.8×10^{6} litres per day. The irrigation wells in the coastal zone seem to be negligible in number and hence draft from these wells can be neglected. The results of the investigation indicate that out of an estimated annual recharge of 27 billion litres, the annual groundwater draft is found to be only 6.4 billion litres which points towards a great untapped potential underneath. These figures agree with the results obtained with the groundwater fluctuation method.

Water quality problems due to coconut husk retting, industrial waste, to fishing and agriculture are discussed. The general groundwater quality of open well in Kozhikode coast are studied from a network of 36 open wells. The chemical parameters like pH, T.D.S., chloride, magnesium, calcium, Iron, total hardness and conductivity of water samples from open wells are determined.

Generally water quality of open wells along coast are found neutral in character during pre-monsoon season. The well water becomes alkaline in character in other seasons. Perched water table conditions of the wells located in coastal alluvial zone and adjacent coir retting zones may be the cause of low pH in well water. Results reveal that certain pockets in Kozhikode coastal stretches are found to contain hard water and are due to concentration of lime industries. Groundwater is found to contain excessive iron (greater than 1 ppm) at Beypore port, Edakulam Beach and in Kozhikode city near KSRTC bus stand.

The field investigation and chemical data on water samples from wells at Aliyur, Payyoli and Chaliyam indicate that groundwater remain unpotable throughout the year. This unpotability is due to the high pH, Iron and TDS. Barring the pockets mentioned above groundwater along the coast of Kozhikode is found to remain potable throughout the year.

Sea water intrusion studies along the coastal belt of Kozhikode region show the qualitative response of change of depth-to-water table to the change of water quality parameters (TDS and Chloride) in the coastal unconfined aquifer. Pattern of variation of quality parameters with depth-to-water table is similar to other coastal aquifers.

An exponential decrease of QDI (Quality Depth Index) with well distance (from the the shoreline) is observed. The coastal aquifers of Kozhikode can be divided into sensitive and insensitive.

The QDI variation is in between 2000 and 60 ppm/m for TDS and in between 800 and 15ppm/m for chloride. Nearer the well to the coast, higher is the value of QDI. At higher distances from the shore, it is found that QDI is insensitive to the change in depth.

The estimated width of sensitive zone in Kozhikode coast extends up to 400 m from the shore. This zone should be avoided while drilling any deep tube wells or bore wells along the coast.

Identification of sensitive zone is extremely important, because much care has to be taken to maintain minimum possible depth for groundwater table. This can be achieved by a combination of restricted groundwater withdrawal and appropriate recharging in this zone.

Groundwater must be managed efficiently and within the management there should be a programme of periodic monitoring of wells to determine whether groundwater resources are shrinking or becoming more saline.

Preservation of natural vegetation, preservation of beach ridge gradation, regulation of growth of wells and construction of barriers are the major suggestions put forth for reducing the seawater intrusion problems along the coast.

The extact depth of fractured zones giving saline zones are given in Section 9.3.4. Similar saline problems are also found at Vadakara, Thiruvangur, Beypore and Kozhikode beach. Saline groundwater can be sealed off putting concrete blocks inside the bore and gradually the hole can be plugged with cement thus arresting the salinity intrusion permanently. The salinity in these fractures may be due to interconnections of fractures towards the sea. The saline water trapped in the clay and soil layers may also be percolating down and causing the salinity in these fractures.

The salinity levels show the following variations in different stretches of the entire coast.

	Pre-Monsoon chloride in ppm.	Monsoon chloride in ppm.	Post monsoon chloride in ppm
a) Aliyur-Kottakkal stretch	100-5000	20-100	20-30
b) Kottakkal-Kollam stretch	50-150	20-150	10-30
c) Kollam-Korapuzha	50-100	10-30	10-30
c) Korapuzha-Kallayi	150-300	50-200	50-150
d) Kallayi-Kadalundikadavu	50-200	30-50	20-50

The sea level is estimated to be rising 3 mm per year due to the normal eustatic processes accelerated by Greenhouse effect. If we assume a rise in sea level at the above mentioned rate the parts of coastal stretches that will be affected along the Kozhikode coast are parts of Aliyur-Kottakkal stretch, Elathur and low lying areas adjacent to Korapuzha, low lying parts of Moratupuzha, Chaliyam and Kadalundikadavu.

The management of groundwater systems are studied on the basis of natural and man-made problems in Kozhikode coast. The problems due to natural phenomena include, coastal erosion, sea level rise and the damages due to tidal influx. The later problems of groundwater management in Kozhikode are due to man-made factors such as (i) mining and development (ii) coir retting (iii) lime and other industries (iv) fishing industries (v) agriculture (vi) seawater intrusion (vii) indiscriminate drilling and associated problems and (viii) overpumping of bore wells. Suggestions for better management of coastal groundwater system are made. Further studies to be taken up in the protection, management and rational use of groundwater along the coast of Kozhikode are given.

