AN INTEGRATED HYDROGEOLOGICAL STUDY OF THE MUVATTUPUZHA RIVER BASIN, KERALA, INDIA

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CERTIFICATE

This is to certify that the thesis entitled **"AN INTEGRATED HYDROGEOLOGICAL STUDY OF THE MUVATTUPUZHA RIVER BASIN, KERALA, INDIA"** is an authentic record of research work carried out by **Mr. Girish Gopinath** under my supervision and guidance in partial fulfilment of the requirements for the degree of Doctor of Philosophy and no part thereof has been presented for the award of any degree in any University/ Institute.

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PREFACE

Water is the lifeblood of every living creature on the earth. Through the wonders of nature, water can take different forms. Although about 72 percent of the earth's surface is covered with water, the fresh water including groundwater occupies a small portion of it. It is easy to understand the significance of water in our lives however; it is difficult to understand the characteristics and movement of water with in the earth's surface - the groundwater.

In India, more than 90% of rural and nearly 30% of urban population depends on groundwater for meeting their drinking and domestic requirements. In addition, it accounts for nearly 60% of the irrigation potential created in the country. The spatio-temporal variation in rainfall and regional/ local differences in geology and geomorphology has led to an uneven distribution of groundwater in different regions across the country. So an attempt has been made to develop a scientific database on the Muvattupuzha river basin, Kerala, spreading over an area of 1488 km^2 (latitudes, 9^0 40' - 10^0 10' N and longitudes, 76^0 20' - 77^0 00' E).

The present investigation deals with the hydrogeological characteristics of the Muvattupuzha river basin. Geologically this basin is characterised by Precambrian crystalline rocks overlained by laterites. Groundwater occurs under water table conditions in laterites and semi-confined to confined conditions in fractured crystalline rocks. In weathered crystallines, the depth and intensity of weathering controls the occurrence and movement of groundwater. But in hard crystallines with negligible weathering and lateritisation, the presence of lineaments and joints are the controlling factors. The lateritic clay materials also reduce hydraulic conductivity to some extent in this basin. The occurrence of dykes and veins in the area may at times acts as barriers to groundwater movement. Studies relating to hydrogeology, hydrometeorology, hydrochemistry, geophysics and remote sensing are essential for a scientific management and sustainable development of groundwater resources.

Muvattupuzha river basin experiences serious water shortage during April and May every year. Except a preliminary study by the Muvattupuzha Valley Irrigation Project (MVIP) and Central Ground Water Board (CGWB) in the eighties, no serious attempt has been made to study the behaviour of groundwater characteristics, aquifer parameters, groundwater chemistry, demarcation of potential groundwater zones etc. Hence the groundwater of the Muvattupuzha river basin has been studied by conventional survey (hydrological characteristics, geophysical analysis and groundwater chemistry) and remote sensing techniques. Geographic information system, being the best tool to create scientific groundwater database, has also been employed.

The thesis has been addressed in 7 chapters with further subdivisions. The first chapter is introductory, stating the necessity of an integrated study and drawing it from a careful review of literature relevant to the present study. It also provides a description about the study area, geology, drainage, physiography, climate and landuse. It also contains the major objectives of the present study.

Chapter 2 deals with the methodology adopted in this work. The collection of groundwater samples, processing techniques, various laboratory methods adopted in the analysis of water samples, pumping test analysis, resistivity data analysis, satellite data collection, image processing techniques and Geographic Information System are presented in detail.

The hydrogeology of the basin is discussed in chapter 3. The systematic description of water level study, water fluctuation study, pumping tests etc. and their results are covered in this chapter.

Chapter 4 deals with the hydrogeophysical characteristics based on resistivity analysis. The layer parameters and probable phreatic potential zone are identified.

Chapter 5 examines the groundwater quality of the basin for the pre and post monsoon seasons. The suitability of the groundwater for various purposes like domestic, irrigation and industries are evaluated.

Chapter 6 integrates the remotely sensed data (hydrogeomorphology, lineament, landuse etc.), terrain parameters (slope, drainage etc.) and geophysical data with the help of Geographic Information System to demarcate the groundwater potential zones of the basin. By in putting hydrogeological, geophysical and hydrogeochemical data in GIS a strong database of this basin has been generated.

A summary of the work and the major conclusions drawn thereof are given in Chapter 7.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Groundwater plays an important role in meeting the requirements of humans. Exploitation of groundwater reservoir as a viable source of drinking water and for domestic use (or even for small scale industries) is safer and economical than surface water, as groundwater is not only found almost everywhere but also generally uncontaminated. As a result groundwater investigation has assumed top priority in recent years. Groundwater is often thought of as an underground river or lake, but this type of occurrence is seen only in caves or within lava flows. Instead, groundwater is usually held in porous soils or rock materials. The area where water fills these spaces is called the saturated zone; the top of this zone is called the water table. The water table may be shallow (only a foot below the ground surface) or it may be deep (hundreds of feet down) and may rise or fall depending on many factors. Heavy rains or melting snow may cause the water table to rise while an extended period of drought may cause the water table to fall.

Groundwater is stored in, and moves slowly through, layers of soils, sand and rocks called aquifers. The nature of groundwater flow depends on the size of the pores in the rock or within the soil particles and how well the spaces are interconnected. Aquifers typically consist of gravels, porous sedimentary rocks and fractured crystalline rocks. Water in aquifers at times reaches the surface of the earth naturally through springs. Groundwater can also be extracted from a well manually or can be brought to the surface by a pump. Some wells, called artesian wells, do not need a pump because of natural pressures that force the water up and out of the well.

People all around the world face serious water shortage because of the over exploitation of groundwater (for domestic, industrial and agricultural purposes). It is estimated that around seven billion people out of the projected 9.3 billion in the entire world will face water shortage, and out of these, 40% will suffer acute water crisis. Considering the threat of freshwater scarcity looming large over the horizon, the government has taken several initiatives to make people aware about the pressing need to conserve and augment this precious resource. Taking into consideration the Government of India has declared the year 2003 as the 'Freshwater Year'. As far as India is concerned the future is a bit more worrisome since we have only 2.45% of the world's landmass supporting 16% of the world's population and freshwater resource not exceeding 4%. Further the groundwaters are now a days getting polluted extensively by human activities. Landfills, septic tanks, leaky underground gas tanks and the overuse of fertilizers and pesticides are some of the causes of groundwater pollution. The presence of a permeable layer above an aquifer usually plays a role in infiltering the pollutants from the surface to the groundwater. If groundwater becomes polluted, it will no longer be safe for drinking.

The Government of India after a detailed deliberation over the water problems adopted National Water Policy 2002 as given below

- Water is precious national resource and its planning, development and management to be governed by national perspectives.
- Accord first priority to drinking water in allocation of water.
- Priority for drought- prone areas in planning of project development.
- Develop information system related to water data at the national and state levels and create a network of data banks.
- Plan water resources on the basis of the hydrological units such as a river basin or sub basin.
- Transfer of water from one river basin to another, especially to areas of water shortage.
- Plan water resources' projects preferably on multi-purpose projects adopting multi- disciplinary approach.
- Prepare plans having regard to human and ecological aspects including those of the disadvantaged sections in society.
- Exploitation of groundwater to be regulated with reference to recharge possibilities and avoid detrimental environmental consequences due to over exploitation.
- Management of water resources for diverse use to include users, stakeholders and governmental agencies.
- Monitor surface and groundwater for quality and effluent treatment before releasing.

- Evolve a master plan for flood- prone areas for flood control and management of each flood-prone basin.
- Educate users and stakeholders in conservation and preservation of water resources.

Kerala is having a unique hydrogeological and climatic condition. The surface and groundwater resources of the state play a crucial role in the development of various activities like irrigation, industrial and domestic uses. The state experiences wide variation in the rainfall pattern (average 3107 mm) from eastern hilly areas to the western coastal regions and a major part of the rainfall goes as surface run off particularly during monsoon season. The steady base flow from the groundwater emerges as surface run off during the non-monsoon periods. A realistic estimation of surface/ groundwater and other related information for each watershed are needed to mitigate water scarcity, water pollution and ecological problems in the state.

The present study deals with the different hydrogeological characteristics of a central Kerala river basin - the Muvattupuzha. Geologically the basin is encountered with laterites and underlained by the Precambrian metamorphic rocks. Supply of water from hard rock terrain is rather limited. This may be due to the small pore size, low degree of interconnectivity and low extent of weathering of the country rocks. The groundwater storage is mostly controlled by the thickness and hydrological properties of the weathered zone and the aquifer geometry. The over exploitation of groundwater, beyond the 'safe yield' limit, cause undesirable effects like continuous reduction in groundwater levels, reduction in river flows, reduction in wetland surface, degradation of groundwater quality and many other environmental problems like drought, famine etc.

Scientific management of groundwater resources requires studies relating to hydrogeology, hydrometeorology, hydrogeochemistry, geophysics and remote sensing. All management policies for water resources, before the onset of remote sensing techniques, have crippled by the limitations of conventional methods used in resources survey and monitoring. The effective management of groundwater resource can be done only when there is an adequate knowledge about its spatial and temporal distribution. Thus remote sensing techniques give a new dimension to the effective management by satisfying the primary need and helps in real time analysis of such scarce and valuable resources. This can be substantiated by studies like resources evaluation with the aid of remote sensing. Time bound conventional data and real time remotely sensed data are compared and correlated to produce the most exciting results for conservation, optimum utilization and management of the resources. In this study both conventional survey (hydrological characteristics, geophysical and groundwater chemistry) and remote sensing techniques have been employed to decipher the characteristics of the Muvattupuzha river basin.

1.2 REVIEW OF LITERATURE

Groundwater studies have gained greater importance in recent years as is evidenced by several special publications and by conducting several international seminars and workshops sponsored by International Association of Hydrological Sciences (IAHS) and other organizations worldwide (UNESCO/IAHS, 1967; Wright and Burgess, 1992; Sheila and Banks, 1993). In India, for long years groundwater investigations were confined mostly to the unconsolidated alluvial and semi-consolidated sedimentary tracts (Singhal, 1984). In the recent years, however, emphasis is being given equally to the exploration of groundwater resources in hard rock areas also.

Exploration of groundwater is carried out following one or combination of a few methods (Karanth, 1987) namely, geological and hydrogeological methods (geology, drainage density, lineament, hydrogeomorphology etc.), surface geophysical methods (electrical, seismic, magnetic, gravity and radiometric), hydrogeological well logging (inventory of existing wells, rainfall infiltration etc.) and tracer techniques as stated by Sarma and Sharma (1987).

Philip and Singhal (1991) have compared the groundwater levels of different geomorphologic features. Their study revels that wells located in the erosional valleys have deeper water levels, varying from 3.4 to 6.5m below ground level as compared to other landforms. Karanth (1987) has also pointed out that water level fluctuations map are indispensable for estimation of storage changes in aquifers. He further inferred that the water level fluctuation is controlled by recharge and draft of groundwater and the diverse influences on groundwater levels include meteorology, tidal phenomena, urbanization, earthquakes and external loads. In addition, Todd (1980) also suggested that the land subsidence could occur due to changes in underlying groundwater conditions.

Chabdler and Whorter (1975) have estimated the salt-water intrusion in Indus river basin applying pumping test methods. A number of techniques are available to analyse the pumping test data of wells. The pump test data are interpreted, either manually or with the aids of computers. However, the graphical and isoline representation of permeability, transmissivity and specific capacity indices were adopted by many workers (Adyalkar et al., 1966; Sammel, 1974; Nightingale and Bianchi, 1980; Ruston and Sing, 1983). Pumping test data can be analysed by the conventional Theis and Cooper-Jacob methods (Eagon and Johe, 1972; Wesslen et al., 1977). Leaky and unconfined aquifer models are also used for aquifer parameter determination in crystalline rocks (Sridharan et al., 1990; Boehmer, 1993; Sekhar et al., 1993; Levns et al., 1994; Kaehler and Hsieh, 1994).

The topography and landforms have strong influence on well yield, especially of shallow wells, as they influence the thickness of weathered zone (LeGrand, 1967; McFarlane et al., 1992; Henriksen, 1995). Wells located in valleys have greater yield than that of those located on steep slopes, sharp ridges and interfluvial areas. Therefore, to a certain extent the well yields can be predicted using the topographic considerations. In central Malawi, higher well yield are reported from areas of low relief as compared with areas with high relief adjacent to inselbergs (McFarlane et al., 1992; Sridharan et al., 1995). The influence of landforms on well yields is also demonstrated by Perumal (1990) from a study of granite-gneiss and charnockite formations in the Athur valley of Tamil Nadu. Fault-controlled buried pediments, where the weathered horizon is thicker, will also give higher water yield as compared to other landforms (Perumal, 1990).

The concept of optimum depth of wells holds good in crystalline fractured rocks as the permeability usually decreases with depth. An overall decrease in well yield with depth is reported from various crystalline rock terrains in different parts of the world (Davis and Turk, 1964; UNESCO, 1979; Woolley, 1982; Henrisken, 1995). Based on the well productivity data, Davis and Turk (1964) have suggested that the optimum depth of wells in crystalline rocks should be between 50 and 60 m.

Geophysical survey is necessary to ascertain the subsurface geological and hydrogeological conditions and its applications for groundwater exploration are reviewed by a few workers (Zohdy et al., 1974; Beeson and Jones, 1988; deStadelhofen, 1994). Using Schlumberger electrical soundings, Worthington (1977) has attempted to evaluate groundwater resources of the Kalahari basin, South Africa. Verma et al., (1980) have used histograms, curve types and iso-apparent resistivity (based on apparent resistivity) and Schlumberger sounding curves to investigate the groundwater potential in metamorphic areas near Dhanbad, India. Vertical Electrical Sounding (VES) surveys are highly useful, economical and reliable in groundwater investigation and assessment. This

(VES) can also be used for the direct assessment of aquifer parameters (excluding storativity), which in turn can be used for the estimation of dynamic and static groundwater reserves (Paliwal and Khilnani, 2001). The above study revels that the thickness of the aquifer in buried pediments and alluvial plains are 10 to 29 m and 17 to 54 m respectively. Contouring the apparent resistivity is an important method, through which one can easily identify the groundwater potential areas, movement pattern etc., (Sarma and Sarma, 1982; Balakrishna et al., 1984; Balasubramanian et al., 1985).

The chemical composition of groundwater is mainly related to soluble products of rock weathering with respect to space and time (Raghunath, 1987). In addition to the leaching of minerals, man can adversely alter the chemical quality of groundwater by permitting highly polluted water to enter into the fresh water strata through improper construction of wells, disposal of animal and municipal wastes, sewage and other industrial wastes (Sakthimurugan, 1995). The disposals of effluent from the tanneries are the main source causes the change in physical, chemical and biological characteristics of groundwater in Sempattu area, Tiruchirappalli (Manivel and Aravindan, 1997). The hydrogeochemistry and groundwater flow patterns in the vicinity of Stratford-Upon-Avon have been studied by Lloyd (1976). He used Durov's diagram to differentiate the major ionic constituents of groundwater flow. The study further revels that faulting has a dominant control on groundwater movement. Similar type of work has been attempted by Daly et al. (1980) for Castle Comer plateau, Ireland.

Zaporozec (1972), Freeze and Cherry (1979), Matthess (1982), and Lloyd and Heathcote (1985) have given a detailed account of various methods for plotting of water quality data. Based on the dominance of anions and cations, the groundwater of Vaippar basin has been classified by Sivaganam and Kumaraswamy (1983). Gupta (1987) has evaluated the groundwater quality of the northern part of Meerut districts, Uttar Pradesh, using Collin's bar graph, Hill-Piper trilinear diagram, Durov's diagram and U.S.S.L diagram. Stiff and bar diagrams have been used to analyse the groundwater quality of Dejima upland by Changyan Tang (1989). Based on these methods groundwater are classified into five groups as very good, good, moderate, poor and bad. Kelley (1940), Eaton (1950) and Wilcox (1955) have proposed certain indices by considering the individual or paired ionic concentrations, to find out the alkali hazards and Residual Sodium Carbonate (RSC). These indices can be used as criteria for finding out the suitability of water for irrigation.

As the art of remote sensing possesses unique potentialities of widely displaying the size, shape, pattern and spatial distribution of the various aquifer systems, their signatures of deformation and the morphogenetic landforms, the scientist too have embarked into this technology for groundwater exploration. Ramasamy and Bakliwal (1983) have stated that an integrated approach involving geology, geomorphology and landuse pattern using remotely sensed data could give significant information for targeting groundwater. Howe (1956), Ray (1960), Lattman and Parizek (1964), Boyer and Maguer (1964), Setzer (1966) and Mollard (1988) have extensively used the black and white aerial photographs in mapping the areal extent of various aquifer systems and lineament pattern for groundwater targeting. Many scientists have carried out the hydrogeological, structural and hydrogeomorphological interpretations with the help of raw and digitally enhanced satellite multispectral data (Brakeman and Fernandaz, 1973; Bowder and Pruit, 1975; Moore and Duestsch, 1975; Ottle et al., 1989).

The importance of geomorphology for hydrological study in hard rock terrain of Bihar Plateau through remote sensing have been carried out by Philip and Singhal (1991). Thillaigovindrajan (1980) has brought out the techniques of the practical utilisation of remote sensing in groundwater exploration by studying various geomorphological units of southern Tamil Nadu. Thiruvengadachari (1978) has studied the hydrologic landuse pattern of the southern part of Tamil Nadu from satellite data and prepared various landuse maps. This landuse map has become the basis for further studies in groundwater exploration and exploitation, irrigation, flood control and watershed management. Sankar (2002) has evaluated the groundwater potential zones using remote sensing data of upper Vagai river basin, Tamil Nadu. He identified four groundwater potential zones for Vaigai area as very poor to poor, poor to moderate, moderate to good and good to very good, after demarcating and integrating geological, geomorphological, lineament analysis and well details. Remote sensing (SPOT-HRV data) is very effectively used in brining out the relation between lineament and vegetation anomalies of Botswana (Gustafsson, 1993).

Digital image processing is used for extracting information from digital data and its application in geology has been discussed by Drury (1987), Sabins (1987) and Gupta (1991). The digital enhancement technique has been found to be more rewarding for subsurface geological/hydrogeological investigations rather than the image classification approach (Siegal and Abrams, 1976; Gupta, 1991).

Applications of GIS are to identify and display locations of well, tapping of particular aquifer or a group of aquifers (Barker, 1988). It can also be used to relate hydrochemical quality with lithology. Kalkoff (1993) has attempted to relate stream water quality with the geology of the catchment area of the Roberts Creek watershed, Iowa. Groundwater pollution can be effectively evaluated by GIS and for developing pollution potential map (Aller et al., 1987; Halliday and Wolfe, 1991). In the northern part of Australlia, salinity hazard mapping has been carried out by Tickell (1994) using GIS. Groundwater modelling based on GIS has been attempted by many (Richards et al., 1993; Roaza et al., 1993; El-Kadi et al., 1994). Groundwater prospecting zones in Dala – Renukoot area, Uttar Pradesh has been mapped through integration of various thematic maps using Arc/Info GIS (Pratap et al., 2000) and the resultant groundwater prospect map of the area showing five classes namely excellent, very good, good, moderately good and poor is generated.

1.3 PREVIOUS WORK IN MUVATTUPUZHA RIVER BASIN

Muvattupuzha Valley Irrigation Project (MVIP), in 1976, carried out a detailed survey in the Muvattupuzha river basin for constructing new irrigation canals to solve the groundwater problem of this basin. Under the above programme the northern and central parts of the study area are irrigated by canal system. In spite of this there is a severe water shortage in this area during the April and May.

Reappraisal hydrogeological survey has carried out in the Muvattupuzha river basin covering a drainage area of 2,394 km^2, within Ernakulam, Idukki, Kottayam and Alleppey districts (Najeeb, 1985). From this survey it has been found that wells located near valley fills have the highest specific capacity and also the chemical quality of water (from shallow aquifer, deep aquifer, fractured aquifer, springs and rivers) has been found to be generally good and fit for all domestic and agricultural purposes. Nagarajan (1987) and Menon (1988) have carried out respectively hydrometeorological and hydrological investigations in the Muvattupuzha and Meenachil river basins. Ramachandran and Ramam (1988) have conducted surface geophysical surveys for groundwater in parts of Meenachil and Muvattupuzha basins. Litholog of bore wells drilled in the Meenachil and Muvattupuzha river basins has been studied by Najeeb (1985). Balchand (1983) has studied the dynamics and quality of the surface water of the Muvattupuzha river in relation to effluent discharge from Hindustan newsprint factory, Piravom. The landuse pattern of Muvattupuzha catchment area has been studied by Nair (1987) and explained that the different landuse types are distinctly governed by physiography and climate of the region.

1.4 STUDY AREA

Muvattupuzha river is one of the major perennial rivers in the central Kerala. It originates from the Western Ghats and drains mainly through highly lateritised crystalline rocks. It debouches into the Vembanad estuary near Vaikom. It has a length of about 121 km and a catchment area of about 1,554 km^2 (CESS, 1984). The Muvattupuzha river basin is bounded by the Periyar river basin on the north and the Meenachil river basin on the south. The river discharge ranges from 50 m^3/sec (pre monsoon) to 400 m^3/sec (monsoon) with peak discharge during June to October. Considerable changes have taken place in the flow characteristics of the Muvattupuzha river after the commissioning of the Idukki hydroelectric power project in 1976, across the adjoining Periyar river (Balchand, 1983). The tail-race water (19.83-78.5 m^3/sec) has been diverted into the Thodupuzha tributary from Moolamattom power station. This tail-race water (almost constant) plus surface run off have altered the morphological characteristics of the river.