At the present rate of groundwater exploitation and well development a scarcity for groundwater resources is likely to be experienced along Kozhikode Coast by the year 2058. Based on the hydrogeological studies, type of extraction structures and the availability of water future development plan of groundwater resources for Kozhikode coast is drawn. Specific recommendations for managing the groundwater resources are brought out taking into account the conservation, quality and salinity aspects.

11.2 Recommendations for Further Research

Based on the above study the following recommendations are made on the scientific management of groundwater resources of coastal belt of Kozhikode.

The coastal belt needs an oriented development on the basis of aquifer types. Regulation of groundwater withdrawal as per sustained yield capacity to retain the chemical quality of formation water tapped by the structure is also required.

A detailed study is recommended in the sand-laterite boundary for assessing the feasibility of making subsurface dams to arrest the subsurface flow of water in small valleys and between the laterite hills.

Groundwater development and conservation practices like harvesting rain water, deepening tanks and ponds and constructing sumps for collecting water are to be planned in the sand-laterite border area.

Periodic monitoring of groundwater levels and chemical quality to safeguard the precious groundwater reservoir from salinity and other quality problems is required.

Investigate and study the dominant characteristics of physico-chemical properties of goundwater under the action of natural and artificial factors and their relationship with physiological reaction in human body and various diseases. For example the harmful substances such as phenol , ethane, mercury, chromium, arsenic, etc, having detected in water, the organic substances such as nitrate, pesticide and fertiliser, the radio active pollutants, and even the hardness of water which have brought serious harm to people's health in a number of industrial cities.

For managing the groundwater along coast an investigation on groundwater contamination caused by man's activity and it's prevention is an important component. For managing the groundwater system along the coast, there is a need to study the conditions of groundwater contamination, the source of pollution access of pollution, the intensity, distribution of pollution and also develop new techniques for relevant protection and treatments.

The groundwater quality is bound to affect the service life of machinery and concrete structures placed below the ground surface as part of foundation of bridges, buildings and the like.

It also would accelerate the corrosion of metallic pipes and tanks leading to leakage of fluids that are either transported or stored in these coastal areas. Contamination of aquifers of low lying coastal areas is a serious threat warranting research to identify suitable remedial measures.

Coastal aquifers face a very high probability of recharge by waters of high salinity by the entry of large volumes of sea water into the lagoons and wetlands, by way of washover of sea water to the backshore during storms, and by landward translation of sea water/ freshwater interface due to its deformations all resulting from the problem of sea level rise. Any new drinking water supply scheme proposed close to the seashore should be shifted to inland locations.

The new investments in the coastal zones for new buildings, bridges etc. should be planned taking into account the possible deterioration due to low groundwater quality resulting also due to sea level rise. Other appropriate measures are also to be adopted to face the challenges of sea level rise in the coastal areas.

Groundwater desalination plants are to be designed in the coastal areas for supply of drinking water to those areas under threat of saline intrusion. Other suggestions made in the Govt. of India notification (Department of Environment, 1991) may also be implemented for preservation of groundwater system in the coastal stretches of Kozhikode.

REFERENCES

REFERENCES

Ahmed, E. (1973). Coastal gemorphology of India, Orient Longmans, Bombay, 222 p.

Baba, M. (1986). Kerala's coastal zone - a management Proposal. Centre for Earth Science studies, Thiruvananthapuram. No. 47-1986, pp. 6-12.

Basak, P. and Nazimuddin, M. (1983). Groundwater in the coastal belt : Trivandrum District. GW/R - 67/83, Centre for Water Resources Development and Management, Kozhikode, 48 p.

Basak, P. and Vasudev, (1983) Saltwater intrusion in Typical coastal aquifers of Kerala. Workshop on Recent Advances in Groundwater Exploration and Management, NGRI, Hyderabad, 14 p.

Basak, P. (1992). Kerala's Water Resources Myths, Facts and Realities. Centre for Water Resources Development and Management Kozhikode, 8 p.

Basak, P., Narasimhaprasad, N.B. and Nazimuddin, M., (1988) Tubewell and dugwell interactions in Malaparamba, Proc. Seminar on Groundwater Development and Management, Water Technology Centre, Coimbatore pp. 61-65.

Boulton, N.S. (1963) Analysis of Data from Non equilibrium tests allowing for delayed yield from Storage, Pro. Inst. Civil Engineers (London) Vol. 26, pp. 66-93.

Braester, C. (1981). Report on Mathematical modelling of Noyil Groundwater basin, SIDA, Stockholm, 12 p.