For this study, the Muvattupuzha river basin lying between latitudes 9^0 40' and 10^0 10' N and longitudes 76^0 20' and 77^0 00' E (Fig. 1.1) has been selected. Before joining the Vembanad lake at Vettikattumukku towards the western margin of the basin it bifurcates into Ittupuzha and Murinjapuzha. The present work is confined upto Vettikattumukku, covering the river course of

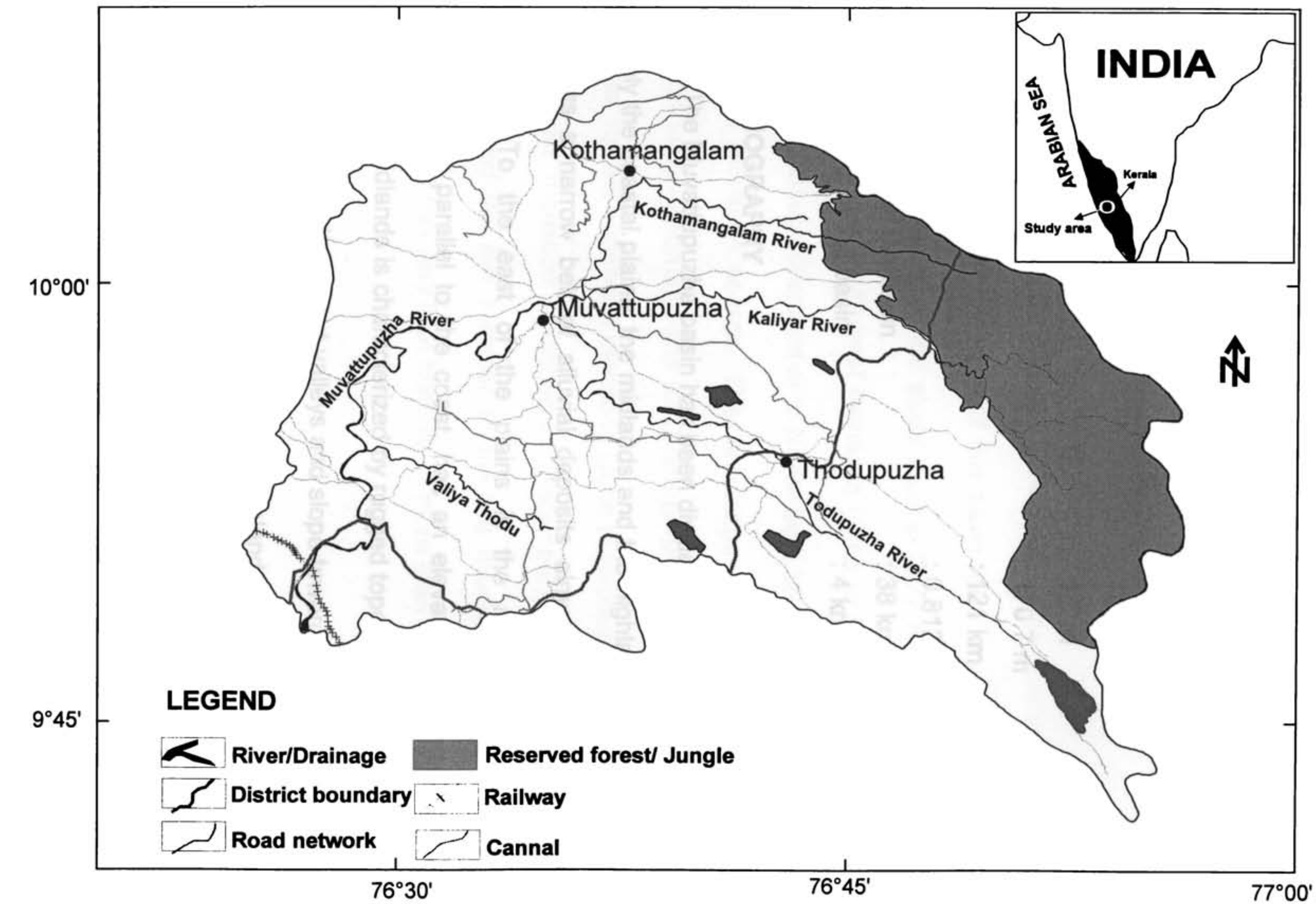


Fig. 1.1 Base map of the Muvattupuzha river basin

almost 116 km and thus the area of the river basin covered is only about 1488 km^2.

The important characteristic features of the Muvattupuzha river drainage basin (MVIP, 1976) are as follows:

Total catchment area	: 1554 km^2
Maximum altitude	: 1093.6 m
Minimum altitude	: 1.5 m
Mean altitude	: 170.7 m
Total length of the river	: 121 km
Mean slope	: 0.813
Maximum width of the basin	: 38 km
Minimum width of the basin	: 4 km

1.5 PHYSIOGRAPHY

The Muvattupuzha basin has been divided into three physiographic units namely the coastal plains, the midlands and the highlands. The coastal plains occur as a narrow belt of alluvial deposits almost parallel to the present shoreline. To the east of the plains is the midlands, which again is approximately parallel to the coast, has an elevation ranging from 6-80 m aMSL. The midlands is characterized by rugged topography consisting of small hills separated by deeply cut valleys and slope towards the west. It is generally covered by thick laterite cappings. The highland region (lying approximately to the east of 76^0 45'east longitude) is characterized by a roughly north-west trending ridges and high ranges of Western Ghats, which vary from 350 - 1000 m in height. The highest point in highland is 1194 m aMSL at Palkolammedu and is composed of Archean crystalline rocks.

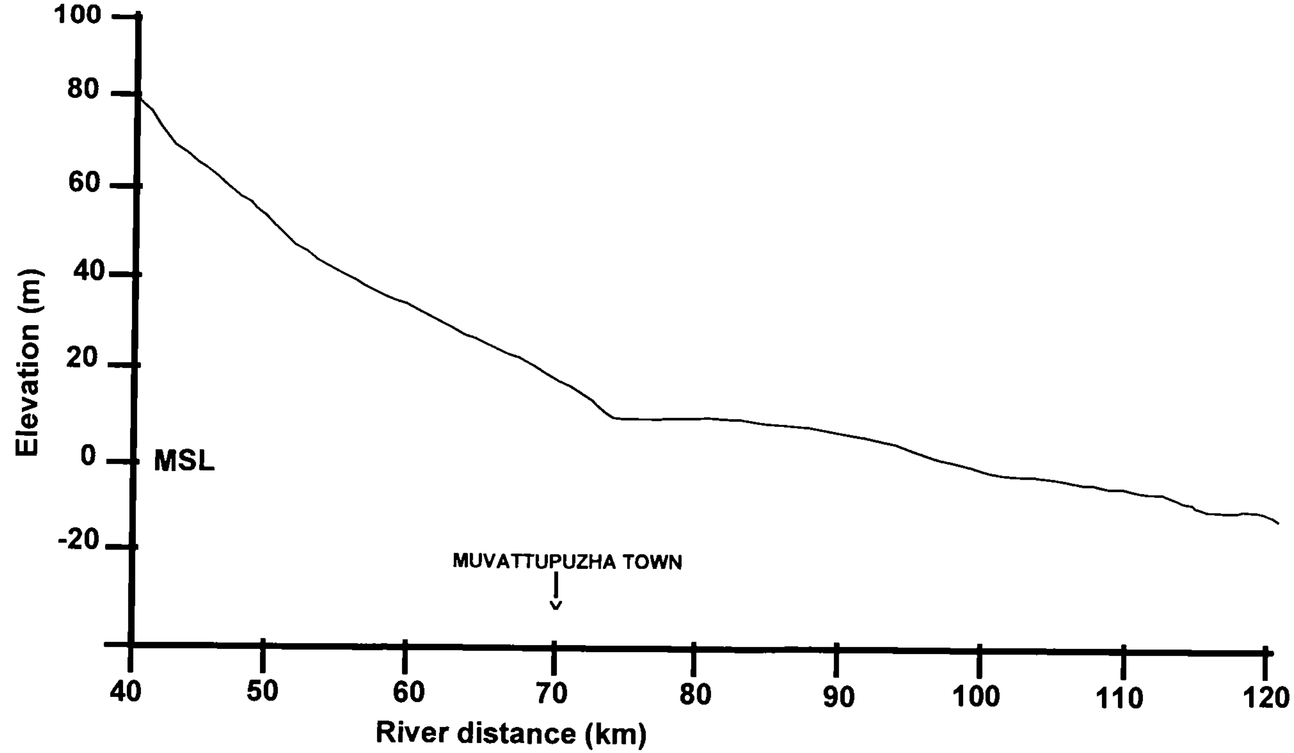
Fig. 1.2 depicts the longitudinal profile of river channel through the Thodupuzha-Muvattupuzha-Ittupuzha river systems. The profile shows gentle to moderate slope up to Muvattupuzha town. Then the gradient decreases considerably and the profile nears to Mean Sea Level (MSL).

1.6 CLIMATE

The Muvattupuzha drainage basin enjoys characteristic tropical humid climate. The high altitude areas of this basin have a temperate climate. The average annual rainfall of the study area is 2677 mm of which 1600 mm is received during the south-west monsoon (June to August) and 689 mm is on north-east monsoon (September to November). Maximum rainfall occurs during southwest monsoon season. The temperature of the basin varies between 10^0C (January - February) and 32^0C (March-May). Four seasons are identified in a year viz. the southwest monsoon (June to September), northeast monsoon or the post monsoon (October to December), the winter (January and February) and the hot summer or the pre monsoon (March to May). The catchment area has very high humidity of more than 80%.

1.7 DRAINAGE

Muvattupuzha River is about 121 km long and has a dendritic drainage pattern (Fig. 1.3). Muvattupuzha river (means joining of three rivers) is formed by the confluence of three tributaries, viz. Kothamangalam, Kaliyar and Thodupuzha rivers. The Kothamangalam river originates from Vanchimala and



(Source: Padmalal, 1992)

Fig. 1.2 Longitudinal profile (gradient) of the Thodupuzha-Muvattupuzha-Ittupuzha river channels

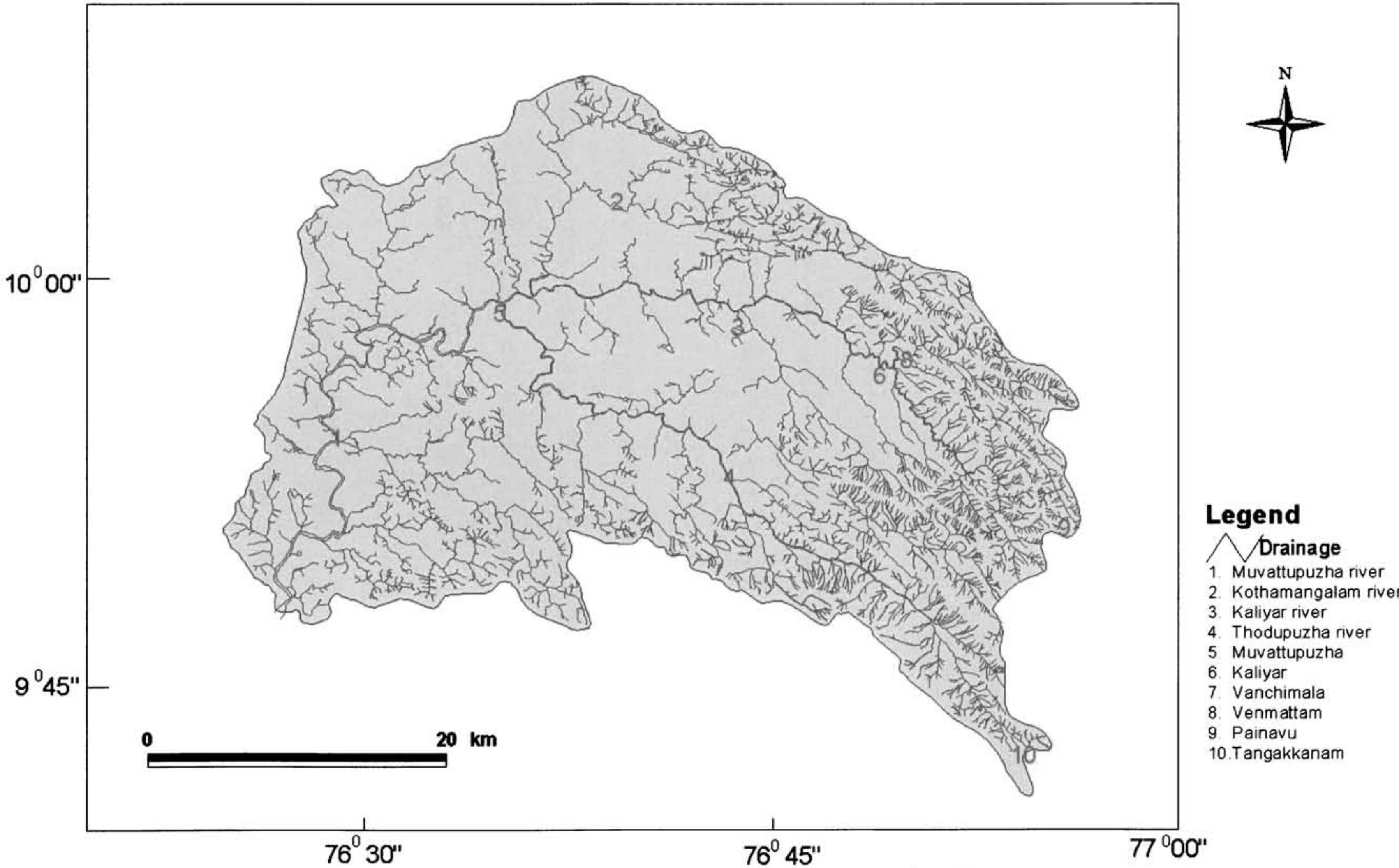


Fig. 1.3 Drainage network of the Muvattupuzha river basin

flows in a WNW direction for about 25 km and then turn right angle near Kothamangalam town and flows in a SSW direction for about 10 km and joins Kaliyar river (Plate 1.1).

The Kaliyar river originates near Painavu in Idukki district and flows in a NW direction for about 25 km with the name Velurpuzha and then takes the name Kaliyar river. Kannadi river joins the Kaliyar near Venmattam. One of the major tributaries of Kaliyar river is Karimannur river. Kaliyar river changes its trend near Naduvakad and flows in a westerly direction for about 20 km till the confluence of Thodupuzha river.

The Thodupuzha river originates from Tangakkanam hills (southwest part of the study area-Fig. 1.3) and its main tributaries are Valiathodu, Nach and Idakkaipuzha river. The Thodupuzha river flows in a north-western direction through Thodupuzha town till it joins with Kaliyar near Muvattupuzha town.

Both Kothamangalam and Kaliyar rivers join near Muvattupuzha town and forms the Muvattupuzha river, which initially takes an overall westerly direction till it reaches Kadamattom and thereafter flows towards south with a meandering course till it reaches Thalayolaparambu.

1.8 GEOLOGICAL SETTING OF THE STUDY AREA

The Muvattupuzha river drains through highly varied geological formations of Precambrian crystallines, Tertiary sedimentary rocks and laterites (Fig.1.4). Charnockites, hornblende-biotite gneisses and other unclassified

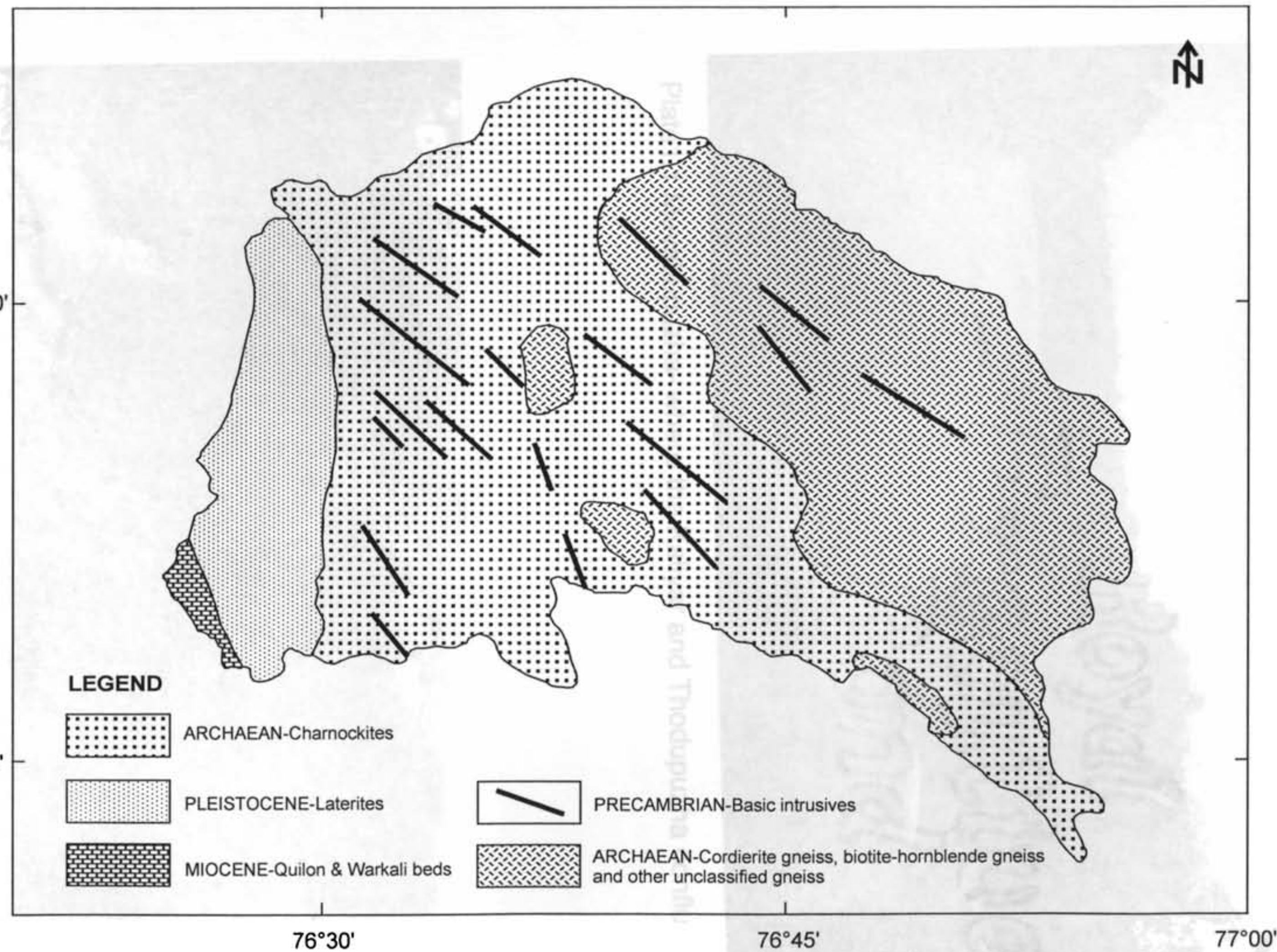


Fig. 1.4 Geology of the Muvattupuzha river basin

(Source: GSI, 1995)

Plate1.1 Muvattupuzha- where the Kaliyar and Thodupuzha confluence.

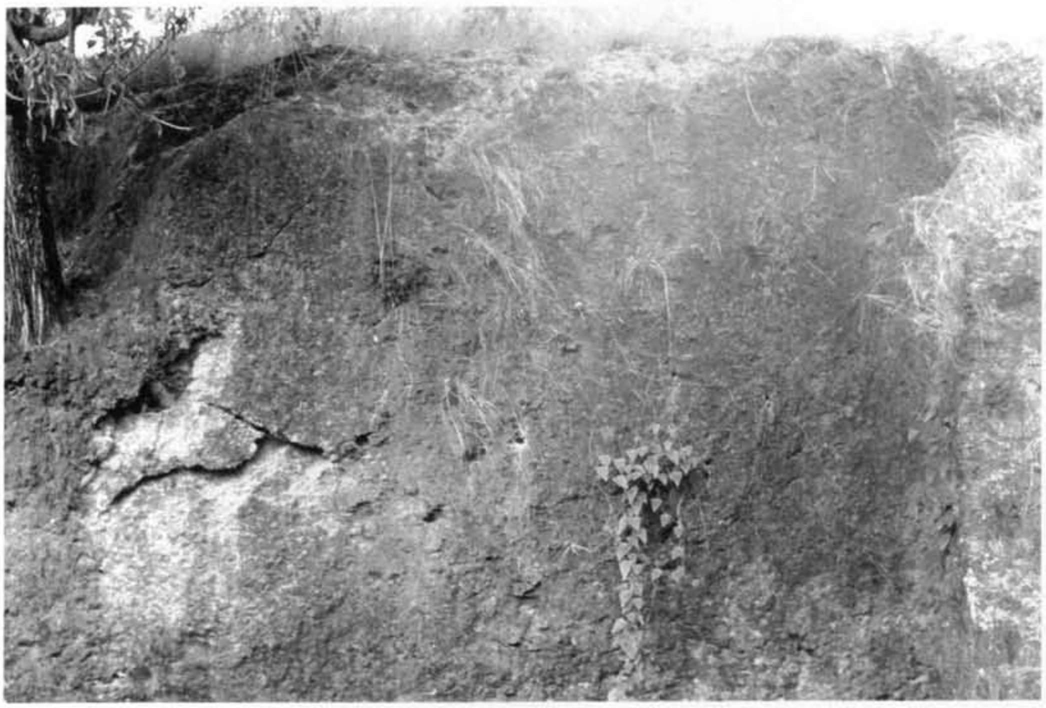


Plate1.2 The laterite over burden seen in the western part of the Muvattupuzha river basin.

gneisses form a major portion (~85%) of the drainage basin. They are often intruded by acid (granite, pegmatite and quartz vein) and basic (gabbro and dolerite) rocks. Laterites and sedimentary beds are prominently found on the western part of the river basin (Fig.1.4).

Archaeans: Archaeans (Fig.1.4) are mainly composed of charnockites and hornhlende-biotite gneisses. Calc-granulite occurs only at places particularly in the eastern part as elongated bodies within garnet-biotite gneisses (Najeeb, 1985).

Charnockites (consisting of massive charnockites, charnockites gneisses and pyroxene granulites) occur to the east of coastal alluvium. It extends from Tripunithura to Thalayolaparambu on the west, Kothamangalam to Thodupuzha on the east. Some of these rocks show foliations, with varying trends from NNW-SSE to NW-SE. To the east of charnockites is the hornblende-biotite gneiss. These rocks are the resultant of regional migmatisation of older rocks (Mahadevan, 1964). Bore hole lithology from the basin gives a succession of top soil, weathered charnockites, fractured charnockites, massive charnockites and charnockites with pegmatite veins (Fig. 1.5).

Intrusives: Dolerite and gabbro are the main intrusives in the Archaean rocks. These are swarms of dolerite dyke trending in NW-SE direction in the central part of Muvattupuzha river basin. A very prominent feature of this basin is the presence of NNW-SSE trending gabbro dykes (extending upto the northern part of the basin) having a width of upto 300 m. The other intrusives include

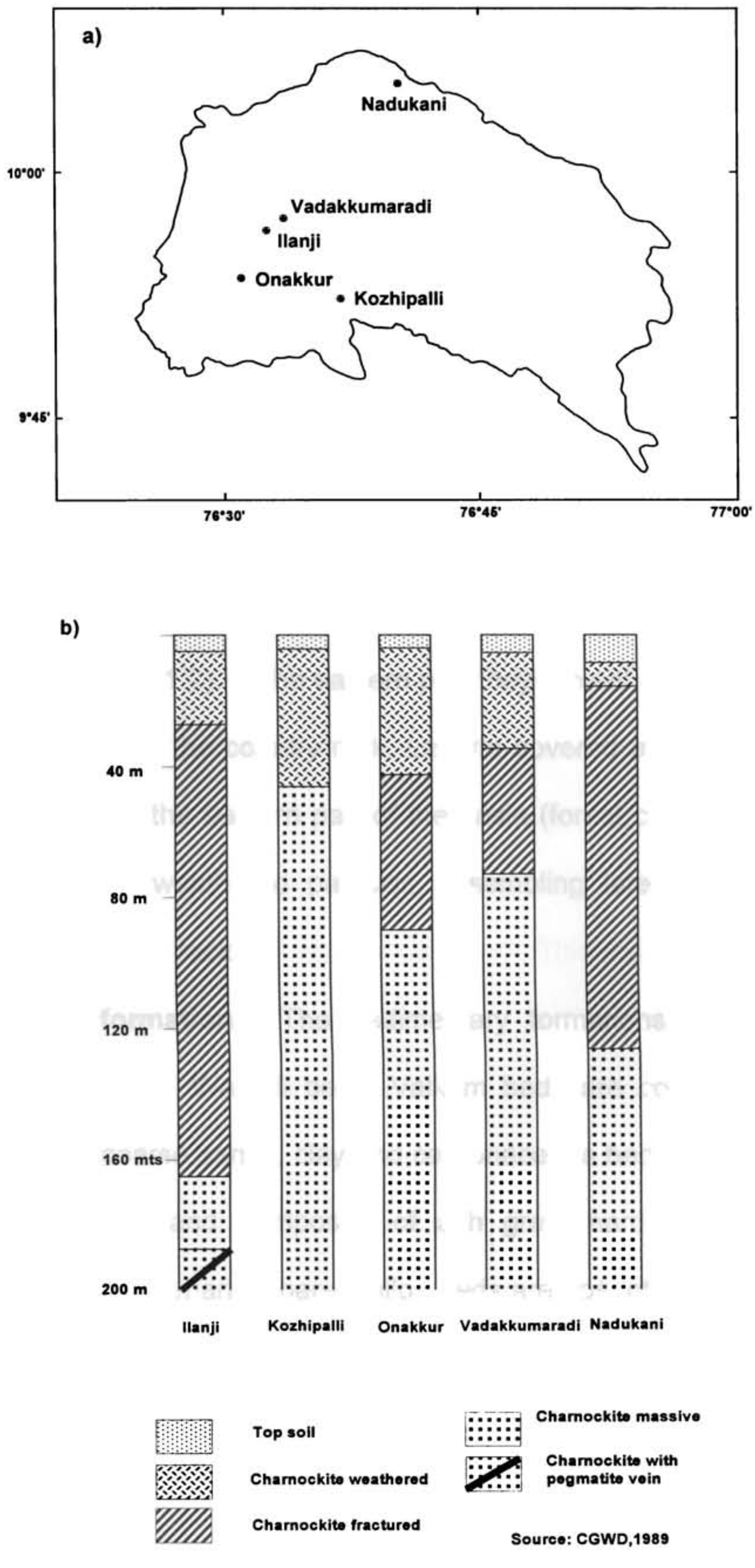


Fig. 1.5 Location of (a) bore hole stations and (b) bore hole lithology of the stations

pink granites and quartzo feldspathic veins. Pink granites are seen at Puduveli near Kuttatukulam. Veins are seen transversing through in garnet biotite gneiss near Kalikod, Kaliyar estate, Murialthodu and Edamaruku in the eastern part of the area.

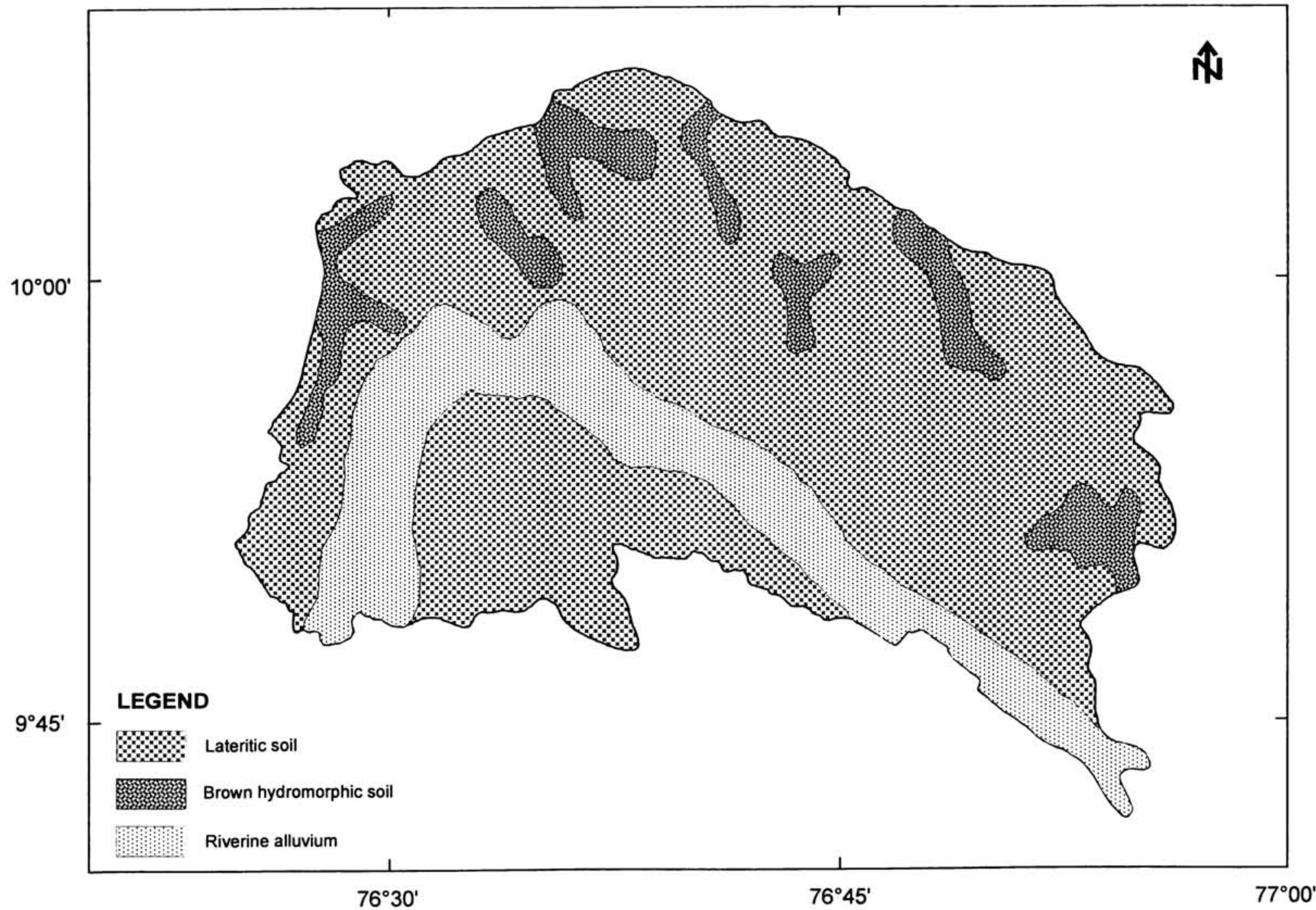
Residual laterite formations: Laterites are one of the major litho units in the western part of the basin. These insitu laterites are products of weathering and lateritisation of existing Archaean country rocks. At many places the process of lateritisation is not completed, and hence gneissosity, foliations and joints of the parent rocks are well preserved. The thickness of lateritisation is also vary widely from place to place and is maximum on the western part where it is around 20 m (Plate 1.2). In the eastern part they are either absent or observed as thin mantle over the country rock. Laterite covered areas are not properly demarcated along the eastern part of the basin (forest cover) since a reddish brown corona of weathered particles, resembling laterites is encountered above the crystalline rocks.

Sedimentary formations: The sedimentary formations are composed of Vaikom, Quilon and Warkali beds. Vaikom beds are composed of gravels, coarse to very coarse sands, clay and carbonaceous beds. Quilon beds overly the Viakom beds and composed of ash grey, hard compact limestone, calcareous clay and marl. Where Quilon beds are absent the Warkali beds are overlained by the Vaikom beds. Warkali beds consist of fine to medium grained semi-consolidated sandstone, coarse to very coarse sand, variegated clay with thin lenticular bands of lignite. This formation is observed on the western most part of the basin with very small areal extent.

1.9 SOILS

Three types of soils occur in the study area viz. lateritic soil, hydromorphic soil and riverine alluvium (Fig. 1.6). Lateritic soil is the most extensive soil type found in the area, occurring all along the midland area bordered by coastal alluvium on the west and forest loam on the east. The fertility of laterites is generally poor with low contents of nitrogen, phosphorous, potash and organic components. They are generally acidic with pH ranging from 5 to 6.2 (CESS, 1984). The major crops supported by the soil are coconut, tapioca, rubber, arecanut, pepper, cashew and spices.

The hydromorphic soil invariably occurs along the valley portion and is formed as a result of transportation and deposition of sediments from the adjoining hillocks either as alluvium or colluvium. This soil is usually clayey with moderate amount of organic matter, nitrogen, and potash and is deficient in lime and phosphate. They are the ideal soil for paddy cultivation. However, at places they require liming to reduce acidity. Riverine alluvium is restricted to the banks of rivers and their tributaries. The soil has moderate content of organic matter, nitrogen and potash, thus suitable for the cultivation of a variety of crops like coconut, paddy, tapioca, pepper, arecanut, banana, vegetables etc.



(Source:Dept. of Agriculture, Kerala, 1978)

Fig. 1.6 Soil map of the Muvattupuzha river basin

1.10 LANDUSE

Man's intervention in the catchment area of Muvattupuzha river basin has started a century ago. Before that, the catchment area was covered by luxuriant tropical forests and grasslands. In the second half of the nineteenth century clearing of forests started in highlands for rubber plantations. Nair (1987) has recognised five broad categories of landuse types distributed unevenly in the drainage basin. The highland region is used for rubber plantations. In the upper reaches of the river, in addition to rubber, pepper, tapioca, ginger etc. are also cultivated followed by forestlands, grasslands and arable lands. Extensive wastelands formed of hard crust of laterite which are generally unsuitable for cultivation, are also seen in the area. The lower regions are primarily used for tapioca and paddy cultivation. Since remote sensing is a powerful tool to analyse the landuse pattern, IRS-IC, LISS III data were used to study the current status of landuse pattern as well as for finding groundwater prospects zone of the Muvattupuzha river basin (see chapter 6).

1.11 OBJECTIVES

The major objectives of the present investigation are:

(1) To evaluate the aquifer parameters and yield characteristics through dug well pumping test as well as to decipher the groundwater prospects of this basin through geophysical surveys.

(2) To determine the seasonal variations (pre monsoon and post monsoon) of groundwater quality thereby to evaluate its suitability for various uses.

(3) To demarcate the groundwater potential zones through Geographic Information System (GIS) by the integration of various data obtained through remote sensing, geophysical survey and other terrain parameters like slope analysis, drainage, etc.

(4) To generate a scientific database for the groundwater of the Muvattupuzha river basin using GIS.

CHAPTER 2

METHODOLOGY

2.1 INTRODUCTION

Development of reliable water supplies for rural and urban communities in developing countries depends on the suitability of available water resources for human consumption. As long as ground water development is pursued at a very small scale (scattered dug wells with hand pumps), there is little justification for determining further quality parameters. However, once groundwater development is expanded to include irrigation bore wells with motorized pumps, the question of regional groundwater resources becomes important. Sustainable ground water development depends on effectively managing the regional groundwater resources so that adverse environmental impacts are avoided. Management of regional groundwater resources depends upon a thorough understanding of hydrogeology, rainfall conditions, water level, various lithological units, landuse pattern, geomorphology of the terrain and major and minor ions of groundwater chemistry.

Groundwater quality is related to its usage and availability. The study of groundwater resources in relation to water demand, involves the consideration of hydrogeological factors and quality characteristics. If groundwater is withdrawn at a rate greater than its natural replenishment rate, then the depth to groundwater increases and the resource is "mined". Groundwater quality includes the physical and chemical analysis as well as its interpretation. For human consumption, the most important water quality parameters are chemical and bacterial purity. Further focus on chlorides have been increased within the last decade. This increase of awareness is a result of greater emphasis upon hazardous waste sites in the United States, Europe and India the realisation is that many global environmental problems may also have implications for groundwater resources, including the potential influence of acid rain upon groundwater quality.

2.2 FIELD INVESTIGATIONS

As the Muvattupuzha river consists of three tributaries namely Kothamangalam, Kaliyar and Thodupuzha rivers and a vast area is being drained by small stream in the lower parts of the Muvattupuzha river basin, due representation has been given while site selection, groundwater sampling, geophysical survey etc. For convenience of discussion the main Muvattupuzha river basin has been divided into four sub basins (Fig. 2.1)

1. the northern Kothamangalam river basin
2. the central Kaliyar basin
3. the southern Thodupuzha river basin and
4. the western Muvattupuzha sub basin falling west of Muvattupuzha town in a north south direction

2.2.1 Groundwater sample collection

Groundwater samples have been collected from 55 dug wells in the Muvattupuzha river basin. Sampling was done during the year 2001 covering

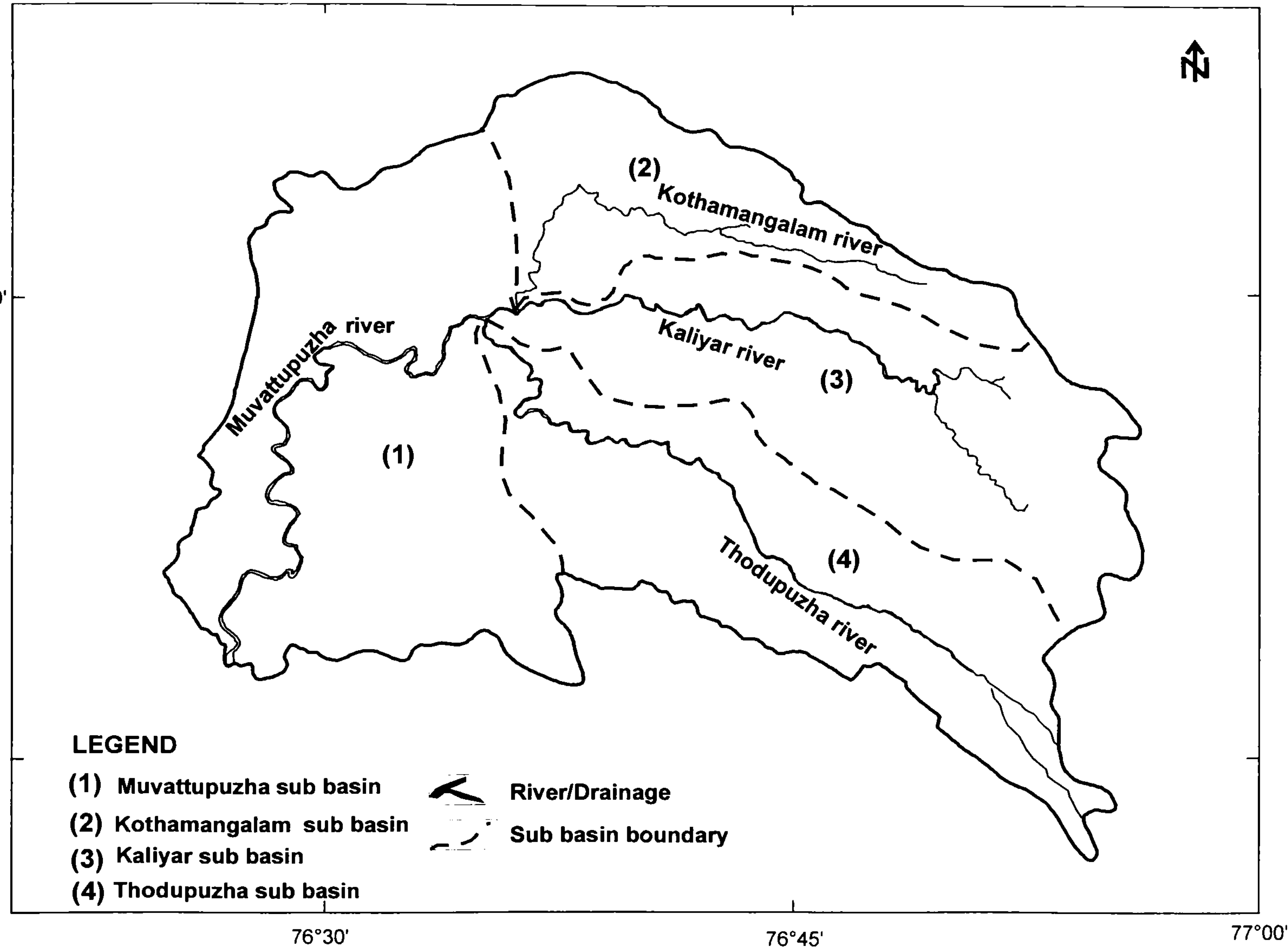


Fig. 2.1 Sub basins of the Muvattupuzha river basin

both pre monsoon (April) and post monsoon (December) periods. Groundwater samples were collected in a pre cleaned plastic polyethylene bottles. Prior to sampling, the sampling containers were rinsed two to three times with the respective groundwater under sampling. Many of the water quality parameters pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured in the field itself. For fixing total iron, samples were preserved in the field by adding concentrated HCl (2ml/100ml) as a preservative agent and transported to the laboratory following standard guidelines (APHA, 1985). For bacteriological analysis the samples were collected aseptically in sterilised bottles and transported to the laboratory in icebox maintaining the temperature at 4^0 C. Coliform tests were done within 12 hours of sampling.

2.2.2 Aquifer tests

Hydraulic properties of rock materials can be estimated following several techniques with in the field itself. The choice of a particular method depends on the purpose of the study and scale of investigations. For small-scale problems, like seepage of water into mines, packer test, slug test and tracer test are preferable. In case of groundwater development and management on a regional scale, usually pumping method is preferred. In the present investigation pumping test has been conducted for 17 dug wells.

Pumping tests: Pumping test is one of the most useful means in not only for determining the aquifer hydraulic characteristics, but also in the determination of yield and drawdown, specific capacity and designing of wells. Pumping test is an expensive procedure and therefore should be properly planned. The cost of testing depends on the number of pump tests and the duration of the tests. Before conducting pump test, certain factors should be kept in mind such as geology of the area and hydrological conditions of the test locations.

Numerous techniques are available for analysing the pumping test data of wells of which the classical methods are mostly graphical in nature. The hydraulic properties in hard rock formations are usually influenced by the nature of weathering of the rock, which is more, pronounced near the surface. The permeability of hard rocks generally decreases with depth. In the present study dug wells with depth ranging from 3 to 15 m are taken into consideration. In some cases the wells have not reached the unweathered basement rock.

Choice and shape of well: For selection of wells for pump test, it is necessary to know the geological and hydrological conditions of the area. In this basin majority of the wells are situated within valleys (having a considerable thickness of laterite capping) and a very few in the hilly terrain. In this work while selecting wells, due representation has been given for each of the geological formations that has a major share in the formulation of the basin. But in the eastern part of the study area only a few pump test are conducted because of the forest and hilly regions. The 17 pumping test wells are all circular in shape. Circular wells are preferred as they have equivalent perimeter from top to bottom.

Measurements: The measurements, to be taken during an actual pumping tests, fall into three groups (1) pre-pumping phase measurements, (2) pumping phase measurements and (3) recovery phase measurements. The pre-pumping phase measurements include radius of well, depth of well below measuring point, depth of static water level below measuring point and initial depth of water column in the well. In the pumping phase, measurements of constant well discharge, drawdown at the end of pumping phase, time taken for pumping and drawdown within the well diameter in minutes during pumping are taken. And in recovery phase, measurements of drawdown within well diameter in minutes after stopping the pumping are recorded. Pumping test should not be started before the already existing water level changes in the aquifer are known, including both long-term regional trends and short-term variations of the water level. Hence, for some days prior to the actual test, the water levels in the well should be measured twice a day. This is not practically viable in a developing country like India as the farmers of this region rely on one or two wells for their irrigation and therefore, long duration pumping test could not be conducted. Prior to the pumping test, a request is made to the well owner not to start the pump until the observer informs them to do so. Water level measurements were made using a steel tape. Well discharge can be measured using different types of wires; circular orifice wire being the most common (Driscoll, 1986)

Time interval of water level measurements: The duration of the pumping test depends on the type of aquifer and the purpose of the test. Usually the test is continued till the water level is stabilised so that both the non-steady and steady state methods of analysis can be used for computing aquifer parameters. In pumping test, immediately after starting the pump or its stoppage, the fall or rise of water levels is very rapid and hence the water level measurements should also be very rapid during this period. Kruseman and de Ridder (1990) have proposed a range of time intervals for pumping measurements of wells in confined, leaky and unconfined aquifers and are at 24h, 48h and 72h respectively. The time intervals adopted during pumping and recovery phase of the present investigation are given Table 2.1.

Table 2.1 Time intervals for pumping and recovery phases

Time since pumping started (Minutes)	Time intervals in minute
(1) Pumping Phase	
0 – 50	5 –10
50 – 120	10 –15
120 - shut down of the pump	15 – 30
(2) Recovery phase	
0 – 30	5
30 - Final recovery reading	15 – 30

Discharge and recharge measurements: In order to avoid the complications of calculations, the discharge rate should preferably be kept constant throughout the test. The discharge measurements have been made using the standard procedures of Kruseman and de Ridder (1970) during the pumping phase whereas the recharge rate or recovery phase has been computed by multiplying the drawdown with the cross-sectional area of the well. In the present study the pumping test data were analysed using the computer programme- APE- in Basic language (Appendix-1).

2.2.3 Major geophysical techniques used in groundwater exploration

Some of the important techniques which, have proven effective in resolving horizontally layered aquifers (and confining beds) are resistivity soundings, electromagnetic (EM) soundings in the frequency domain or time domain (TEM), high-resolution shallow seismic reflection, seismic refraction, and controlled-source audiomagnetotellurics (CSAMT). Electrical methods (resistivity, EM, TEM, CSAMT) which measure the electrical conductivity contrast between sedimentary layers, dependent on the grain size, mineralogy (sand/clay ratio), and water content (saturated versus unsaturated). Seismic methods rely on acoustic velocity contrasts, which again dependent on grain size, degree of consolidation, density, and water content of a formation.

Bedrock aquifers or fractured-rock systems are often delineated using electrical methods such as VLF (very low frequency EM) profiling, horizontal-loop EM (HLEM, slingram, terrain conductivity, etc.) profiling, seismic refraction and CSAMT. EM methods rely on geometric coupling of a transmitted time-varying magnetic field with a planar conductor, such as an enhanced-conductivity fault or fracture. Seismic refraction is sometimes very useful in detecting bedrock associated with a fracture or fracture zones. If a fracture zone is wide enough, a lateral velocity contrast can sometimes be detected.