Bindu Madhav, U. and Basak, p.(1982). Minor Irrigation and Management of Water resources. Proc of Workshop. on Development Planning and Technology transfer, Thiruvananthapuram, CSDT, 10 p.

Census of 1991, (1991) Final population totals, Directorate of census operations, Thiruvananthapuram, Kerala.

Centre for Water Resource Development and Management; (1983). Use of open with in the coastal belt of Kerala for small scale Irrigation. Interim report Centre for Water Resources Development and mangement. Kunnamangalam, (MBR), Kozhikode, Kerala, India.

Centre for water Resources Development and Management, Groundwater Division, (1983). Kozhikode Coast; well Use Statistics Research Report No. GW/BD - 32/83, Kozhikode, 48 p.

Department of Agriculture, (1978) Government of Kerala. Soils of Kerala, 20 p.

Department of Environment and Forests, Government of India (1991). Douglas, B.C., (1991). Global sea level rise. J. Geophys. Res., 96: pp. 6981-92.

Hicks, S.D., (1978) An average seapotential sea level series for the United States. J. Geophys. Res., Vol. 83 (C3): pp. 1377-1379.

Intergovernmental Panel on Climate Change (IPCC), (1990) Strategies for adaption sea level rise, Report of the coastal zone Management Subgroup, WMO & UNEP, 122p.

Jacob, C.E. (1940) On the Flow of water in Elastic Artesian aquifer, Trans. Am. Geophys. Union, 21,pp.574-586.

Jacob, C.E. (1944) Notes on determining Permeability by pumping tests under water table conditions, U.S. Geological Survey, Mimeo. Report.

Jacob, C.E. (1946) Drawdown test to determine effective radius of Artesian well. Proc. Am. Soc. Civil Engrs. Vol. 79, No. 5.

Jacob, V.C., (1991a) Groundwater Exploration needs, scopes, contraints etc. Proc. Seminar on Development and management of groundwater in Irrigation and other water sectors. Centre for Water Resources Development and Management, Thiruvananthapuram, pp. 3-7.

Jacob, V.C., (1991b) Groundwater Pollutions in Kerala. Proc. Seminar on Development and management of groundwater in Irrigation and other water sectors. Centre for Water Resources Development and Management, Thiruvanthapuram, pp. 383-387.

James, E.J. (1982). "Circulation Mixing and Pollution Distribution in Estuaries - A review". Journal of Institution of Engineers (India), Vol. 63, pp. 4-9.

James, E.J. (1983). "Exchange of fresh and salt water in the Beypore Estuary on the Malabar Coast". Journal of the Institution of Engineers (India) Vol. 64. pp. 81-87.

James, E.J. and Ramanathan., (1983). "Salinity distribution, Pollution dispersion and tidal flushing in the Beypore Estuary on the Malabar Coast". Journal of the Institution of Engineers (India), Vol. 63, pp. 59-63.

Kerala State Land Use Board (1989). Land Resources and Land Use in Kerala, 157 p.

Komar, P.D. Lanfredi, N., Baba, M., Dean, R.G., Dyer, K., Healy, T., 1 be, A.C., Terwindt., J.H.J and Thom, B.G (SCOR-WG-89). The response of beaches to sea level changes: a review of Predictive models, J. Coastal Research , (in press). Vol. 7(3), pp.895-921.

Krishnan, M.S. (1956). Geology of India and Burma. The Madras Law Journal Office, Madras, 555 p.

Kruseman G.P and Ridder N.A (1976) Analysis of evolution of Pumping test data, Bulletin 11, pp. 59-57.

Nataraj, A.G., (1983). Studies on Estuarine Dynamics with Special reference to Tidal Streams Intrusion in the west coast. M.E. Thesis. University of Mysore.

Nazimuddin, M. and Devapalan Nair, (1984) Hydrogeological environments in Kozhikode Corporation area through Remote Sensing. Centre for Water Resources Development and Management Kozhikode. GW/R-81/84, pp. 5-11.

Nair R.K., (1976). "Groundwater in Kerala" Special Publication No. 5 Geological Survey of India, pp. 123-125.

Nazimuddin, M. and Basak, P., (1983). Studies on the behaviour of Groundwater levels along Kozhikode coast. Research Report No. GW/R-82/83. Groundwater Division, Centre for Water Resources Development and Management, Kozhikode, Kerala, India, 20 p.

Nair K.K., (1987[a]). Geomorphological and Quarternary geological studies, along the coastal plain in parts of Cannanore and Kasaragod. Journal Geological Society of India, vol. 29, pp. 433 - 439.

Nair M.M., (1987[b]). Coastal Geomorphology of Kerala Vol. 29, No. 4. Geological Survey of India, pp. 450 - 458.

Pricket, T.A. (1965). Type - curve solution to Aquifer tests under Water-Table conditions. Groundwater Vol.3 No.3.

Rajagopalan, S.P. Nazimuddin, M. and Unnithan. (1981). "Specific capacity of open wells in Kozhikode Coast". Research report GW/R-09?81, Centre for Water Resources Development and Management, Kozhikode, Kerala, India, 14 p.

Rajagopalan, S.P., Balakrishnan, V. and Prabha Sanker, P.N. (1983). "Pumping tests and analysis data of open wells in the coastal tract of Kozhikode District, GW/R-56/83. Centre for Water Resources Development and Management Kozhikode, Kerala, 43 p.

Reghunath, H.M. (1982). "Groundwater" Wiley Eastern Ltd., Publications. pp 346.

Roy, P. and Connell, J. (1989). Greenhouse : Impact of Sea level rise on low coral islands in the South Pacific. Research Institute for Asia and the Pacific Occasional Paper 6, 55 p.

Theis,C.V. (1935). The Relation Between the Lowering of Piezometric Surface and the Rate and Duration of Discharge of a well using Groundwater storage. Transaction, American Geophysical Union, Vol. 16,pp.519-524.

Todd D.K., (1959). Groundwater Hydrology, John Wiley, New York and London, p. 185.

Walton, W.C. (1962). SElected Analytical methods for Well and Acqifer Evaluation. Illinois State Water Survey, Bulletin 49.

Walton, W.C. (1987). Groundwater Pumping Tests Design and Analysis, Lewis Publishers, pp. 40 - 75.

Wyrtki, K., 1990. Sea level rise: The facts and the future: Pacific Science, 44, pp. 1-16.

APPENDICES

Appendix - 1

LOCATION OF PERMANENT OBSERVATION WELLS ALONG KOZHIKODE COAST

SL.NO.	Well No.	Place	Latitude & Longitude
1	2	3	4
1.	KB 1	Pazhithala	11 41 26 75 32 21
2.	KB 2	Aliyur	11 41 33 75 33 38
3.	KB 12	Madapalli	11 38 46 75 33 36
4.	KB 16	Muttungal	11 37 30 75 34 51
5.	KB 19	Kuriyadi Beach	11 36 12 75 34 36
6.	KB 30	Purakkara	11 34 15 75 35 18
7.	KB 31	Puthupanam	11 34 12 75 36 15
8.	KQ 2	Kottakkal	11 33 24 75 35 54
9.	KQ 3	Iringal	11 33 21 75 36 36
10.	KQ 7	Kottakkal	11 32 51 75 35 42

1	2	3	4
11.	KQ 18	Meladi Beach	11 30 42 75 36 33
12.	KQ 20	Payyoli	11 30 00 75 37 45
13.	KQ 30	Tikkodi	11 29 09 75 37 27
14.	KQ 39	Purackal	11 28 09 75 38 57
15.	KQ 46	Kollam	11 27 24 75 41 00
16.	KQ 37	Kadulur Beach	11 28 57 75 38 18
17.	KQ 52	Edakulam Beach	11 25 06 75 42 27
18.	KQ 53	Edakulam	11 25 06 75 42 27
19.	KQ 47	Kollam Beach	11 27 00 75 40 45
20.	KQ 57	Pookad Beach	11 23 21 75 43 00
21.	KQ 58	Tiruvangur	11 23 18 75 43 00
22.	KQ 65	Kannankadavu	11 21 15 75 43 54
23.	KQ 66	Korapuzha	11 21 12 75 44 30

24.	KK 6	Puthiyanirathukadavu	11 19 30 75 44 05
25.	KK 8	Puthiappa	11 19 03 75 44 55
26.	KK 16	West Hill	11 16 36 75 45 54
27.	KK 23	Mavoor Road	11 15 09 75 47 15
28.	KK 26	East Kallayi(Kothi Road)	11 13 45 75 46 45
29.	KK 25	East Kallayi	11 14 18 75 47 36
30.	KK 31	Meenchantha	11 12 33 75 47 42
31.	KK 34	Naduvattom Beach	11 11 48 75 47 54
32.	KK 39	Beypore	11 10 15 75 48 24
33.	KK 41	Beypore	11 15 00 75 48 06
34.	KK 49	Kadalundi	11 08 21 75 49 51
35.	KK 42	Beypore Port (Chaliyam)	11 09 39 75 40 27
36.	KK 52	Kadalundi	11 07 27 75 49 30