Buried-valley aquifers and other preferential-flow pathways have been delineated using electrical, seismic, and micro-gravity methods. The large physical property contrast between consolidated bedrock and overlying unconsolidated sediments has been successfully exploited by a variety of geophysical methods. Electrical methods (resistivity and EM) are often useful because there is a large resistivity (conductivity) contrast associated with the large porosity change between unconsolidated and consolidated materials. Seismic refraction and reflection methods also detect this porosity contrast as an acoustic velocity contrast. Micro-gravity methods have been used to detect buried valley aquifers due to the density contrast between unconsolidated and consolidated materials. It should be noted that gravity method is very useful in urban areas since it is relatively insensitive to cultural noise sources such as buildings, utility lines, and fences.

There are limitations to which geophysical methods can be used to accomplish. Sufficient physical property contrast between lithological units of interest must exist in order for specific geophysical methods to be of use. For example, the ionic content of pore water within the saturated zone of a granular aquifer may not allow it to be distinguished from the overlying unsaturated zone using electrical methods. However, an alternate method like seismic refraction might be successful. Conversely, a lithologic variation from silty sand to sandy silt may be significant to groundwater flow, might be identifiable with a resistivity survey and not seismic refraction. It is for these reasons that multiple geophysical methods are usually recommended. Often a combination of different geophysical methods can provide a more comprehensive picture of hydrogeological variation in the subsurface. This expansion of related information can often be critical in solving regional groundwater problems. The depth of investigation and resolution of specific geophysical methods are often a significant limitation. As a general rule, greater the depth of investigation, lesser the resolution or detail, which can be obtained about the target. In addition, often higher the required resolution at depth, higher the cost of obtaining that resolution.

Electrical resistivity methods: Electrical resistivity is one of the most widely used geophysical techniques, which gives good indication on the occurrence of fractured horizons, as well as quantity and quality of ground water. However, this survey should be carried out at locations where the subsurface geology is better known. The electrical resistivity of geological formation depends upon the material as well as upon the bulk porosity and water content of the formation. Thus the electrical resistivity of a dry formation is much higher than that of the same formation when it is saturated with water. This will provide useful controls in the interpretation of geophysical data in terms of subsurface geology, which can be extrapolated to other areas.

The geoelectrical properties of country rock and sediments together with its spatial distribution give the geological information of an area. Both can be acquired by electrical resistivity survey. In simple terms, this method involves the application of an electrical current to the ground via two source electrodes with the potential difference created at the ground surface being measured between two receiving electrodes. The effective depth of a "sounding" is increased by sequentially increasing the distance between these electrodes. Recorded resistivity values can be considered the weighted average of the resistivity of all the beds down to the deepest bed detected. Differences in resistivity values occur when there is a change in subsurface conditions. These changes may be geoelectric boundaries and typically correspond to changes in either lithologic composition, formation porosity (such as an increase in fracturing), and /or changes in groundwater chemistry. Clearly, the current prefers to flow in a bed of lower resistivity, such as clay; conversely, more the sand and gravel, greater the resistive properties. The various electrical methods commonly employed to solve different geological problems (Bhimashankaram and Gour, 1977; Patangay, 1977) are listed in Table 2.2.

Electrical resistivity method is the most preferred tool in exploring ground water, primarily due to its simplicity of investigational operations, relatively better resolving powers, simpler interpretational procedures, as well as reasonably good results (Todd, 1980). Its application for locating borewells in areas underlained by hard crystalline rocks is very popular (Patangay, 1977; Verma et al., 1980; Ballukraya, 1996). Depending upon objectives, a resistivity survey may be employed via several techniques, the most commonly used are Vertical Electrical Sounding (VES) and horizontal profiling. The VES technique is analogous to electrical drilling because the result is a one-dimensional interpretation of the subsurface, similar in profile to a common drill log. This technique typically involves the correlation of multiple sample locations to produce geoelectric cross-sections from which the general stratigraphy and structural setting are identified. Unlike electrical resistivity method horizontal profiling provides a two-dimensional profile of the subsurface, similar to viewing

Table 2.2 Electrical Methods employed for common hydrogeological problems

Nature of the problem	Methods used
1. Assessment of subsurface structure	VES, DES, FEMS,RIS
2. Study of horizontal and vertical distribution of aquifers	VES, DES, FEMS, RIS
3. Tracing salt water – fresh water interface	VES, FEMS, RIS, IP, EP
4. Estimating groundwater quality	VES, FEMS, RIS, IP
5. Mapping valley fills	VES, FEMS
6. Mapping thick sediments over impermeable substratum	VES, RIS, IP, VES
7. Tracing groundwater movement	SP
8. Depth to the water table	VES, IP, VES, RIS, FEMS

EP – Electrical Profiling

DES – Dipole Electrical Sounding

FEMS – Frequency EM Sounding

IP –Induced Polarisation

SP – Spontaneous Polarisation

RIS – Radio Interference Sounding

RP – Radiowave Profiling

VES – Vertical Electrical Sounding

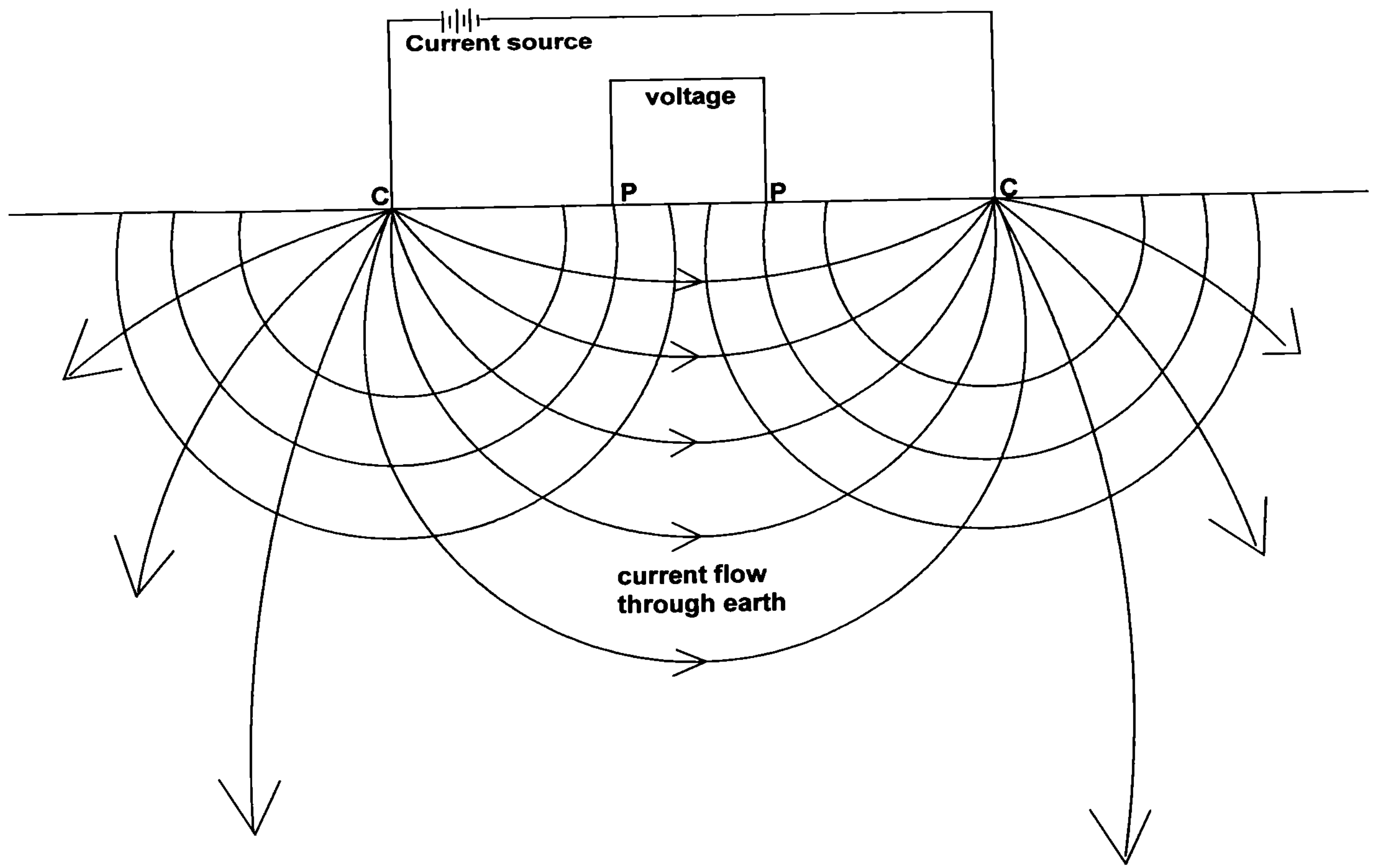
the wall of an excavated trench. This technique is typically used when greater details are needed.

Basic principles: In the electrical resistivity method, electric current is introduced into the earth through two current electrodes. The electric potential depends upon the resistance of the earth material and the amount of current flow. Two potential electrodes, positioned within the field of current electrodes, give potential data. The data on current flow and potential drop are converted into resistivity values; the field resistivity values are apparent rather than true. The electrical resistivity survey for groundwater is comprised of sounding and profiling. The sounding technique is used to determine variations in electrical resistivity with depth, whereas profiling is used for delineating lateral variation of resistivity across an area.

Electrode configuration: The electrodes are normally linear and the potential electrodes are placed in between current electrodes and are symmetric with respect to the centre of the configuration. The most common electrode spacing is the Wenner and Schlumberger arrangements. In Wenner configuration, the electrode spacing 'a' (both current and potential electrode spacing) is kept equal. On the other hand the Schlumberger configuration, the distance 'L' (current electrode separation) is varied, while keeping 'l' (potential electrode separation) constant.

In Vertical Electrical sounding (VES), also called electrical drilling, the distance between electrodes is steadily increased with regular intervals so that the electric current penetrates deeper and deeper levels. Broadly the depth of investigation of resistivity survey is directly proportional to the electrode spacing (Bhattacharya and Patra, 1968; Zohdy et al., 1974; Koefoed, 1979). The electrode configuration used in this study is Schlumberger arrays (Fig. 2.2).

The apparent resistivity is plotted against the electrode separation. This resistivity curve is then interpreted in terms of horizontally stratified materials, thereby obtaining the number of layers, their respective thickness and resistivity, with the help of standard curves prepared by Oreelana and Mooney (1966) for Schlumberger arrays. Standard computer programme is also available for this purpose. In the present work, the resistivity data has been processed by an automated curve matching method through numerical computed techniques. For this purpose, computer software IPI2 developed by Moscow University has been used. In this software the Root Mean Square (RMS) error should be less than 2%. The results are validated by curve matching techniques (theoretical curves constructed for an assumed geo-electrical section). Twenty-seven VES surveys are conducted (during April and May) in this investigation and another thirteen VES data are obtained from Central Ground Water Board (CGWB) to cover the entire basin. In this study the maximum electrode spacing (AB/2) in VES is 100 m, whereas the data collected from CGWB for the same area, the A/B/2 varies from 200 to 300 m.



C = current electrode

P = potential electrode

Fig. 2.2 Schlumberger electrode configuration for resistivity survey

2.3 LABORATORY WORK

2.3.1 Chemical analysis

Seasonal concentrations of various anions and cations of the groundwater were chemically analysed (Table 2.3) using standard procedures (APHA, 1985). Major focus was given to the concentrations of ions such as Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, CO_3^{--}, SO_4^{--} and Cl^-. Sodium and potassium in groundwater samples were analysed using Flamephotometer (Systronics FPM digital model). Calcium, magnesium and total hardness were estimated by EDTA (0.01M) titrimetric method, whereas chloride was determined by argentometric titration using standard silver nitrate as reagent. Carbonate and bicarbonate concentrations of the groundwater were determined titrimetrically against standard hydrochloric acid (0.01N). Sulphate concentration was carried out following turbidity method using Spectrophotometer. The total iron and sulphate in samples were analysed through a double beam UV-Visible Spectrophotometer (Hitachi Model 2000). The fluoride concentration was based on the colorimetric method using SPADNS reagent. TDS, EC and pH measurements were carried out in the field using TDS meter (CM-183), conductivity meter (CM-183) and pH meter (pH scan1) respectively. The values of TDS and EC were validated using the following relationship 1µS/cm = 0.65 mg/l.

Table 2.3 Methods followed for the determination of various physical and chemical parameters of groundwater

Sl. No.	Parameters	Methods
1	pH, TDS & conductivity	Electrolytic
2	Na^+ and K^+	Flame photometry
3	Ca^{++}, Mg^{++}, HCO_3^-, CO_3^{--}, Cl^- and total hardness	Titrimetry
4	SO_4^{--}, total iron and fluoride	Spectrophotometry

Minor errors in the chemical analysis of groundwater may occur due to (1) the reagents employed (2) limitations of the methods or instruments used (3) presence of impurities including distilled water and (4) the personal error of the analyst. To minimize these errors analytical grade reagents were used. Also the instruments were periodically calibrated to assure the quality of generated data.

Cation-anion balance is especially important in the case of ground water analysis. Cation-anion balance check is a convenient technique to assess the reliability of measurements and the accuracy of data. The accuracy in the chemical analysis of water samples can be checked by calculating the cation-anion balance, in that the sum of major cations should be equal to the sum of major anions which is expressed in meq l^{-1}. To account for source dependency an allowable error limit of 10% is acceptable. The percentage error termed as ion balance error (e), can be determined following the equation given by Matthess (1982).

$E = \varepsilon\gamma c - \varepsilon\gamma a / \varepsilon\gamma c + \varepsilon\gamma a$

γc = cation sum in meq/l

γa = anion sum in meq/l

The ionic concentration of groundwater can be expressed in two different ways:

i) the ppm (parts per million, mg/l) concentration and

ii) epm (equivalent per million, meq/l) concentration

The evaluation of data were carried out using several standard techniques of groundwater hydrochemistry. These techniques include graphical methods like (a) hydrochemical isocone maps (b) hydrochemical diagrams such as Hill-piper and Durov's diagrams and (c) Johnson's (1975) hydrochemical facies diagram. The suitability of target water for irrigation was determined by the U.S.S.L. (1954) diagram. Gibbs's (1970) diagram was used to study the mechanism, which control groundwater chemistry.

E.Coli: To assess the bacteriological quality of water samples, E.coli analysis was carried out only for a single season (post monsoon). For the detection of E.coli, the samples were streaked on mac conkey agar plates. The brick red bacterial colonies in the agar plates after incubation indicate the presence of E.coli.

2.4 SECONDARY DATA COLLECTION

2.4.1 Rainfall and water level data

The twenty-seven National Hydrographic Stations maintained by CGWB were utilized for analysing the trend of ground water level for 10 years (1992 to

2001). The water level data of the pre and post monsoon seasons of the above period were used for finding out the trend of water levels, the water level fluctuations, the groundwater flow directions and for preparing grid deviation maps (for details see chapter 3). Hydrometerological data were collected from Indian Meteorological Department in order to prepare well hydrographs.

2.5 SATELLITE DATA COLLECTION AND IMAGE PROCESSING

The satellite data of IRS-1C LISS III (1997, geocoded FCC) and IRS-1D LISS III (1999, both digital and geo-coded FCC) of the study area were used. Geocoded data were checked in the field to obtain ground control points and digital data were processed in the laboratory using digital techniques. LISS III camera, one of the three sensors used in IRS-1C, provides multispectral data in four bands; two in visible (0.52-0.59 and 0.62-0.68 μm), one in Near Infra Red (NIR, 0.77-0.86 μm) and one in Short Wave Infra Red (SWIR, 1.55-1.70 μm) regions of the electromagnetic spectrum. It has a spatial resolution of 23.5 m in visible and near infra red region and 70.5 m in short wave infrared region. A path row based full scene product covers an area of 141 x 141 km^2.

The details of the satellite data are given below

Data	Data details
Satellite data	Path & Row: 100/67
IRS 1C LISS III	Date: 11.10.1997
IRS 1D LISS III	Date: 24.02.1999

2.5.1 Data analysis

Two major methods of data analysis for extracting resource related information from data products, either independently or in some combination with other collateral information, are Digital Image Processing (DIP) Techniques and visual interpretation. Analysis and interpretation of satellite data were done by employing both visual interpretation and digital image processing.

2.5.1a Digital image processing

Digital image analysis techniques involve the manipulation and interpretation of raw digital images with the aid of a computer. The different steps followed in digital image processing techniques include loading of satellite data, rectification and restoration, image enhancement and information extraction. The digital data from CD ROM was imported to the hard disc following the data import option of the software ERDAS IMAGINE. Image rectification and restoration are pre-processing techniques employed to remove the noise from the image. The above mentioned satellite images were rectified with reference to Survey of India topomap nos. 58 B/8, 58 B/12, 58 B/16, 58 C/5, 58 C/9, 58 C/13 and 58 C/14 and field Ground Control Points (GCPs). An Area of Interest (AOI) i.e. Muvattupuzha watershed was selected as a subset from rectified images. The rectified images were classified (supervised and unsupervised) on the basis of ground truth observations. Area covered by different classes was estimated by multiplying with spatial resolution. Accuracy test is also performed in order to confirm the perfection of the procedure.

Correcting geometric distortions: Geo-referencing of satellite imagery is one of the most time consuming tasks in remote sensing (Lillesand and Keifer, 1994). There are three basic approaches to geo-referencing satellite images. In the first, a certain number of GCPs are used. With a minimum number of GCPs we can use a polynomial model to relate image and map coordinates and determine the polynomial coefficients by a least squares approach. This mathematical model makes the determination of map coordinates of all image pixels possible. The accuracy is checked with an independent set of GCPs not used in the construction of the least square model, and the final Root Mean Square (RMS) error is usually taken as a measurement of accuracy.

Image enhancement: Image enhancement is a method of enhancing the visible interpretability of an image. To find out the health status of vegetation of the study area, Normalized Difference Vegetation Index (NDVI) is carried out. NDVI is the computation of ratio images using data in infrared and visible bands of the electromagnetic spectrum. It is defined as: NDVI = (IR-R) / (IR+R). This ratio image technique is the most commonly used by vegetation scientists to correlate photosynthetic activity and vigour in green biomass by taking advantage of spectral behaviour of vegetation in the infra red and red regions of the EM spectrum. Healthy vegetation reflects 40 to 50% of the incident NIR (0.7 to 1.1 μm) energy with chlorophyll absorption being 80 to 90% of the incident energy in the visible band (0.4 to 0.7 μm). Segmentation of

NDVI images helps in differentiating forest cover density and understanding the health of vegetation.

Image classification: Image classification is the process of sorting pixels into finite number of individual classes or categories based on their DN values. If a pixel satisfies a given set of criteria, then that pixel is assigned to the class corresponding to those criteria. Two popular image classifications are in use namely unsupervised and supervised.

Unsupervised classification: Unsupervised classification is more computer-automated. It allows the user to specify parameters, which can be used as guidelines by the computer software to identify the statistical patterns in the data and group them without using any ground truth data. Performing an unsupervised classification is simpler than a supervised classification, because a particular algorithm automatically generates the signatures.

Supervised classification: In this process, the user will select pixels representing different classes in training sets based on ground truth data. Therefore user can control the classification more closely than in the unsupervised classification. Later, the computer software identifies the pixels of similar characteristics and classifies the entire image using the data set fed by the user. If the classification is accurate, then each resulting class corresponds to a pattern that user has originally identified. Information about the data, number of classes desired and the algorithm to be used are required before selecting training sets.

2.5.1b Visual interpretation

In addition to DIP analysis, visual analysis of satellite data has also been followed for extracting information on various natural resources. The elements of image interpretation include colour, tone, texture, shape, size, drainage pattern and associated landforms. Success in visual image interpretation varies with the training and experience of the interpreter, the nature of objects or phenomena being interpreted and quality of the images being utilized. In the present work thematic maps such as geomorphology, lineament and landuse were prepared from visual interpretation of LISS III geocoded products.

2.6 GEOGRAPHIC INFORMATION SYSTEM

While remote sensing system remains a powerful tool for the collection of classified spatial data, the GIS acts as a powerful tool for the management and analysis of spatial data. Most of the GIS utility maps as their primary source of spatial data and remote sensing systems produce such spatial data in the form of maps. The interpreter generally utilizes these complex maps for visual search and retrieval but when the same data are digitised, GIS is the best for their integration. For finding out groundwater potential zones, GIS can play a vital role for demarcation of various zones. Pratap et al. (2000) have demarcated groundwater prospecting areas using remote sensing and GIS in Dala-Renukott area, Uttar Pradesh and have classified the area into five zones such as excellent, very good, good, moderately good and poor.

2.6.1 Development of groundwater prospect zone

After reviewing the capabilities of GIS in groundwater potential assessment, it is decided to use GIS in conjunction with geological, geomorphological, hydrogeological and geophysical data and a detailed methodology is given in Fig. 2.3. Most GIS systems do not as such support the complete analytical functionality to perform the groundwater analysis. The GIS software used for the present study is Arc/Info rather than other raster and vector based GIS. It has the capability of transferring raster to vector module. The development of GIS database in the desired format is complex in nature particularly for the hydrological analysis. The GIS spatial database is composed of thematic layers of various information on resistivity, geology, geomorphology, drainage density, lineament density etc. All the maps were scanned using CADIM image scanning software. The scanned maps were then transferred into Arc/Info and edited using Arctools. These edited maps were used for the analysis.

These maps were georeferenced to common reference point in the UTM plane co-ordinate system. This was accomplished by establishing reference points common to all maps chosen for the purpose. All the base maps were transformed to a common format for further analysis. A partial listing of various GIS data base components and map representation of GIS derived data base are given in the Table 2.4a & b. The following steps have been performed to establish the required GIS database.