Note :- KB Denotes the district Kozhikode, Taluk Vadakara

KQ Denotes the district Kozhikode, Taluk Quilandy

KK Denotes the district Kozhikode, Taluk Kozhikode

Appendix - 2

GROUNDWATER LEVELS ALONG ALIYUR - KOTTAKKAL COASTAL STRETCH

Location and Well Nos	1980 Water level in m b.g.l.		1980 Fluctuation in m (F)	1981 Water level in m b.g.l.		1981 Fluctuation in m (F)	1982 Water level in m b.g.l.		1982 Fluctuation in m (F)	1983 Water level in m b.g.l.		1983 Fluctuation in m (F)	Average fluctuation in m
	maximum	minimum		maxi mum	minimum		maxi mum	minimum		maxi mum	minimum		
Pozhithala KB 01	2.90	1.25	1.65	3.20	1.46	1.74	2.70	1.01	1.69	2.94	1.59	1.35	1.61
Aliyur KB 02	2.73	1.96	0.77	2.90	1.53	1.37	3.56	1.88	1.68	3.35	1.88	1.47	1.32
Madapalli KB 12	2.16	1.01	1.15	2.39	0.92	1.47	2.44	0.77	1.67	2.50	1.24	1.26	1.39
Muttungal KB 16	2.33	0.57	1.76	2.12	0.62	1.50	2.43	0.42	2.01	2.77	0.82	1.95	1.81
Kuriyadi Beach KB 19	2.67	1.82	0.85	2.79	1.58	1.21	2.75	1.63	1.12	2.90	1.93	0.97	1.04
Purakkara KB 19	1.03	0.15	0.88	1.39	1.27	0.12	1.68	1.32	0.36	1.21	1.21	0.00	0.45
Puthupanam KB 31	2.23	1.46	0.77	1.95	1.46	0.49	2.42	1.30	1.12	2.58	1.60	0.98	0.84

Appendix - 3

GROUNDWATER LEVELS ALONG KOTTAKKAL - KOLLAM COASTAL STRETCH

Location and Well Nos	1980 Water level in m b.g.l. maxi-mum	1980 Water level in m b.g.l. mini-mum	1980 Fluctu-ation in m (F)	1981 Water level in m b.g.l. maxi mum	1981 Water level in m b.g.l. mini-mum	1981 Fluctu-ation in m (F)	1982 Water level in m b.g.l. maxi mum	1982 Water level in m b.g.l. mini-mum	1982 Fluctu-ation in m (F)	1983 Water level in m b.g.l. maxi mum	1983 Water level in m b.g.l. mini-mum	1983 Fluctu-ation in m (F)	Aver-age fluct-uation in m
Kottakkal KQ 2	4.84	3.61	1.23	4.76	3.31	1.45	4.90	3.42	1.48	4.86	3.69	1.17	1.33
Iringal KQ 3	1.27	0.58	0.69	1.30	0.59	0.71	1.39	0.41	0.98	1.36	1.04	0.32	0.68
Kottakkal KQ 7	0.96	0.80	0.16	0.80	0.67	0.13	0.92	0.49	0.43	0.87	0.86	0.01	0.18
Meladi KQ 18	2.44	1.81	0.63	2.65	2.05	0.60	2.53	1.72	0.81	2.75	2.29	0.46	0.63
Payyoli KQ 20	3.12	0.69	2.43	2.74	0.63	2.11	3.11	0.43	2.68	3.40	0.70	2.70	2.48
Thikkodi KQ 30	3.43	0.82	2.61	3.80	1.22	2.58	3.54	0.99	2.55	3.77	1.33	2.44	2.55
Kadalur beach KQ 37	4.03	1.94	2.09	4.23	1.94	2.29	3.23	1.77	1.46	4.55	2.08	2.47	2.08
Purakkal KQ 39	2.28	0.46	1.82	2.73	0.66	2.07	3.43	0.51	2.92	3.41	0.74	2.67	2.37
Kollam KQ 39	1.76	0.52	1.24	1.53	0.73	0.80	1.71	0.66	1.05	1.89	0.82	1.07	1.04
Kollam beach KQ 47	1.72	0.63	1.09	1.61	0.60	1.01	1.70	0.79	0.91	1.92	1.10	0.82	0.96

Appendix 4

GROUNDWATER LEVELS ALONG KOLLAM - KORAPUZHA COASTAL STRETCH

Location and Well Nos	1980 Water level in m b.g.l.		1980 Fluctuation in m (F)	1981 Water level in m b.g.l.		1981 Fluctuation in m (F)	1982 Water level in m b.g.l.		1982 Fluctuation in m (F)	1983 Water level in m b.g.l.		1983 Fluctuation in m (F)	Average fluctuation in m
	maximum	minimum		maxi mum	minimum		maxi mum	minimum		maxi mum	minimum		
Edakulam beach KQ 52	1.50	0.35	1.15	1.52	0.68	0.84	1.47	0.42	1.05	1.91	0.59	1.32	1.09
Edakulam KQ 53	3.41	0.75	2.66	3.20	1.15	2.05	3.65	0.35	3.00	-	-	-	2.57
Pookad beach KQ 57	2.48	0.65	1.83	2.50	1.29	1.21	2.43	0.92	1.51	2.75	0.99	1.76	0.58
Tiruvngur KQ 58	2.56	0.89	2.52	1.34	1.34	1.18	2.53	0.93	1.60	2.85	1.16	1.69	1.54
Kannankadavu KQ 65	1.93	1.47	0.46	-	-	-	1.98	1.42	0.56	2.34	1.90	0.44	0.49
Korapuzha KQ 66	1.78	0.06	1.72	1.87	0.40	1.47	1.64	1.47	0.17	1.97	0.30	1.67	1.26 1.26