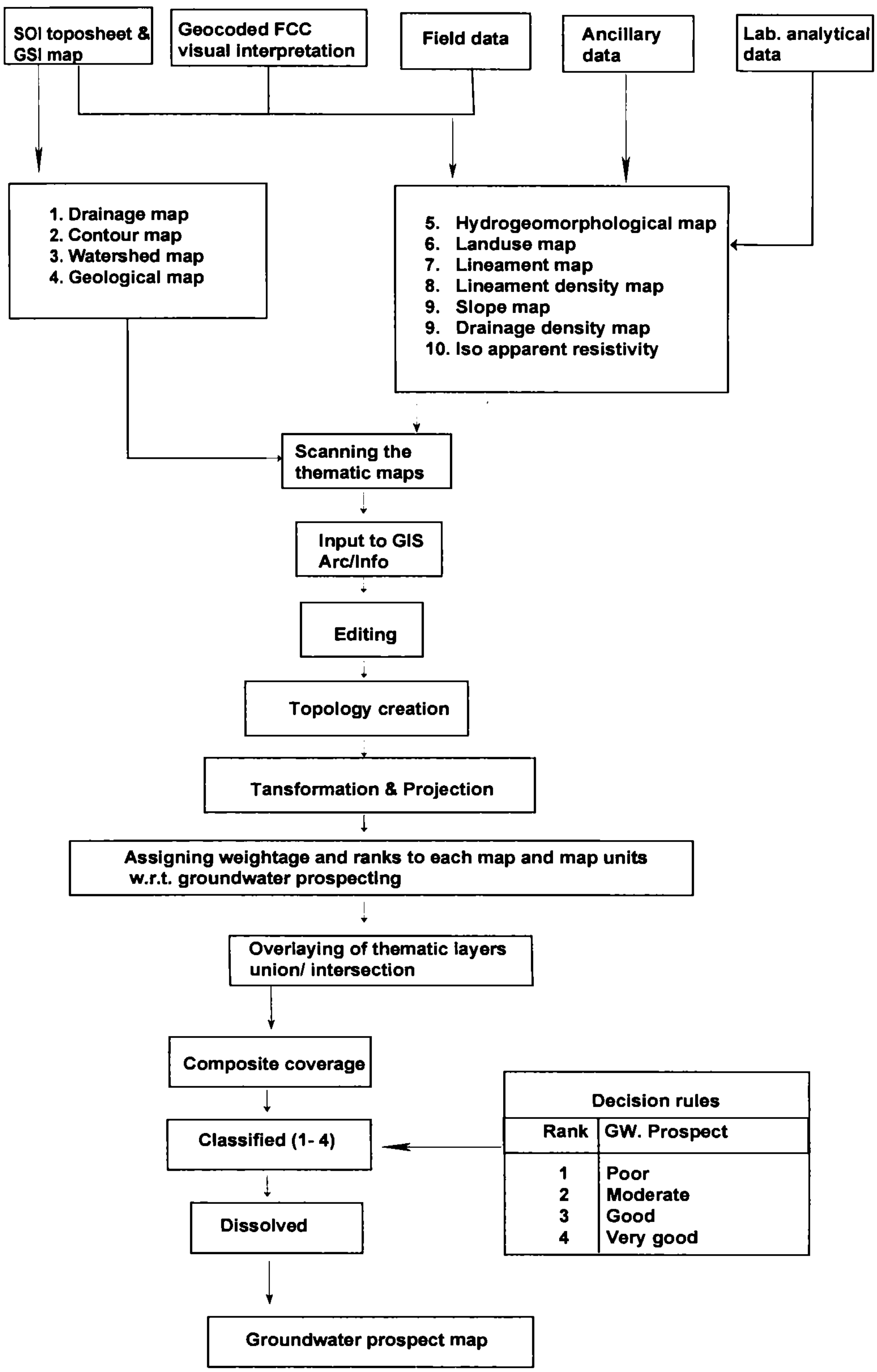


Fig. 2.3 Flow chart showing the methodology for delineating groundwater prospect zones in GIS

- Fixing the boundary line of the study area.
- Cleaning, building and data editing with in the GIS for removing dangles, gap in the scanned images.
- Creating attributes database into files for all the maps.
- Clipping of the entire map in order to convert them into a standard format.
- Different GIS derived maps and coverage in the standard format.

Table 2.4a GIS database Components and their method of representation

Data source	Database components	Method of representation
SOI topographic sheets at 1:50,000 scale	Drainages and contours	Line
Geology map at 1:5,00,000 scale (GSI)	Rock type boundary	Polygon
Resistivity survey	High and low resistivity zone	Polygon
IRS – 1C, LISS III	Lineaments Lineaments density Geomorphology Landuse	Line Polygon Polygon Polygon

Table 2.4b Map representation of GIS derived database and their data format

S. No.	Map	Format
1	Existing drainage network map	Vector
2	Drainage density	Vector
3	Geology map	Vector
4	Watershed and sub watershed map	Vector
5	Resistivity map	Vector
6	Geomorphology	Vector
7	Lineament	Vector
8	Lineament density	Vector
9	Slope map	Vector
10	Landuse	Vector

In order to demarcate the groundwater potential zones in the Muvattupuzha river basin different thematic maps were prepared in 1:50,000 scale from conventional data and remotely sensed data. The thematic maps on (i) resistivity (ii) lithology (iii) drainage map and (iv) contour map were prepared using the data obtained through field investigation, from secondary sources and Survey of India topographical sheets in 1:50,000 scale, while (v) hydrogeomorphology (vi) lineament map and (v) landuse were prepared using Indian Remote Sensing Satellite (IRS-IC), Linear Imaging Self scanning Scanner- III (LISS-III) geocoded photographic products. Each theme was assigned a weightage depending on its influence on the movement and storage of groundwater and each units in every theme map is assigned a knowledge based ranking depending on its significance to groundwater occurrence. The suitable weightages have been assigned (see chapter 6) after considering the characteristics listed below.

Polygons	**Characteristics**
Resistivity	massive and consolidated nature in relation to high resistivity signal w.r.t. depths.
Lithology	rock type, weathering character, thickness of weathering, joints and fractures etc.
Geomorphology	type of landforms, areal extent, associated vegetation etc.
Drainage density	drainage density value.
Lineament density	lineament density value.
Slope analysis	based on the percentage of slope.
Landuse	type of landcover.

All the themes are overlaid in Arc/Info, two at a time and the resultant composite coverage is classified into four groundwater prospect categories such as (i) very good (ii) good (iii) moderate and (iv) poor with respect to groundwater occurrence. This output map is correlated with the groundwater data collected in the field.

2.6.2 Integration of spatial and non-spatial data

For developing a strong database for the Muvattupuzha river basin, the integration of spatial and non-spatial data was carried out and methodology followed is shown in Fig. 2.4. In the present study large volumes of non-spatial data has been generated from hydrochemical data of 55 locations in the basin, which includes major cations, anions, total iron, fluoride etc. In GIS these kind of non-spatial data can be put into feature attribute tables of respective coverages (spatial data). In this case the coverage is point coverage with respect to locations as points. Similarly parameters such as hydrological and geophysical data were also incorporated into the GIS.

2.7 SOFTWARES USED

Silicon Graphics workstation based ERDAS IMAGINE version 8.5 (DIP) and Arc/Info version 7.2.1 and Arcview 3.1 (GIS) are used for digitisation of various thematic maps, data analysis and presentation of maps. All these softwares are very effective and user friendly.

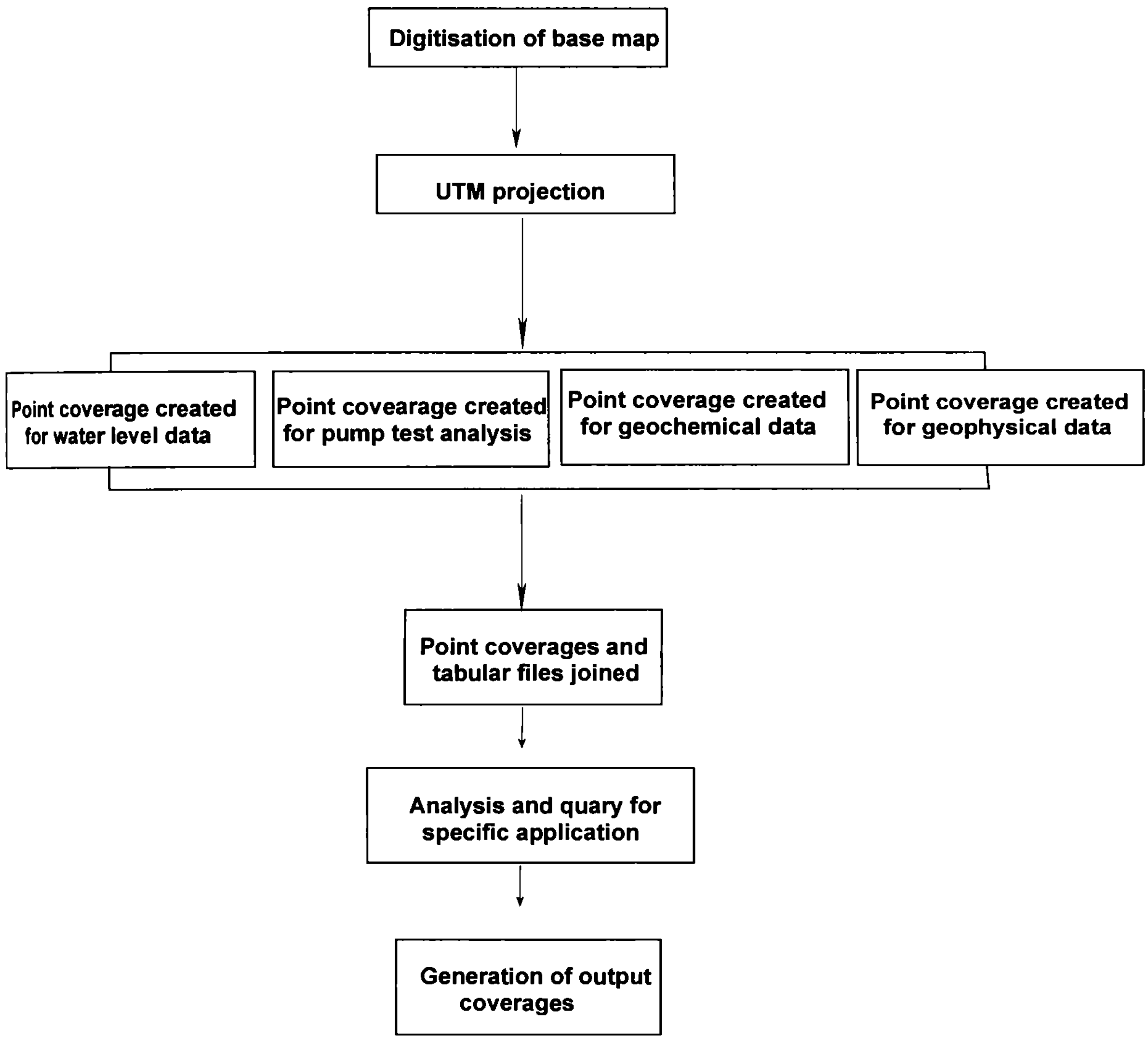


Fig. 2.4 Generation of GIS based spatial and non spatial database

CHAPTER 3

HYDROGEOLOGY

3.1 INTRODUCTION

In the last few decades, due to the need for safe drinking water for the vast rural populations, especially in the developing countries, terrains with crystalline rocks are being investigated in detail for groundwater development. Different landforms of crystalline rocks like structural hills, inselbergs, pediments, buried pediments, erosional valleys, valley fills etc. play vital role for groundwater occurrence. The groundwater storage capacity of crystalline rocks depends on the extent and thickness of the weathered layers, also called regoliths, developed over the crystalline basement rocks. The occurrence and movement of groundwater in massive crystalline rocks are mainly controlled by the distribution of fracture systems, discontinuities and permeability. In crystalline rocks the extent of weathering and fracture characteristics also decide the hydraulic conductivity.

Movement and storage of groundwater are governed mainly by the established hydraulic principles. All general flow equations of groundwater are derived from Darcy's law and the equation of continuity. According to Darcy's principles, there are two types of groundwater flows, namely

1. steady state flow and
2. unsteady state flow.

In case of the steady state flow, the magnitude and direction of flow velocities are constant with time at any point in the flow field (Karanth, 1987). Unsteady flow, otherwise known as transient or non- steady flow, occurs when at any point in the flow field, the magnitude and direction of flow velocity changes with time (Freeze and Cherry, 1979).

Evaluation of groundwater resources requires a detailed study on the occurrence and behaviour of groundwater and the various aquifer parameters such as transmissivity, storage coefficient, optimum yield, recovery rate, time for full recovery and specific capacity. The present investigation is aimed at to study the behaviour and movement of groundwater, the diagnostic characteristics of aquifer (transmissivity, storage coefficient, optimum yield, time for full recovery analysis and specific capacity) and groundwater resource in the Muvattupuzha river basin.

3.2 AQUIFER TYPES

Groundwater exists everywhere however, some parts of the saturated zone contain more water than others. An aquifer is an underground formation of either a permeable rock or loose material, which can produce useful quantities of water when tapped through a well (Todd, 1980). Aquifers come in all sizes. They may be small, only a few hectares in area, or very large, covering thousands of square kilometres of the earth's surface. They may be only a few meters thick or they may measure hundreds of meters from top to bottom.

In the study area porosity and permeability depend on the density of fractures and extent of weathering, since the terrain is underlained by crystalline formations where groundwater occurs under phreatic conditions. The analysis of hydraulic properties of these shallow aquifers is given due importance in the present study, since groundwater is being extracted through wells for drinking and irrigation purposes.

Confined Aquifers: A confined aquifer also referred as artesian aquifer, is invariably sandwiched between confining beds (layers of impermeable materials such as clay impede the movement of water into and out of the aquifer). Groundwater in these aquifers is always under high pressure, which makes the water level in a well to rise to a level higher than the water level at the top of the aquifer. The water level in the well is referred to as the piezometric surface or pressure surface. It is important to note that confining beds are not only hamper the movement of water into and out of the aquifer, but also serve as a barrier to the flow of contaminants from overlying unconfined aquifers (Canter, 1985; Taylor and Howard, 1994). For the same reason, however, contaminants that reach a confined aquifer through a poorly constructed well or through natural seepage can be extremely difficult to remove, and if attempted, it will be expensive.

Unconfined Aquifers: In unconfined aquifers, the groundwater fills the aquifers partially and the upper surface of the groundwater (the water table) is free to rise and fall. The water table typically mimics the topography of the land surface in a subdued way, thus the water table also looks like hills, valleys and flats. It is important to note that unconfined aquifers, especially those close to the surface, can be vulnerable to contaminants from activities on the land surface. In this study all the dug wells falls under unconfined condition and the depth vary from 1 to 18m.

3.3 BEHAVIOUR OF GROUNDWATER

Long and short-term fluctuations of groundwater level study will help us to understand the depletion and recharging conditions of an aquifer. Stress and strain in water level due to groundwater recharge, discharge and intensity of rainfall are reflected in water level fluctuation with time. Well hydrographs will represent variation of water level with rainfall. Grid deviation method has been adopted by several workers (Balasubramanian, 1986; Subramanian, 1994) for delineating the zones of recharge and discharge of a river basin.

For the present study groundwater level data from 26 National Hydrographic Stations (NHS), maintained by the Central Groundwater Board (CGWB), were obtained for a period of ten years from 1992 to 2001 (Fig. 3.1). Water level fluctuations, water table contours, grid deviation maps and well hydrographs for the study area have been subsequently prepared.

3.3.1 Water level fluctuation

The magnitude of the water level fluctuation depends on climatic factors, drainage, topography and geological conditions. Monitoring of groundwater fluctuations is very important on many accounts like agricultural practices, aquifer recharge and to study droughts. Most of groundwater assessment

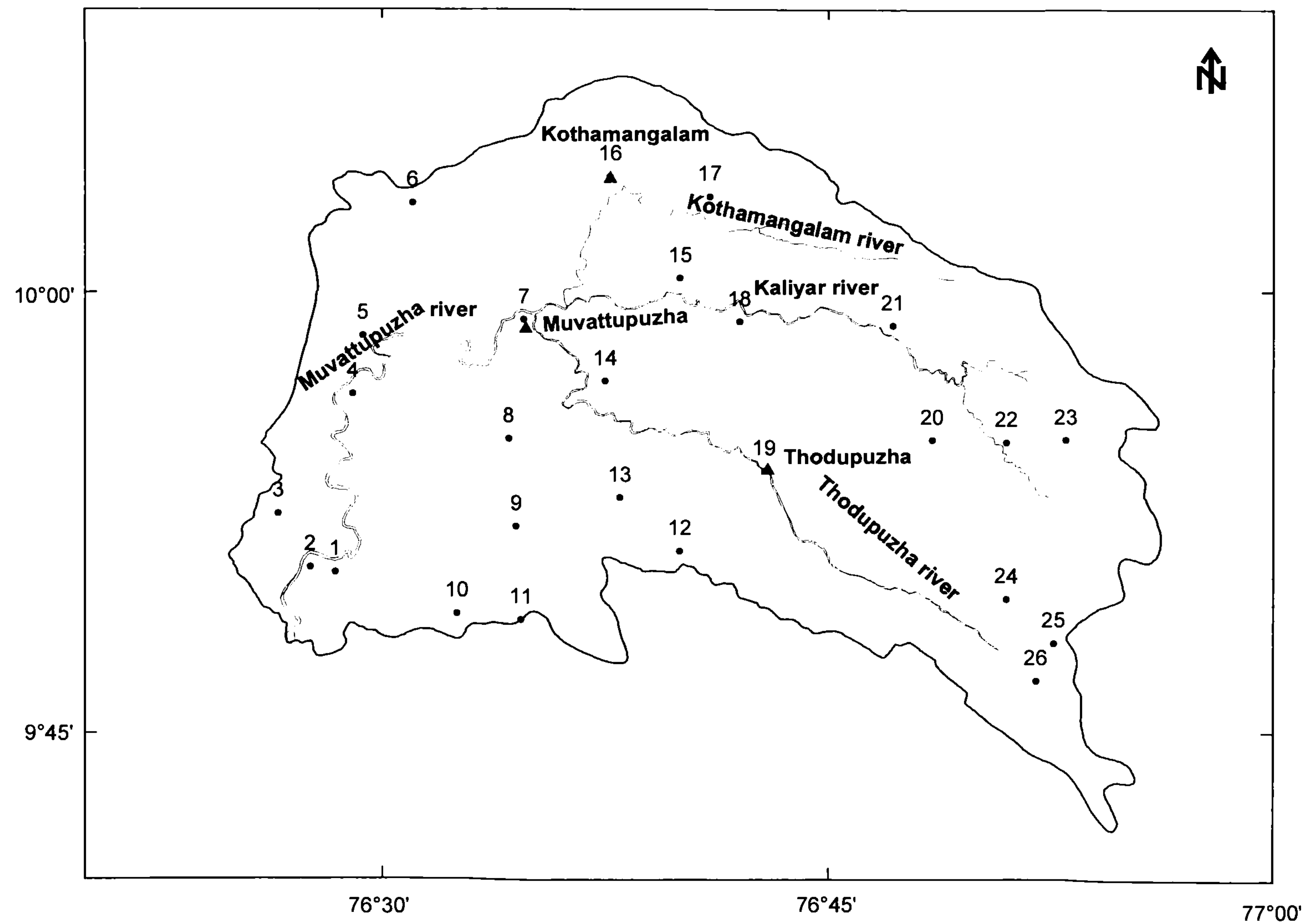


Fig. 3.1 Locations of National Hydrographic Stations (NHS) maintained by CGWB

studies involve correlation of water-table fluctuations in wells against rainfall, surface water body, construction of man made canals for irrigation purposes, artificial recharge and withdrawals from wells.

Abbi et al. (1971) have made a mesoscale study of the groundwater fluctuations of Delhi in relation to rainfall. In this study, monthly variations of groundwater levels against the distance from the Yamuna river course have also been drawn graphically; a regression equation has been derived and its application has been tested. According to Taylor and Oza (1984) groundwater fluctuation is caused by evaporation and transpiration of water by phreatophytes, which include palms, willows, salt grasses and sedges. Groundwater level shows a seasonal pattern of fluctuation as in the case of the glacial fill aquifer in Ohio (Klein and Kaser, 1963). Water level fluctuations can also be caused by winter frost conditions (Schneider, 1961), earth tides (Robinson, 1939) and ocean tides (Gregg, 1996). Water table fluctuations are an effect computed from the differences between maximum and minimum water table levels observed in dug wells. According to Davis and De Weist (1960) water table fluctuations may be effected due to

1) change in groundwater storage, 2) variation in atmospheric pressure in contact with water surface in wells, 3) deformation of aquifers and 4) disturbance with in the well, that is, minor fluctuations attributed to chemical or thermal changes in and near the well.

The average water level fluctuations of this basin from 1992 to 2001 are calculated for 26 wells. The maximum value of 3.45 m has been found on the southern part of the basin (Vazhitala NHS, western part of Thodupuzha sub basin), whereas the minimum of 0.003 m is recorded (Kolenchery NHS, western part of the Muvattupuzha sub basin) on the northwestern part of the basin (Fig. 3.2). Compared to any other basin (Venugopal, 1998; Aravindan, 1999 - where a wider fluctuation are found), the Muvattupuzha basin experiences only a low level fluctuation and this indicates a good groundwater condition, even though some pockets of the basin experience groundwater problem during April and May. As a representative of the basin the water level fluctuations from four NHS namely Vellore, Ramamangalam, Thodupuzha and Karumanoor are presented in bar diagram (Fig. 3.3). Among the four wells the first and second stations fall in the Muvattupuzha sub basin; the third station in Thodupuzha sub basin and the fourth is from the Kaliyar sub basin. It is found that the Kaliyar sub basin is characterised by a grater level of fluctuation than the Muvattupuzha and Thodupuzha sub basins (Fig. 3.3). The high variation in water level in Karumanoor well is due to variation in topography and high gradient (Table 3.1) which, in turn is supported by average water table contour map (Fig. 3.6), slope map (Fig. 6.9) and Digital Elevation Model (Fig. 6.11).