Appendix - 5

GROUNDWATER LEVELS ALONG KORAPPUZHA - KALLAYI COASTAL STRETCH

Location and Well Nos	1980 Water level in m b.g.l. maxi-mum	1980 Water level in m b.g.l. mini-mum	1980 Fluctu-ation in m (F)	1981 Water level in m b.g.l. maxi mum	1981 Water level in m b.g.l. mini-mum	1981 Fluctu-ation in m (F)	1982 Water level in m b.g.l. maxi mum	1982 Water level in m b.g.l. mini-mum	1982 Fluctu-ation in m (F)	1983 Water level in m b.g.l. maxi mum	1983 Water level in m b.g.l. mini-mum	1983 Fluctu-ation in m (F)	Aver-age fluct-uation in m
Puthiyani-rathukadavu KK 06	3.60	1.84	1.76	3.44	2.34	1.10	3.21	2.03	1.18	-	-	-	1.35
Puthiappa KK 08	1.91	0.32	1.59	1.71	0.53	1.18	1.73	0.44	0.29	2.00	0.54	1.46	1.38
West Hill KK 16	2.30	0.17	2.13	2.52	0.43	2.09	2.28	1.06	1.22	3.18	0.35	2.83	2.07
Mavoor Road KK 23	0.80	0.11	0.69	0.85	0.38	0.47	0.77	0.16	1.22	2.18	0.35	2.83	2.07
East Kallayi KK 25	0.95	0.12	0.83	0.05	0.79	0.26	1.45	0.16	1.27	1.32	1.20	0.12	0.63
Kallayi KK 26	2.34	1.63	0.71	2.38	1.61	0.77	2.34	1.52	0.82	2.37	1.55	0.82	0.78

Appendix - 6

GROUNDWATER LEVELS ALONG KALLAYI - KADALUNDIKADAVU COASTAL STRETCH

Location and Well Nos	1980 Water level in m b.g.l. maxi-mum	1980 Water level in m b.g.l. mini-mum	1980 Fluctu-ation in m (F)	1981 Water level in m b.g.l. maxi mum	1981 Water level in m b.g.l. mini-mum	1981 Fluctu-ation in m (F)	1982 Water level in m b.g.l. maxi mum	1982 Water level in m b.g.l. mini-mum	1982 Fluctu-ation in m (F)	1983 Water level in m b.g.l. maxi mum	1983 Water level in m b.g.l. mini-mum	1983 Fluctu-ation in m (F)	Aver-age fluct-uation in m
Naduvattom beach KK 34	3.15	2.35	0.80	3.21	2.52	0.69	3.21	2.31	0.90	3.38	2.56	0.82	0.80
Meenchantha KK 31	1.50	0.42	1.08	1.61	0.42	1.19	1.51	0.43	1.08	2.26	0.37	1.89	1.31
Beypore KK 41	4.29	0.55	3.74	4.29	0.71	3.58	4.30	0.74	3.56	5.05	0.87	4.18	3.77
Beypore Port KK 42	1.93	0.44	1.49	1.87	0.58	1.29	1.93	0.35	1.58	2.09	0.69	1.40	1.44
Kadalundi KK 49	3.09	0.05	3.04	3.35	0.13	3.22	3.11	0.05	3.06	5.00	0.50	19.00	3.19
Kadalundi KK 52	1.55	1.30	0.25	1.57	1.25	0.32	1.43	1.37	0.06	1.57	1.49	0.08	0.18

Appendix - 7

FORMAT FOR WELL USE STATISTICS SURVEY

WELL USE STATISTICS IN DISTRICT

Name and identification of area surveyed

Taluk:
Village:
Panchayat:
Date:

1. Sl. No.

2. Well identification

3. Year of constrn.

4. Dimensions of well in metres
   i) Diameter
   ii) Depth

5. No. of members using the well

6. Nature of well use
   i) Mainly for irrigation
   ii) Mainly for drinking
   iii) Mainly for irrigation and drinking
   iv) Mainly for cleaning