A comparative study of the Muvattupuzha river basin with the adjacent Periyar river basin has been carried out. From the Periyar basin four stations are selected (Neeriyamangalam, Perumbavour, Kaladi and Alwaye) and their fluctuations are represented in bar diagram (Fig. 3.4). A comparison of the above data with Muvattupuzha basin reveals that the trends of fluctuations in Periyar basin are very different. Moreover, in Kaladi NHS, the well gets dried in

Table 3.1 Waterlevel fluctuation and grid deviation computations for NHS of the Muvattupuzha river basin

Sl.No	Station Name	bgl	aMSL	Grid deviation	Maximum	Minimum	Fluctuation
1	Vellorel	6.07	9.93	-84.56	10.20	9.66	0.537
2	Vellore II	4.03	5.97	-88.52	7.02	4.92	2.104
3	Edakkatuvayal	11.01	30.99	-63.50	32.15	29.83	2.318
4	Ramamangalam	5.81	8.19	-86.30	8.45	7.93	0.516
5	Kolenchery	2.93	15.07	-79.42	15.07	15.07	0.003
6	Mannur	4.57	15.43	-79.06	15.81	15.05	0.754
7	Muvattupuzha	6.89	15.12	-79.38	16.13	14.10	2.024
8	Palakuzha North	6.29	183.71	89.22	184.92	182.51	2.406
9	Kuttatukulam	4.05	15.95	-78.54	16.24	15.65	0.591
10	Alapuram	4.00	11.00	-83.49	12.09	9.91	2.181
11	Monipalli	1.46	93.54	-0.95	93.83	93.24	0.588
12	Karimkunnam	3.43	116.57	22.08	116.86	116.28	0.578
13	Vazhithala	4.19	30.81	-63.68	32.54	29.09	3.452
14	Vazhakulam	4.64	13.36	-81.13	13.60	13.12	0.472
15	Pothanikadu	3.51	26.49	-68.00	26.63	26.34	0.295
16	Kothamangalam	5.52	26.48	-68.01	27.03	25.94	1.092
17	Oonukal	5.85	32.15	-62.34	32.95	31.35	1.605
18	Kalur	5.77	30.23	-64.26	31.27	29.20	2.068
19	Thodupuzha	9.15	23.85	-70.64	24.81	22.90	1.901
20	Karumanoor	4.13	33.87	-60.62	34.73	33.01	1.723
21	Kaliyar	5.48	32.52	-61.97	33.13	31.90	1.236
22	Anchelpetty	5.51	114.49	20.00	114.60	114.38	0.228
23	Chinikuzhi	2.44	637.56	543.07	638.03	637.09	0.944
24	Thumbachi	4.57	185.43	90.94	186.48	184.37	2.111
25	Kulamavu	6.73	573.27	478.78	574.45	572.09	2.365
26	Moolamattam	5.16	174.84	80.35	175.31	174.38	0.936

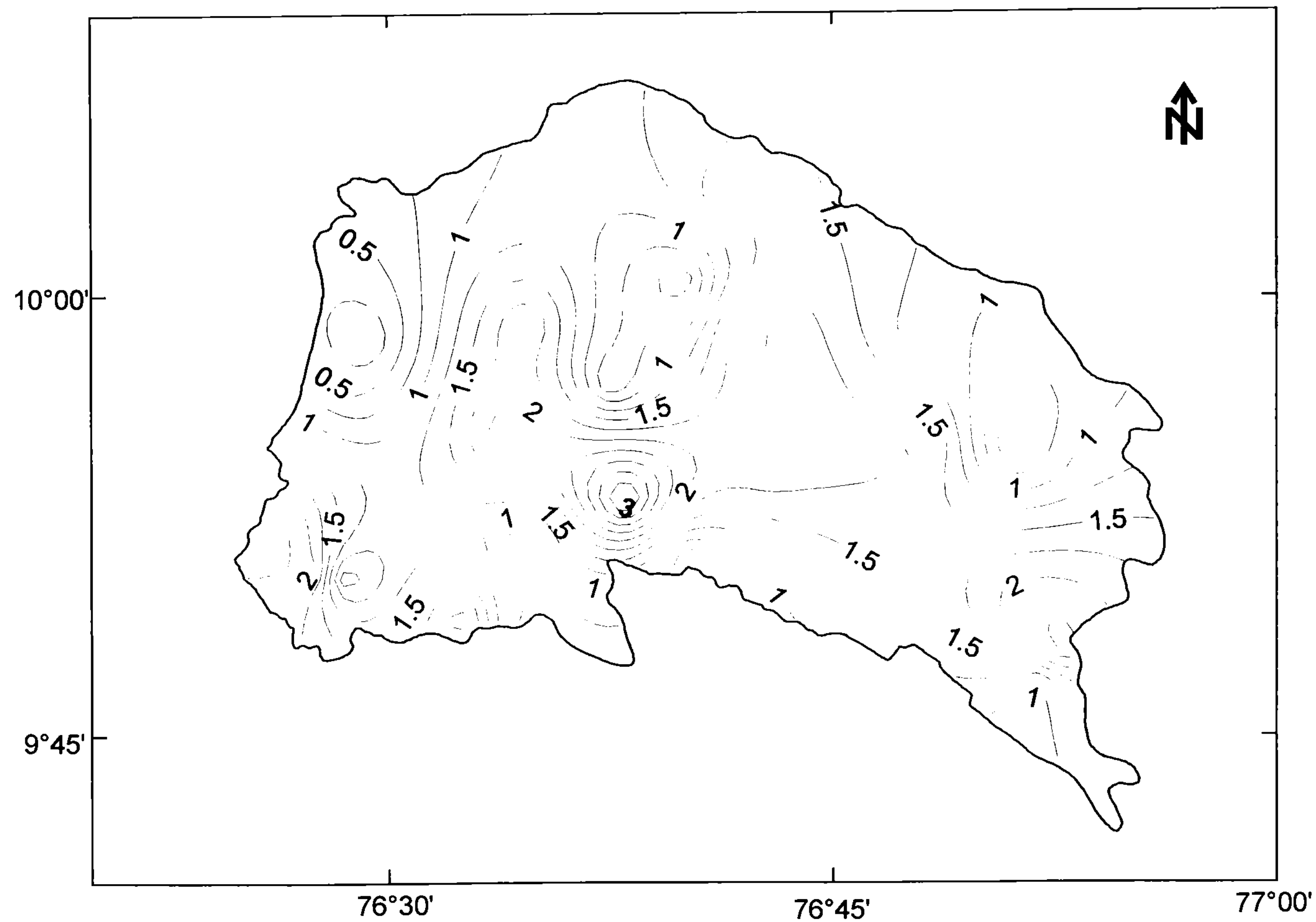


Fig. 3.2 Contour map showing average water level fluctuations (bgl) in m for the period from 1992 to 2001 in the Muvattupuzha river basin

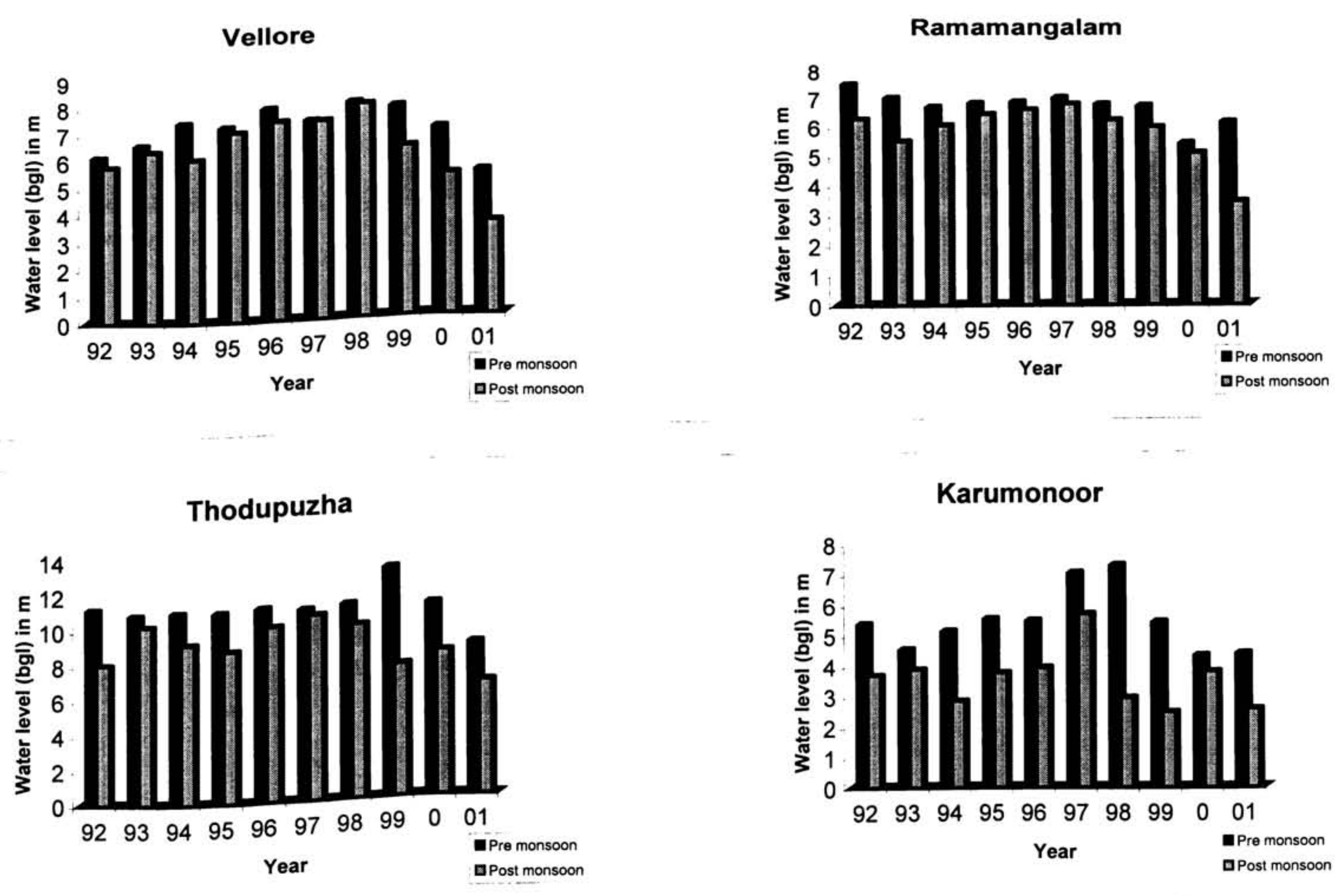


Fig. 3.3 Groundwater level in selected wells of the Muvattupuzha river basin

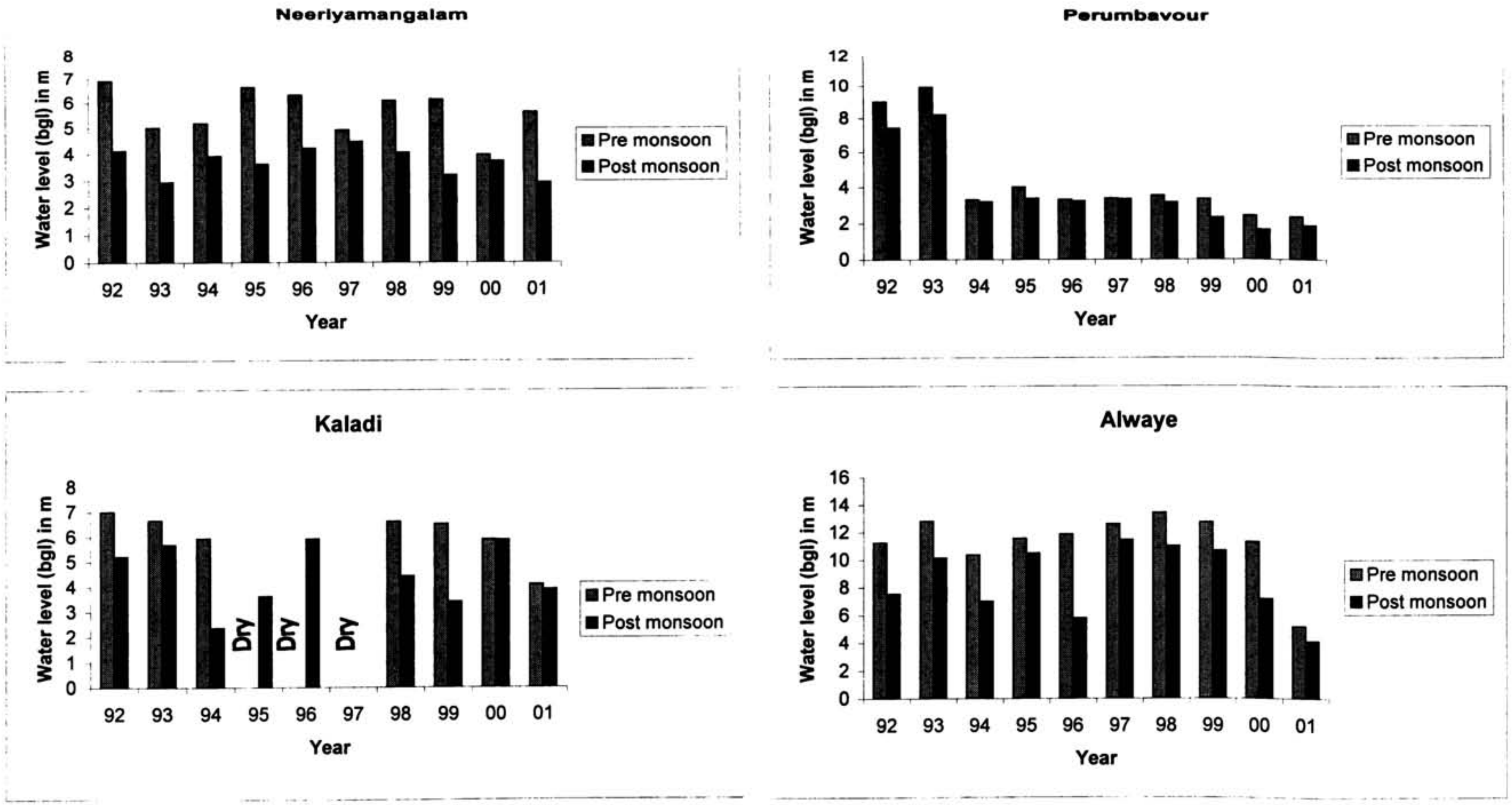


Fig. 3.4 Groundwater level in selected wells of the Periyar river basin

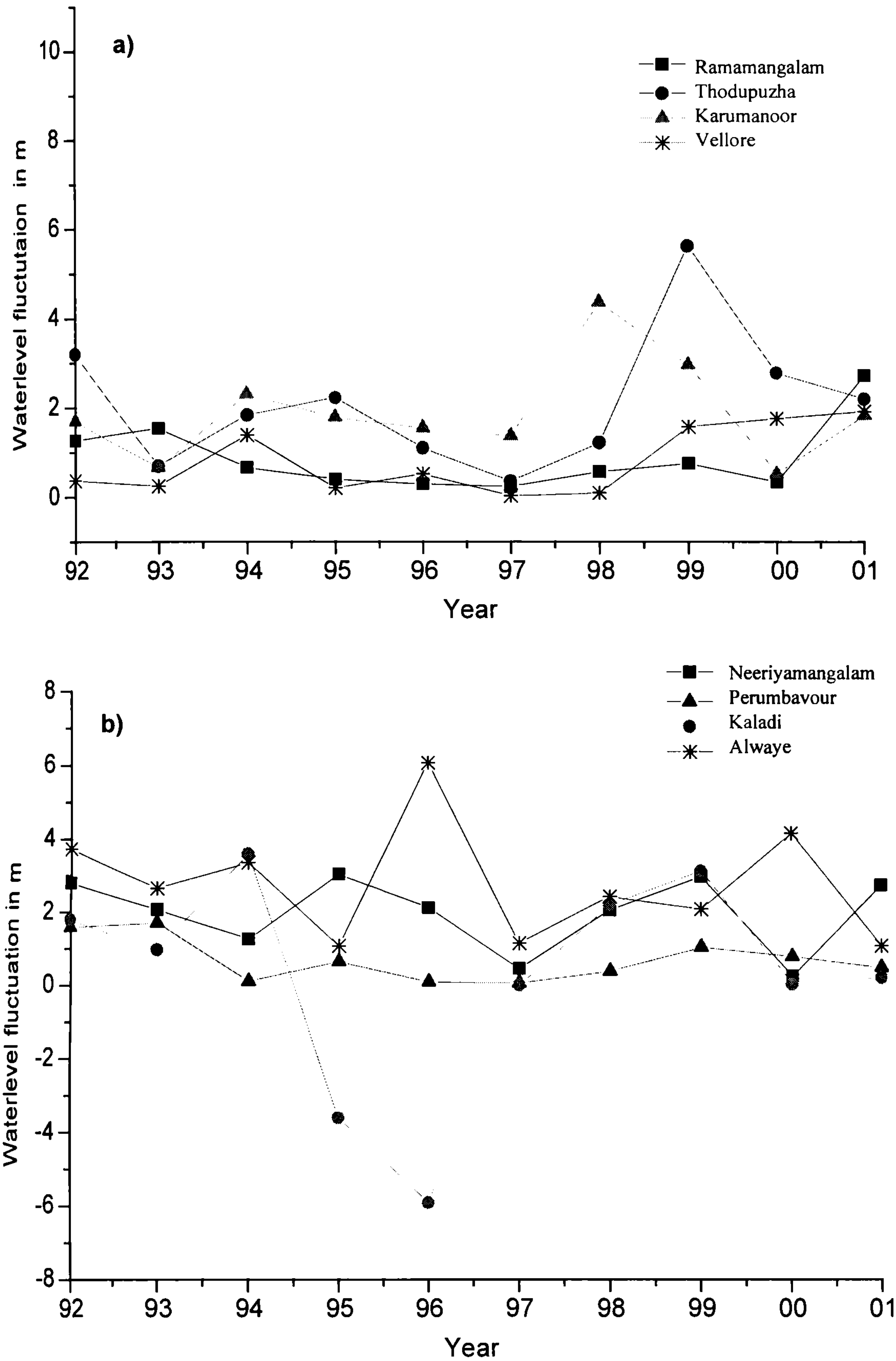


Fig. 3.5 A comparative study of water level fluctuations in selected wells of the (a) Muvattupuzha and (b) Periyar river basins

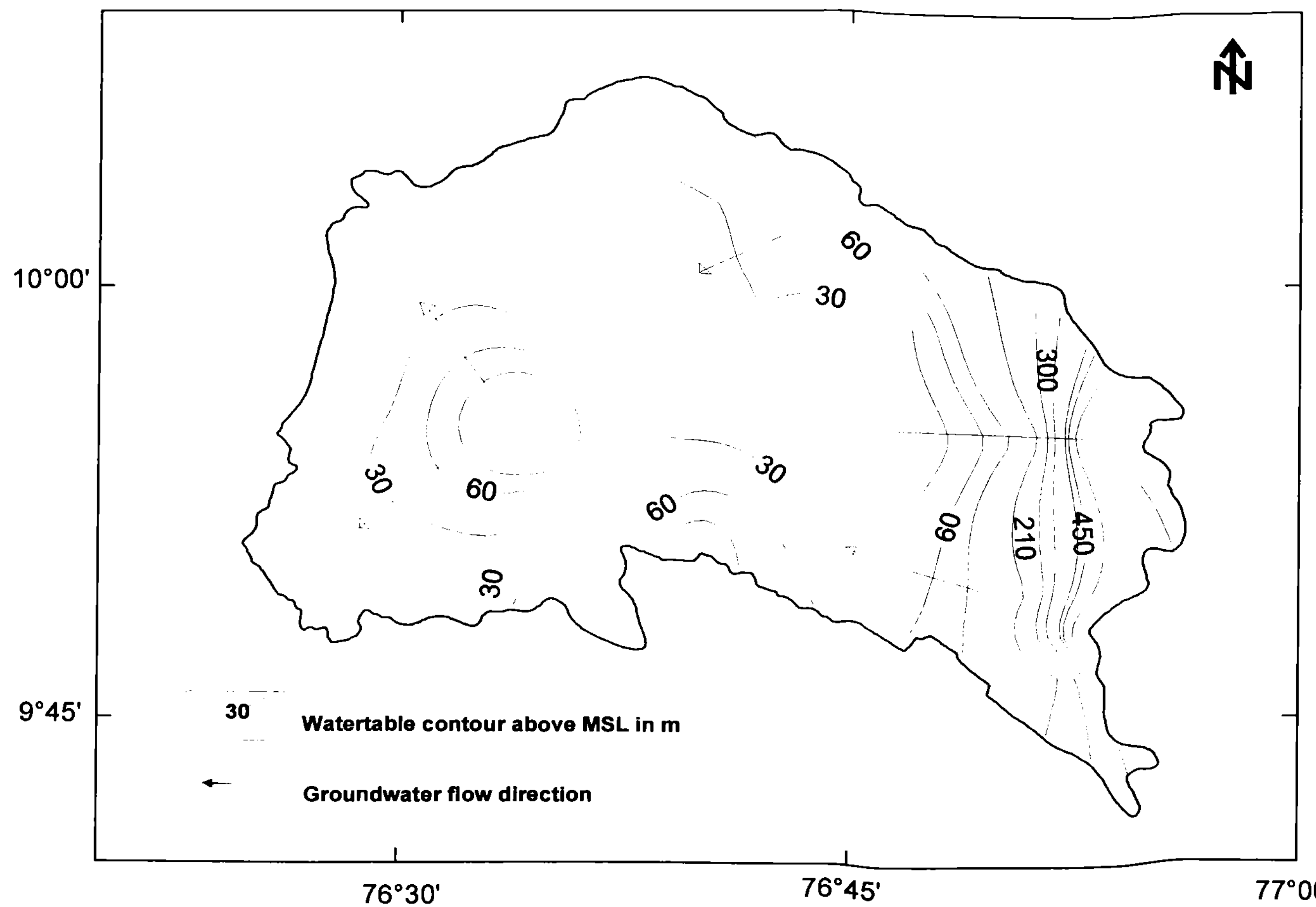


Fig. 3.6 Average water table contour for the period 1992-2001 of the Muvattupuzha river basin

pre monsoon so that it gives a negative fluctuation during 1996 - 97. The comparative fluctuations between selected wells of these two basins are shown in line diagram (Figs. 3.5a & b).

3.3.2 Water table

Investigation on water table characteristics is an important component of many hydrogeological investigations as it provides solid database for groundwater resource management, hydrogeology, aquifer parameter analysis, etc (Kresic, 1997). The water table levels of 26 monitoring wells have been drawn with the help of spot heights. Average water table contour map (Fig. 3.6) was prepared for the years 1992-2001 and the arrows indicate the direction of groundwater flow. The average elevation of water table (Table 3.1) varies from 5.97 m aMSL (downstream) and 573.3 m aMSL (upstream). The water table contour map of this study area reveals that the direction of groundwater flow reflects the surface topography.

3.3.3 Grid deviation map

Grid deviation map is being used to represent the hydrogeological data (Saha and Chakravarthy, 1963). The water level data for the years 1992 to 2001, collected from the 26 NHS maintained by CGWB, were utilised for the present study. The following steps were adopted in preparing the grid deviation water table map of the basin.

1) Monthly water level measured below measuring points has been recalculated to water level altitude above MSL.

2) An average elevation of water table (X1) for each observation well has been computed after calculating the monthly averages of water levels.
3) An average value (X2) of all the average elevations of water table computed in step 2 has been determined for the basin and found to be 94.44 m aMSL. This is called as the basin average or grid average.
4) The deviation {D = (X1-X2)} between the average water level altitude and the average elevation of water levels of individual observation wells have been determined.

The grid deviation results of each locations of the basin are presented in Table 3.1. The positive and negative zones are separated by zero line (Fig. 3.7). A major positive zone lies on the upstream area (eastern part of Kothamangalam, Kaliyar and Thodupuzha sub basins) denoting the highly elevated recharge area. In addition to this two pockets of positive zones are also seen in the central part of the Muvattupuzha sub basin and southern part of the Thodupuzha sub basin. The negative zone lies in the western part of the Muvattupuzha basin covering more than 75% of the terrain. Based on this study the eastern upstream part is considered as recharge zone whereas the western downstream part as discharge zone. A comparison of Fig. 3.6 with Fig. 3.7 shows that the groundwater flow direction more or less coincides with grid deviation map suggesting that topography play a considerable role in groundwater recharge and movement.

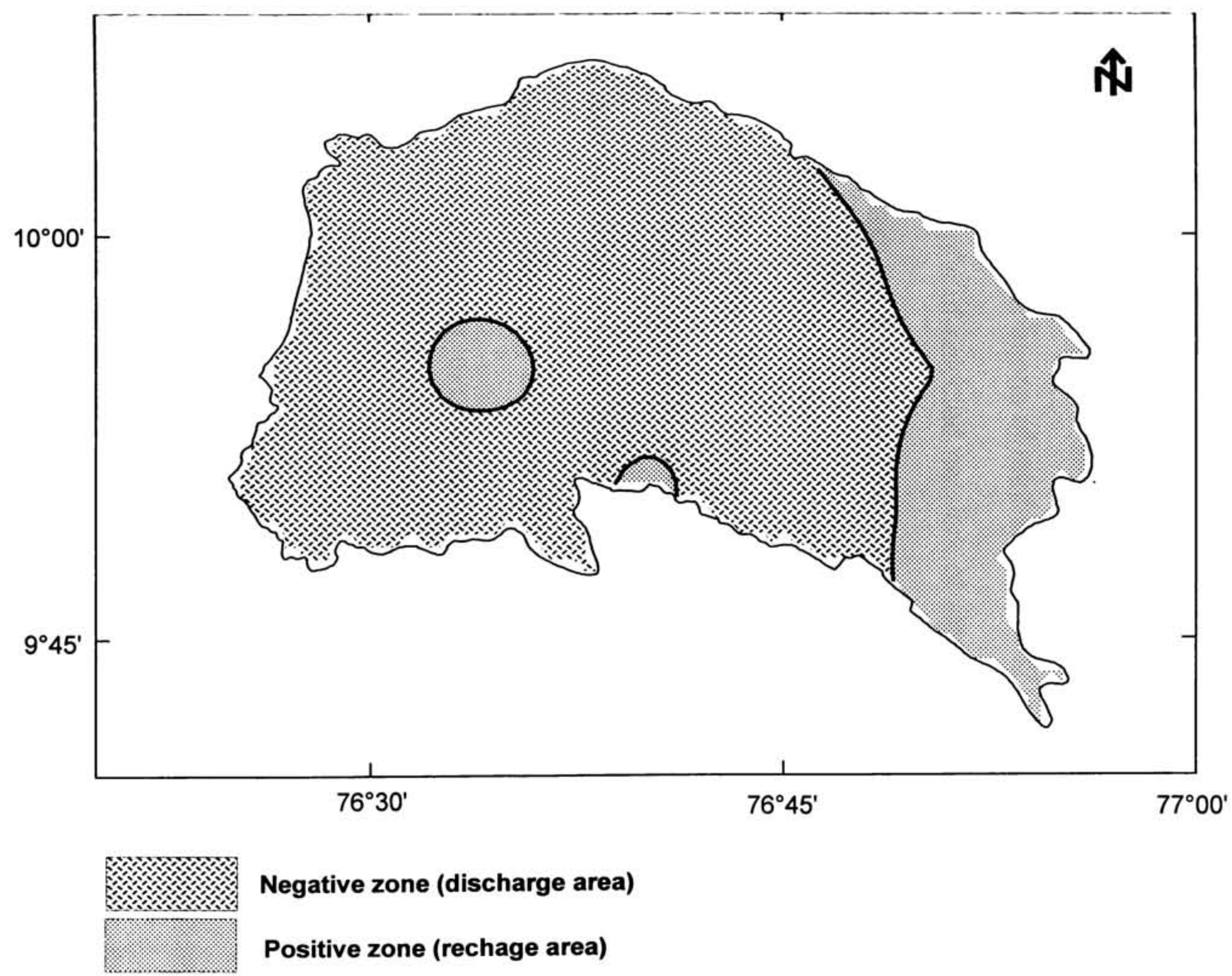


Fig. 3.7 Grid deviation map showing the discharge and recharge area

3.3.4 Correlation of water level with rainfall

The water table of an area is mainly controlled by variations in groundwater recharge, discharge and rainfall (Todd, 1980). The hydrographs of the four selected wells (Vellore, Ramamangalam, Kolenchery and Thodupuzha) along with their monthly rainfall distributions are shown in Figs. 3.8a & b. In these figures the line diagrams at the top represent the quarterly water levels above mean sea level in metre for ten years while the bar diagrams represent the variations of rainfall from 1992 to 2001.

The hydrographs of selected network of stations (Figs. 3.8 a & b) show corresponding peaks and valleys (variations in water level) with rainfall distribution. The best-fit line for the hydrographs will bring out the secular trend of water table with time. The peaks represent low groundwater storage whereas the valleys correspond to more groundwater storage. From Figs. 3.8a & b it is clear that rising of water levels are closely related to increase in rainfall and vice-versa. By analysing these stations it is concluded that rainfall has a major control over the water level fluctuation.

3.4 AQUIFER PARAMETER EVALUATION

Pumping test is commonly used for estimating hydraulic characteristics of crystalline rocks. Aquifer parameters could be evaluated using classical and digital methods. Many of the available classical pumping test analyses are mostly graphical (Cooper and Jacob, 1946; Narasimhan, 1965; Papadopulos and Cooper, 1967; Raju and Raghava Rao, 1967; Adyalkar and Mani, 1972;

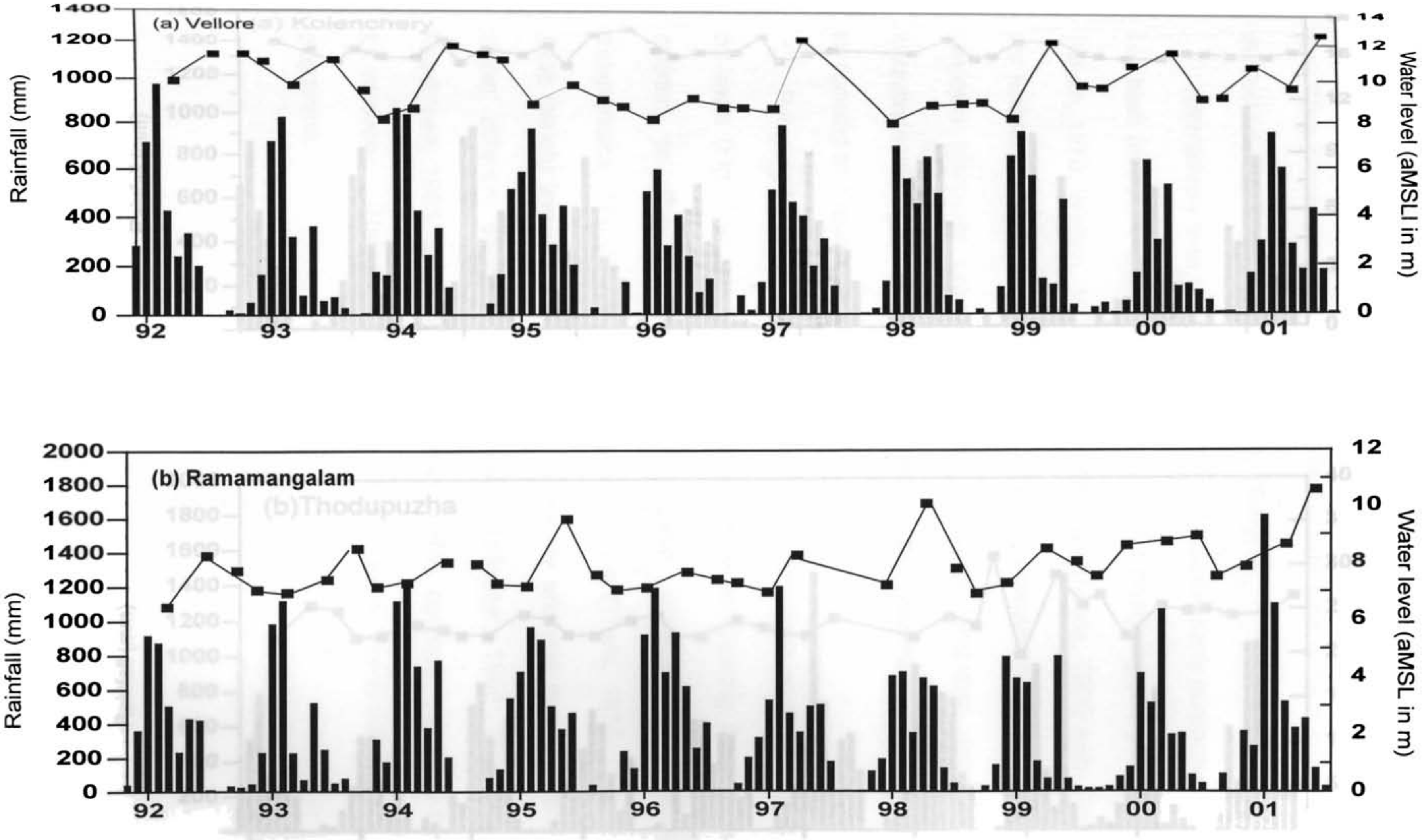


Fig. 3.8a Monthly variation of rainfall and quarterly variation of water table in certain selected stations of the Muvattupuzha river basin

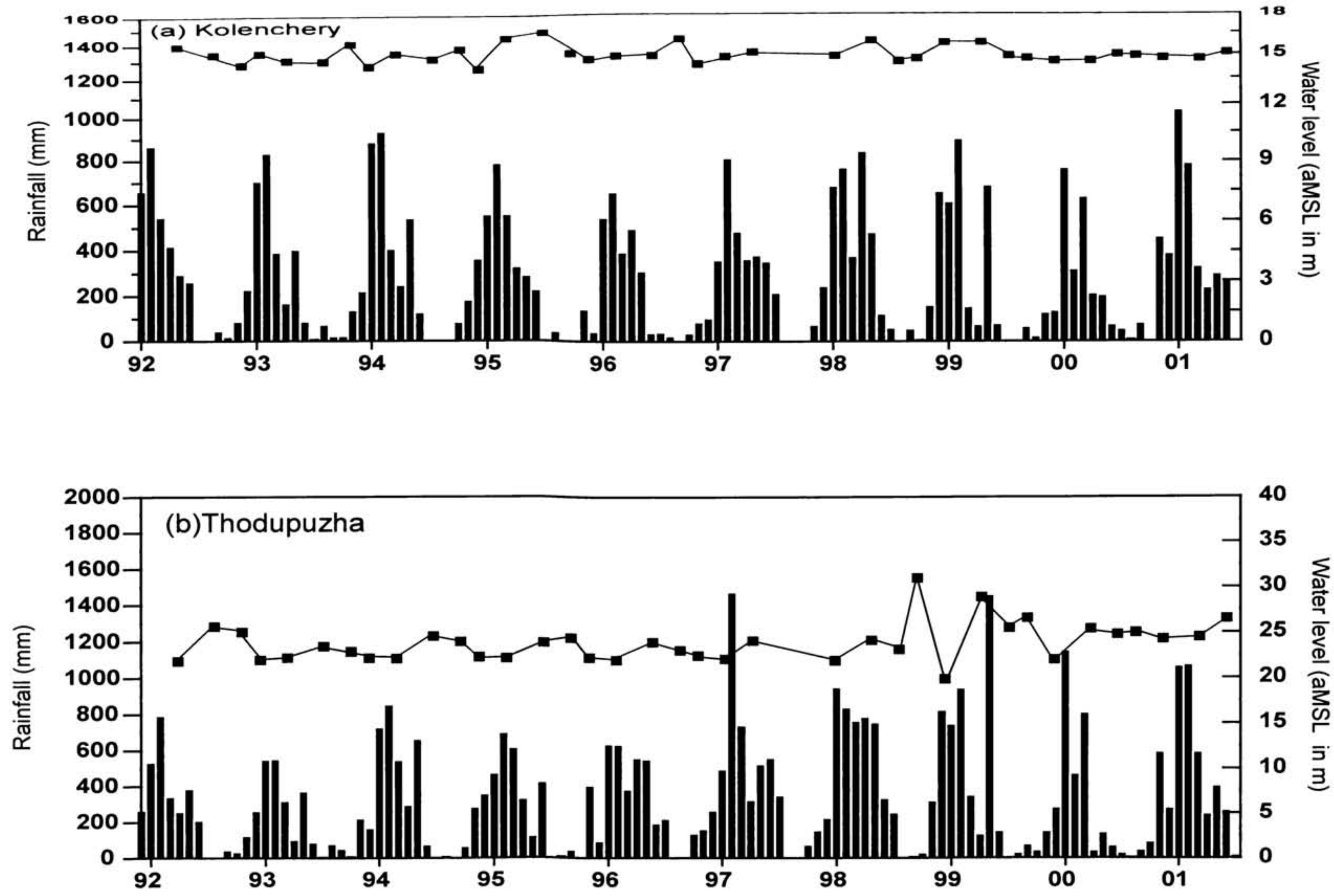


Fig. 3.8b Monthly variation of rainfall and quarterly variation of water table in certain selected stations of the Muvattupuzha river basin

Trilochan Das, 1972; Sammel, 1974; Streltsova, 1974; Zhdankus, 1974; Neuman, 1975; Boultan and Streltsova, 1976; Black and Kipp, 1977; Ruston and Singh, 1983) which require data plotting and individual judgment during the curve fitting procedures. Therefore, it is tedius and time consuming and errors may occur during these procedures (Yeh, 1987).

Alternatively over the last two to three decades many computer methods have been proposed and successfully utilised for analysing pumping test data (Saleem, 1970; Walton, 1970; Rayner, 1980; McElwees, 1980 a&b; Bradbury and Rothschild 1985; Mukhopadhyay, 1985; Balasubramanian, 1986). The composite computer programme (APE) in Basic language developed by Balasubramanian (1986) has been followed in the present study for analysing the pumping and recovery test data.

Pumping tests were conducted in 17 well locations as representative of this basin (Fig. 3.9). Hydraulic properties of water bearing formations are important as they govern the groundwater storage and transmitting characteristics. The different transmissivity values (Theis, 1935; Cooper and Jacob straight line method, 1946 and sensitivity analysis method, McElwee, 1980a), different specific capacity indices (Slichter, 1906; Walton, 1962; Narasimhan, 1965; Singhal, 1973; Limaye, 1973), optimum yield and time for full recovery (Rajagopalan et. al., 1983) were computed using APE programme.

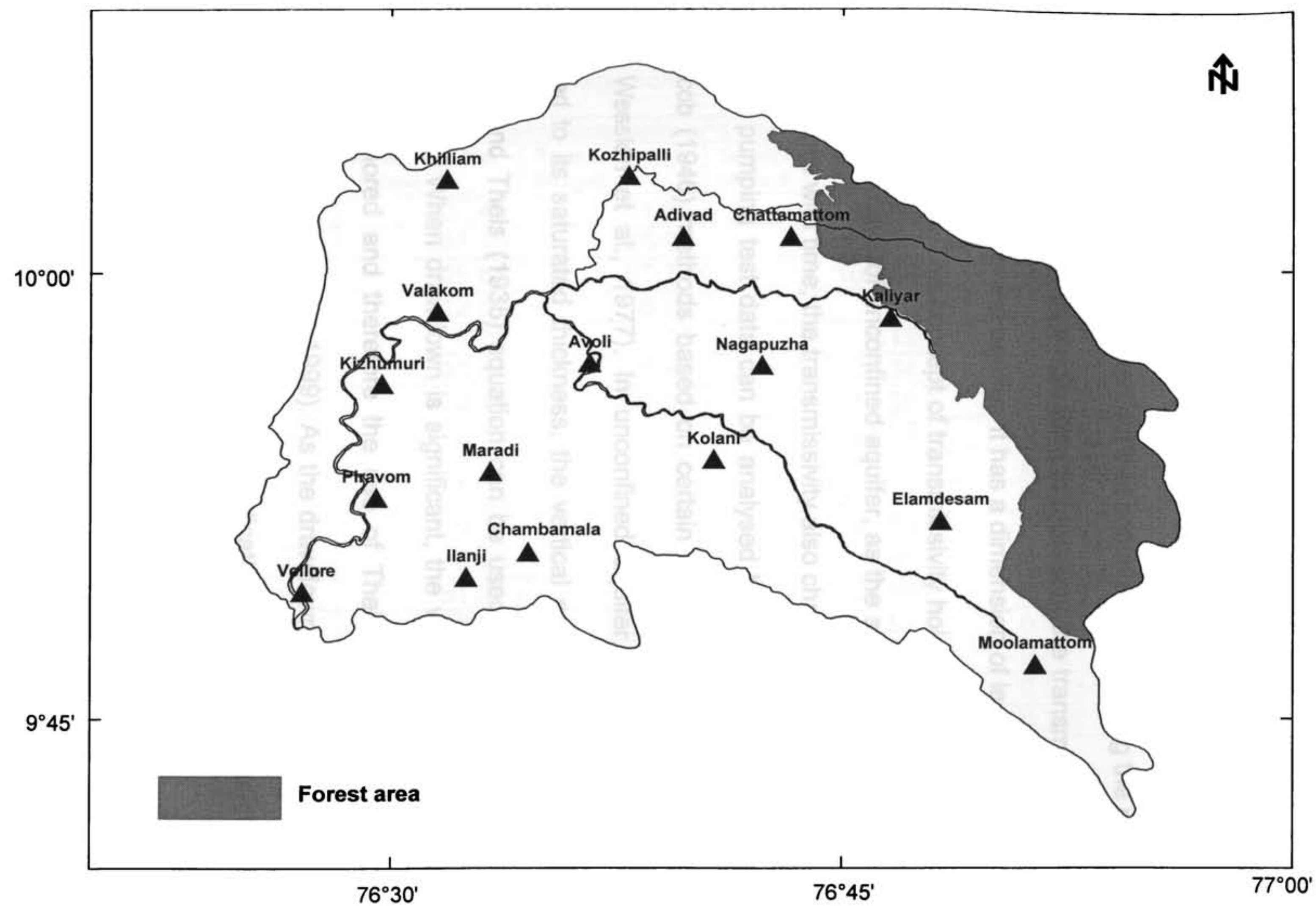


Fig. 3.9 Pump test locations in the study area

3.4.1 Transmissivity

This is defined as the rate of flow of water at the prevailing field temperature under a unit hydraulic gradient through a vertical strip of aquifer of unit width and extending through the entire saturated thickness of the aquifer (Todd, 1980). Theis (1935) pointed out that convenience of using the product of K (hydraulic conductivity) as single term to represent the transmission capacity of the entire thickness of the aquifer. It has a dimension of length and thickness expressed in m^2/day. The concept of transmissivity holds good for the confined aquifer but in the case of unconfined aquifer, as the saturated thickness of the aquifer changes with time, the transmissivity also changes accordingly.

The pumping test data can be analysed by Theis (1935) and Cooper and Jacob (1946) methods based on certain assumption (Eagon and Johe, 1972; Wesslen et al., 1977). In unconfined aquifer, if drawdown is small compared to its saturated thickness, the vertical component of flow can be neglected and Theis (1935) equation can be used to determine the aquifer characteristics. When drawdown is significant, the vertical component of flow cannot be ignored and therefore the use of Theis (1935) equation is not justified (Singhal and Gupta, 1999). As the drawdown is small compared to its saturated thickness and therefore the application of Theis equation for this basin is valid.

The transmissivity values are computed following: Cooper and Jacob (1946) straight-line method, Theis (1935) recovery method and sensitivity analysis (McElwee, 1980a). The results are presented in Table 3.2.

Table 3.2 Various transmissivity values and storage coefficient obtained by the analysis of pumptest data

WELL NO	Location	Transmissivity values m^2/d From			Storage Coefficient
		Jacobs's St. line Method	Theis Recovery Method	Sensitivity Analysis Method	Sensitivity Analysis Method
1	Vellore	337.41	41.85	225.63	0.393
2	Piravom	141.53	65.99	114.82	0.362
3	Ilanji	129.88	57.77	105.39	0.331
4	Chambamala	12.32	6.29	8.96	0.282
5	Maradi	9.70	7.31	6.12	0.256
6	Kizhimuri	26.65	20.86	25.34	0.191
7	Valakom	115.46	31.50	79.68	0.321
8	Kizhillam	170.73	98.26	108.69	0.294
9	Kozhipalli	185.20	5.49	173.70	0.196
10	Adivad	104.92	110.96	75.14	0.299
11	Avoli	149.47	53.72	91.76	0.319
12	Kolani	5.25	3.83	5.01	0.186
13	Chamattom	81.67	25.45	58.66	0.311
14	Nagapuzha	13.72	255.36	4.52	0.012
15	Moolamattom	9.70	8.73	6.12	0.021
16	Elamdesam	9.22	69.95	6.47	0.025
17	Kaliyar	122.20	56.63	73.92	0.307

Theis recovery method: After pumping is stopped, the water level in the pumped wells will start rising and this is known as recovery or recuperation phase. Here the residual drawdown verses arithmetic scale of t/t' on logarithmic scale should form a straight line. Then ΔS' is the change in residual drawdown per log cycle of t/t'.

$T= 2.30Q/4\pi \, \Delta S'$

Where

T = transmissivity in m^2/day

Q = rate of recharge in m^2/day

ΔS'= residual drawdown in m

Cooper and Jacob straight-line method: Transmissivity is obtained by plotting the drawdown verses log t and will be in the form of straight line. ΔS is the change in drawdown over one log cycle of time.

$T= 2.30Q/4\pi \, \Delta S$

Where,

T = transmissivity in m^2/day

Q = rate of recharge in m^2/day

ΔS = drawdown in m

Sensitivity analysis: Sensitivity analysis is the study of a system in response to various aquifer disturbances. McElwee, 1980a; Cobb et al., 1982 and Mukhopadhyay, 1985 have proposed algorithms for computer automated least square fit yielding transmissivity, storage coefficient and average drawdown error by sensitivity analysis. The sensitivity analysis provides both transmissivity (T) and storage coefficient (S). The best fit of T and S are obtained by comparing the computed and observed drawdown values. The computed and observed drawdowns values have matched perfectly well; with very little drawdown error (RMS error). So the transmissivity values obtained through sensitivity analysis are considered for further interpretation in this work.

The maximum value of T observed through the sensitivity analysis method is 225.63 m^2/d at Vellore (southwestern part of the Muvattupuzha sub basin) while the minimum of 4.51 m^3/d is at Nagapuzha (northern part of the Thodupuzha sub basin); (Table 3.2) the average being 68.81 m^3/d. Overall T values with less than 50 m^2/d are observed in the southern part of the Muvattupuzha sub basin and the entire area of the Thodupuzha and Kaliyar sub basins (Fig. 3.10). On the other hand the southwestern part of the Muvattupuzha sub basin (>200 m^3/d) and the northern part of the Muvattupuzha and Kothamangalam sub basins (50-150 m^3/d) show relatively high T values. It may be concluded that there is a general increase of transmissivity towards the southwestern part of the basin (towards the Muvattupuzha sub basin). Hard rock areas having more than 100 m^3/d are treated as good transmissivity values (Sridharan et al., 1995).