7. Nature of water availability
   i) Perennial
   ii) Always fresh water
   iii) Saline in summer

8. Command area in cents

9. Types of crops grown

10 Average withdrawal/ day in litres

11. If abadndoned, why and when?

12. Special Remarks

Appendix - 8

CHEMICAL ANALYSIS OF WATER FROM OPEN WELLS IN COASTAL SANDY ZONE

Name of coastal stretch	Location	Well No	Seasons	E.C. m.mho/cm	T.D.S.	pH	Ca in ppm	Mg in ppm	Fe in ppm	SO4 in ppm	NO3 in ppm	Cl in ppm	HCO3 in ppm
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aliyur -	Aliyur (Pozhithala)	KB 1	01	832.00	510.00	6.65	84.00	4.40	0.30	21.30	-	72.00	14.00
Kottakkal			02	395.00	255.00	7.39	86.00	3.40	0.40	12.20	-	20.00	215.00
Stretch			03	668.00	668.00	7.50	65.60	7.30	-	10.00	-	17.00	362.00
	Madappally	KB 12	01	462.80	295.00	6.60	42.40	Nil	ab	14.70	-	48.00	16.00
			02	58.00	230.40	7.06	32.80	2.40	ab	10.00	-	22.00	217.50
			03	341.60	239.10	7.00	32.80	3.40	Nil	10.00	-	21.00	130.00
	Kuriyadi beach	KB 19	01	1248.00	750.00	6.50	55.20	17.50	0.30	33.30	-	80.00	240.00
			02	728.00	450.00	7.93	22.00	7.00	0.40	15.60	-	42.00	185.00
			03	860.00	602.00	7.00	30.40	15.10	0.70	10.00	-	62.00	196.00
	Purakkara	KB 30	01	624.00	400.00	5.95	37.20	9.00	0.40	17.20	Present	74.00	14.00
			02	884.00	545.00	8.19	36.00	1.20	0.30	21.30	-	15.00	219.00
			03	406.00	284.20	7.30	30.40	15.10	0.70	10.00	-	62.00	286.00
Kottakkal - Kollam	Kottakkal	KQ 7	01	1404.00	850.00	6.15	14.10	21.20	0.40	33.30	-	172.00	60.00
Stretch			02	390.00	249.00	7.82	23.60	5.10	0.40	20.00	-	30.00	152.00
			03	205.50	143.80	6.95	38.40	3.90	0.30	10.00	-	10.00	148.00

* Seasons 01 Pre-monsoon
02 Monsoon
03 Post-monsoon

Appendix - 9

CHEMICAL ANALYSIS OF WATER FROM OPEN WELLS IN COASTAL ALLUVIAL - LATERITE ZONE

Name of coastal stretch	Location	Well No	Seasons	E.C. m.mho/ cm	T.D.S.	pH	Ca in ppm	Mg in ppm	Fe in ppm	SO4 in ppm	NO3 in ppm	Cl in ppm	HCO3 in ppm
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aliyur -	Aliyur	KB 02	01	2132.00	-	3.50	228.00	532.00	1.40	500.00	-	5500.00	Nil
			02	75.50	52.00	7.05	3.40	1.10	-	16.00	-	14.00	12.50
			03	109.90	76.90	6.00	6.40	1.00	0.40	10.00	-	9.00	36.00
Kottakkal Stretch	Kottakkal	KQ 02	01	192.40	129.00	6.15	16.30	0.80	0.30	33.30	-	27.50	32.00
			02	213.20	142.00	7.46	16.80	0.50	0.20	22.20	-	20.00	125.00
			03	167.20	117.00	6.90	22.40	5.40	-	10.00	-	8.00	114.00
	Tikkodi	KQ 30	01	130.00	90.00	5.40	5.80	0.90	0.50	Nil	-	21.50	16.00
			02	208.00	138.00	7.02	15.60	1.20	0.30	14.50	-	23.00	135.00
			03	126.60	88.60	7.15	7.20	0.50	0.60	10.00	-	6.00	60.00
Kollam - Korapuzha	Kollam	KQ 46	01	244.40	160.00	5.70	18.00	2.70	-	22.20	-	11.00	80.00
			02	106.00	73.00	7.27	11.60	Nil	1.50	20.00	-	11.00	51.50
			03	97.90	88.50	6.55	10.40	1.50	1.60	10.00	-	5.00	58.00
	Edakulam	KQ 53	01	156.00	105.00	7.50	9.00	1.70	0.40	13.50	-	26.50	40.00
			02	240.50	158.00	8.16	17.20	0.70	0.20	35.70	-	32.00	101.00
			03	329.70	230.70	7.20	22.40	2.00	0.30	10.00	-	18.00	144.00
	Tiruvangur	KQ 58	01	104.00	70.00	6.15	4.60	4.50	70.00	10.00	-	4.00	60.00
			02	260.00	117.00	7.11	24.80	0.70	0.70	24.40	-	16.00	197.50
			03	186.30	130.40	8.00	20.40	2.00	0.50	10.00	-	6.00	40.00
	Korapuzha	KQ 66	01	936.00	570.00	6.25	64.80	11.20	0.50	119.10	-	105.00	300.00
			02	624.00	390.00	7.88	57.60	7.30	-	58.80	-	52.00	427.50
			03	645.00	451.50	7.25	53.60	7.30	0.20	40.90	-	24.00	322.00
Korapuzha - Kallayi	Puthiya-nirathu-kadavu	KK 06	01	1560.00	840.00	7.20	72.00	26.20	0.90	25.60	-	315.00	70.00
			02	1475.00	880.00	6.61	67.00	10.30	0.20	47.60	-	395.00	160.00
			03	1409.50	986.60	7.00	63.20	8.50	0.10	19.50	Trace	160.00	89.00
Korapuzha - Kallayi	West Hill	KK 16	01	- Water sample not collected									
			02	312.00	200.00	6.76	33.20	1.20	0.20	35.70	-	24.00	200.00
			03	453.90	317.70	6.90	39.20	3.40	-	14.60	-	15.00	125.00
Kallayi - Kadaundi kadavu	Meenchanda	KK 31	01	416.00	260.00	7.20	34.40	4.80	0.80	29.40	-	41.00	180.00
			02	212.50	140.00	7.50	19.20	8.30	0.50	13.00	-	18.00	160.00
			03	334.50	234.10	7.05	38.40	3.40	0.80	10.00	-	12.00	202.00
Kallayi - Kadaundi kadavu	Beypore	KQ 39	01	176.80	117.00	5.35	9.20	1.70	Nil	Nil	-	26.50	20.00
			02	624.00	39.00	8.14	41.00	4.70	0.30	15.90	-	46.00	277.00
			03	358.00	250.00	6.80	4.80	4.40	Absent	11.10	-	16.00	118.00

Appendix - 10

CHEMICAL ANALYSIS OF WATER FROM OPEN WELLS IN COASTAL ALLUVIAL - LATERITE ZONE

Name of coastal stretch	Location	Well No	Seasons	E.C. m.mho/cm	T.D.S.	pH	Ca in ppm	Mg in ppm	Fe in ppm	SO4 in ppm	NO3 in ppm	Cl in ppm	HCO3 in ppm
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aliyur - Kottakkal	Muttungal	KB 16	01	260.00	170.00	6.00	16.80	1.90	0.40	23.30	-	26.50	18.00
			02	254.80	166.00	7.64	22.00	0.70	0.80	27.80	-	24.00	127.50
			03	181.60	127.10	6.75	8.00	6.80	0.50	10.00	-	9.00	92.00
	Puthuppanam	KB 31	01	780.00	480.00	6.40	34.80	34.10	0.40	25.50	-	102.50	60.00
			02	176.80	115.00	7.57	15.00	2.10	0.30	27.00	-	14.00	84.50
			03	358.40	250.00	7.00	1.00	4.40	Nil	9.00	-	16.00	182.00
Kottakkal - Kollam	Iringal	KQ 03	01	1040.00	640.00	7.75	89.20	18.70	Nil	80.70	-	48.50	620.00
			02	572.00	360.00	7.96	50.40	3.90	0.60	19.20	-	18.00	345.00
			03	907.80	635.00	7.45	171.20	13.70	0.30	17.20	-	28.00	610.00
	Payyoli	KQ 20	01	62.40	-	5.40	4.00	0.20	Nil	Nil	-	9.50	25.00
			02	106.00	73.00	7.40	7.00	0.10	Nil	22.20	-	12.00	44.50
			03	97.90	68.50	7.40	6.40	1.50	0.30	10.00	-	5.00	347.00
Korapuzha	Mavoor Road	KK 23	01	1144.00	700.00	8.00	36.00	19.40	1.10	55.60	-	150.00	3.00
			02	1300.00	790.00	7.89	78.00	11.00	0.90	100.00	-	100.00	692.50
			03	1242.30	869.60	7.75	95.20	20.00	Nil	21.10	-	55.00	347.00
Kallayi - Kadalundi kadavu	East Kallayi	KK 25	01	2026.00	1200.00	7.10	54.00	62.00	0.30	104.20	-	244.00	540.00
			02	728.00	450.00	7.80	47.60	11.40	0.20	35.70	-	50.00	415.00
			03	1003.40	702.30	7.40	59.20	7.80	Nil	15.40	-	35.00	335.00
	Kadalundi	KK 49	01	1456.00	870.00	8.30	59.00	12.80	0.50	294.20	-	295.00	200.00
			02	520.00	325.00	7.74	33.80	5.10	0.20	83.30	-	38.00	315.00
			03	668.90	468.20	6.85	105.60	8.80	0.40	29.40	-	25.00	282.00