3.4.2 Storage coefficient or storativity

Storage coefficient is the volume of water that a unit volume of aquifer releases from storage because of expansion of water and compression of aquifer under a unit decline in the average hydraulic head (Singhal and Gupta, 1999). In the present study storage coefficient obtained sensitivity analysis

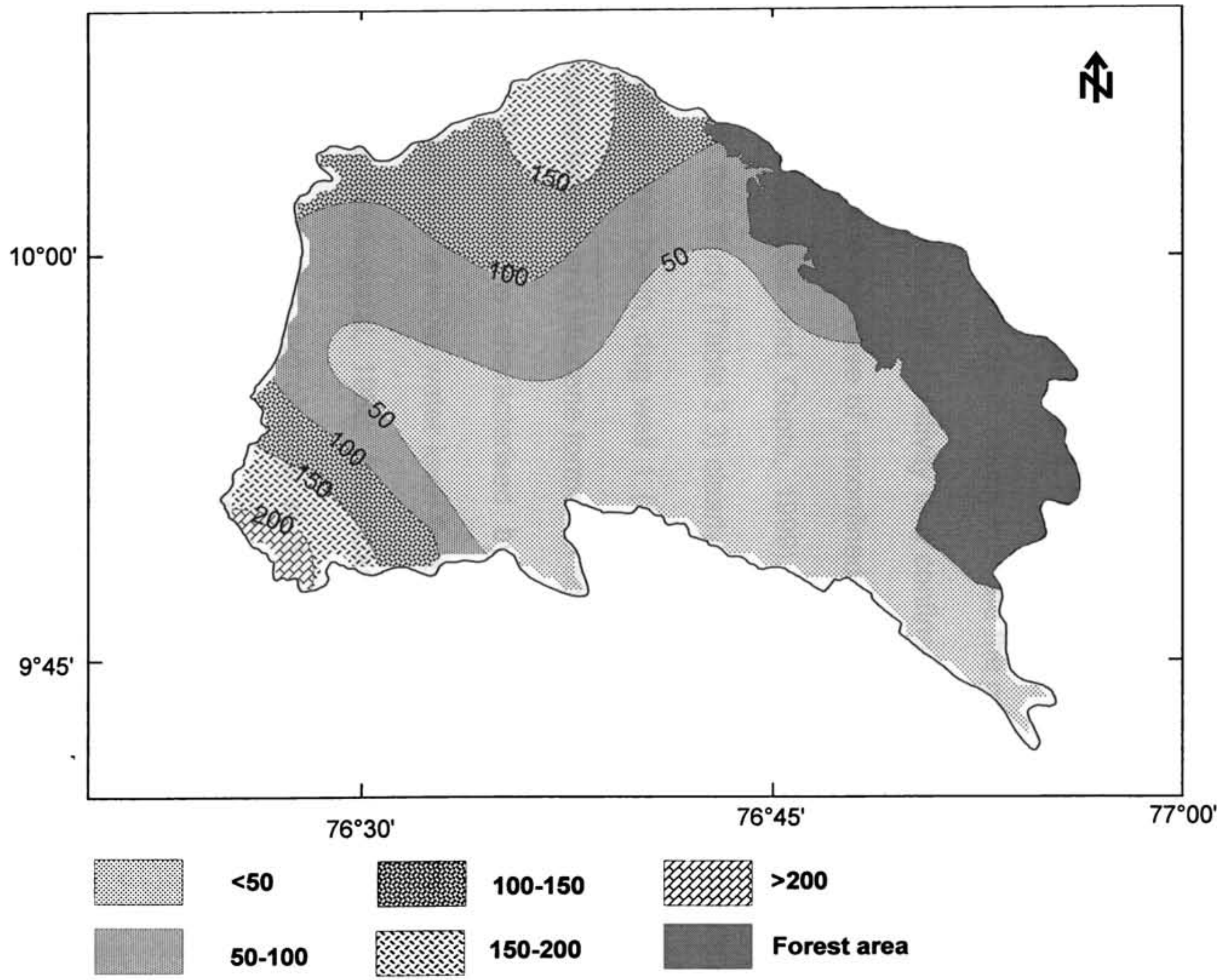


Fig. 3.10 Map of aquifer transmissivity (m^2/day) of the study area based on sensitivity analysis

ranges from 0.012 at Nagapuzha (the northern part of the Thodupuzha sub basin) to 0.393 at Vellore (the southwestern part the Muvattupuzha sub basin); (Table 3.2) and the average being 0.241. The contour map (Fig. 3.11) shows the variation of storage coefficient, with maximum on the southwestern part of the Muvattupuzha sub basin as well as the northern parts of the Muvattupuzha and the Kaliyar sub basins. The identical distribution of transmissivity (Fig. 3.10) and storage coefficient (Fig. 3.11) on the southwestern and the northern part of Muvattupuzha river basin clearly indicate the good aquifer condition.

In general, value of storativity in a confined aquifer will be of the order 10^{-3} to 10^{-6}, while in the case of unconfined aquifer the storativity ranges from 0.05 to 0.30 (Singhal and Gupta, 1999). The observed values of storage coefficient in this study (Table 3.3) clearly support the unconfined nature of the dug wells. In this basin, dug well 1 (Vellore) falls on the boundary between Pleistocene laterite and Miocene formation so it gives very high storativity value (0.393). The basin is characterised by good storage coefficient and is correlated with low level of water level fluctuation compared to any other hard rock terrains (Venugopal, 1988; Aravindan, 1999). Singh and Thangarajan (1998) have conducted hydrological study on the crystalline rocks of Vaipar basin and obtained an average storage coefficient of 0.002 and this low coefficient indicates confined condition.

3.4.3 Optimum yield

Optimum yield is one of the important characteristics of aquifer, which forms the basis for any type of planning and implementation. Optimum yield of

Table 3.3 Various aquifer characteristics derived from pumptest analysis for the study area

Well No.	Location	Recovery rate (m)	Saturated aquifer thickness (m)	Equatioril radius (m)	M1	M2	Time for full recovery from M1	Time for full recovery from M2	Average of M1 and M2	Optimum Yield (m^3/d)
1	Vellore	35.6	1.77	2.12	0.0019	0.0021	18.5	17.3	17.90	50.1
2	Piravom	106.4	2.09	2.40	0.0043	0.0046	8.3	7.8	8.05	43.2
3	Ilanji	97.8	2.07	2.31	0.0044	0.0047	8.4	7.8	8.10	49.8
4	Chambamala	3.2	0.69	0.86	0.0009	0.0015	26.3	37.4	31.85	0.9
5	Maradi	20.9	4.41	1.08	0.0007	0.0009	41.5	51.0	46.25	4.6
6	Kizhimuri	8.7	1.80	1.27	0.0031	0.0032	11.9	10.8	11.35	2.0
7	Valakom	11.1	2.30	1.31	0.0006	0.0007	57.5	52.5	55.00	3.3
8	Kizhillam	48.0	1.75	1.40	0.0003	0.0004	30.2	32.1	31.15	10.5
9	Kozhipalli	3.7	0.49	0.90	0.0004	0.0006	59.9	77.2	68.55	2.3
10	Adivad	298.2	6.50	1.52	0.0012	0.0014	27.6	28.9	28.25	37.2
11	Avoli	41.2	0.79	1.64	0.0007	0.0008	40.2	47.5	43.85	11.1
12	Kolani	10.4	1.72	1.53	0.0127	0.0137	2.8	2.6	2.70	2.8
13	Chamattom	15.8	0.71	1.83	0.0010	0.0014	26.7	32.7	29.70	4.5
14	Nagapuzha	278.2	2.50	2.50	0.0018	0.0019	20.3	17.6	18.95	2.4
15	Moolamattom	25.0	6.41	1.18	0.0007	0.0008	46.9	51.0	48.95	4.3
16	Elamdesam	102.3	3.35	1.90	0.0014	0.0015	25.6	22.4	24.00	2.4
17	Kaliyar	43.3	1.17	1.24	0.0004	0.0006	53.7	77.1	65.40	11.6

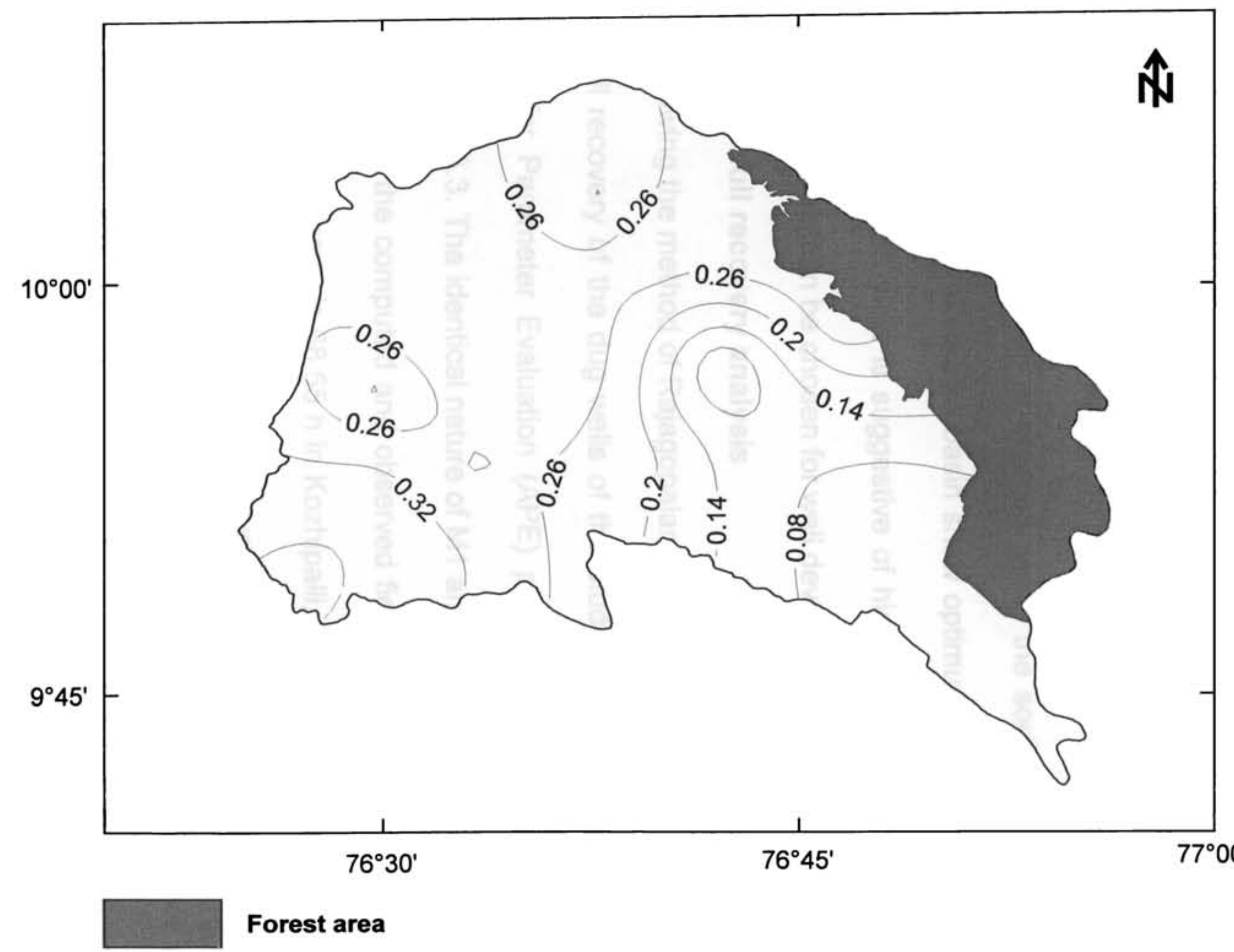


Fig. 3.11 Contour map showing storage coefficient of the Muvattupuzha river basin

a well is the volume of water per unit time discharge by pumping and it is measured commonly as a pumping rate in cubic meters per day (Karanth, 1987).

The optimum yield of the basin ranges from 0.9 m^3/d to 50.1 m^3/d (Table 3.3) with a mean value of 14.29 m^3/d. The highest value is shown by the well located at Vellore (southwestern part of the Muvattupuzha sub basin) while the lowest is by Chambamala (western part of the Muvattupuzha sub basin). Fig. 3.12 depicts the variation of optimum yield; the southwestern and north central parts of the Muvattupuzha basin show optimum yield of more than 30 m^3/d. Higher optimum yield is suggestive of higher permeability. Regions of higher optimum yield can be chosen for well development.

3.4.4 Time for full recovery analysis

Following the method of Rajagopalan et al. (1983) the total time required for the full recovery of the dug wells of the study area have been computed using Aquifer Parameter Evaluation (APE) programme and the results are given in Table 3.3. The identical nature of M1 and M2 (Table 3.3) clearly revels the matching of the computed and observed field values. The maximum time required for full recovery is 68.55 h in Kozhipalli, located at the western part of the Kothamangalam sub basin and minimum is 2.7 h at Kolani, southern part of the Thodupuzha sub basin (Table 3.3). The basin is divided into four zones (<20h, 20 - 40 h, 40 - 60 h and > 60h) and is represented by contour map (Fig. 3.13). For those wells located in the southwestern part of the Muvattupuzha sub basin and southern parts of the basin i.e. the Thodupuzha

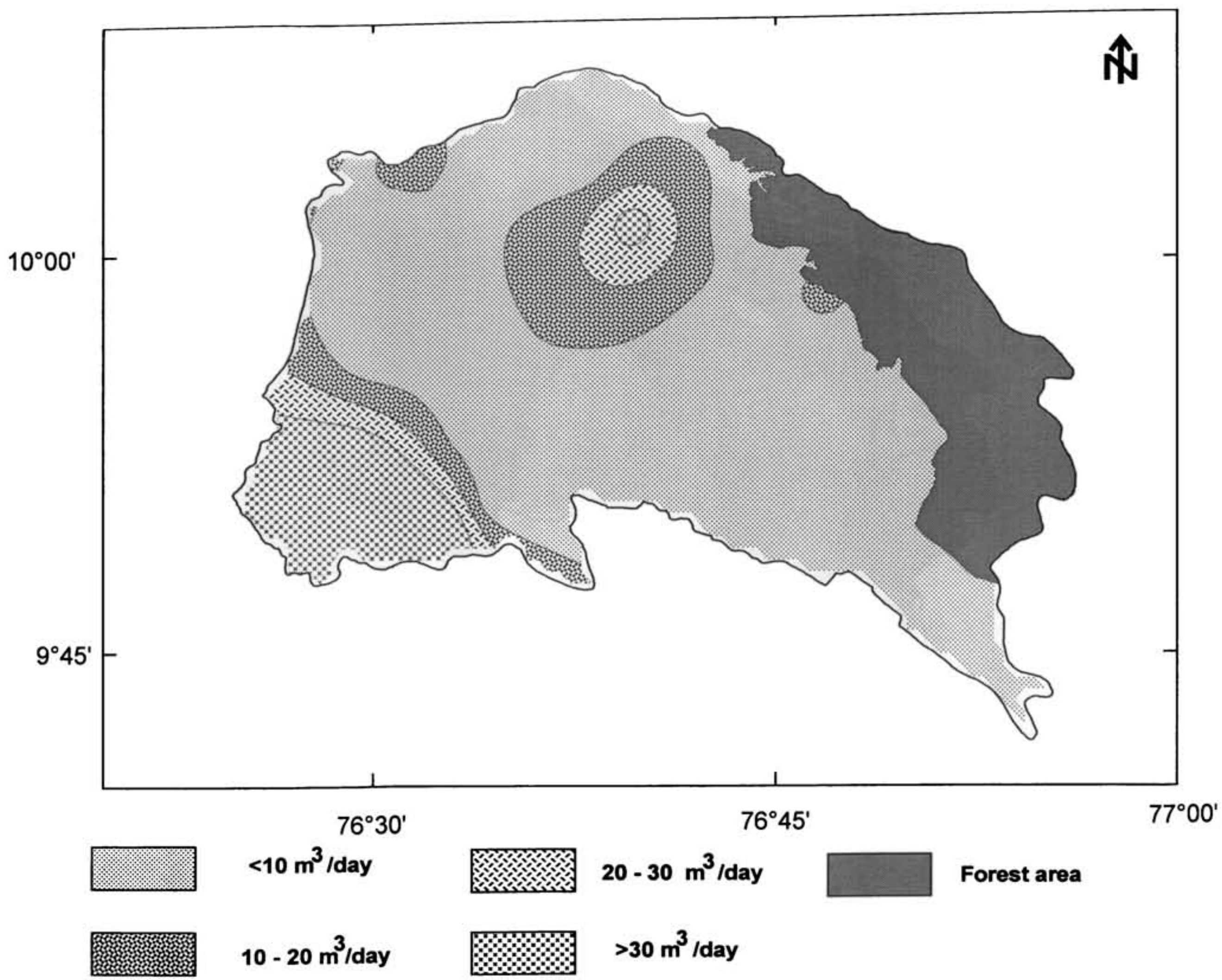


Fig. 3.12 Map showing optimum yield of wells in the study area

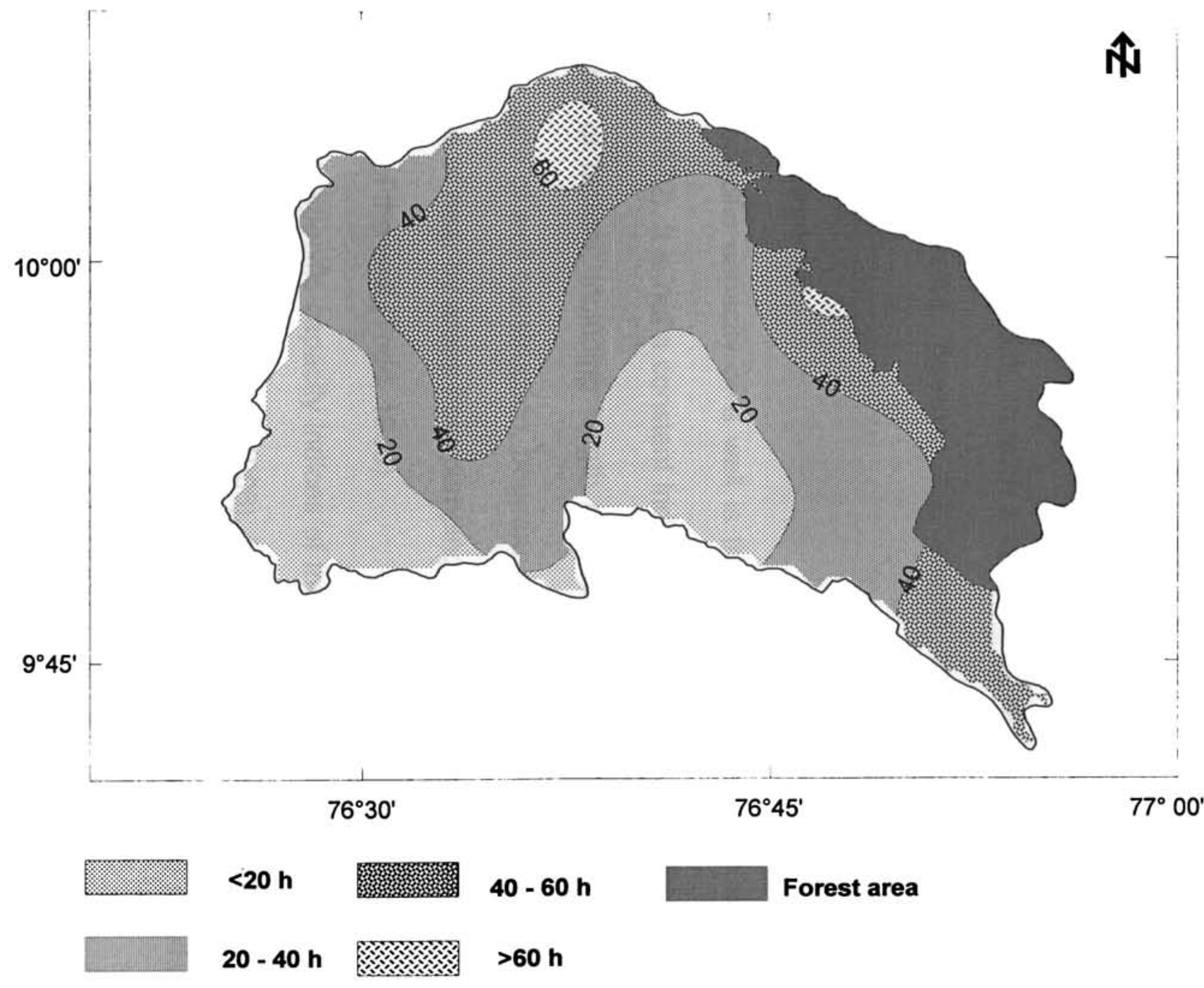


Fig. 3.13 Map showing time required for full recovery of wells in the study area

and Kaliyar sub basins, the time taken for full recuperation is less than 40 hours, whereas a few wells in the northern part of the Kothamangalam sub basin (Table 3.3; Fig. 3.13), the time required for full recovery is more than 40 hours. From this study it is suggest that an increase in the equivalent radius of the well, particularly in the crystalline terrain, can reduce the recuperation time (Venugopal, 1988; Aravindan, 1999). It is also found in some locations that even the high equatorial radius show more recuperation time and this is due to low porosity of the formations. In such areas, drilling deep bore wells can be the alternative measure, however this should be done after a detailed geophysical survey.

3.4.5 Specific capacity

The specific capacity of a well is the ratio of discharge to drawdown (Summers, 1972). It is not a constant index because the drawdown varies with a number of factors, including length of time since pumping began, rate of pumping, type of well construction, boundary conditions with in the aquifer and the influence of near by areas from pumping well. Hence it is a measure of the effectiveness of the well (Todd, 1980).

Different specific capacity indices of the basin are determined following the method adopted by Slichter (1906), Walton (1962), Narasimhan (1965), Singhal (1973) and Limaye (1973) using APE programme and the results are given in Table 3.4.

Slichter's (1906) formula for computing the specific capacity is

$$C = 2303 * (A/t') * \log (s/s'')$$

Table 3.4 Different specific capacity indices of the Muvattupuzha river basin

WELL NO	LOCATION	SLICHITER'S specific capacity index (lpm/mdd/m)	WAKTON'S specific capacity index (lpm/mdd/m^2)	NARASIMHAN'S specific capacity index (lpm/mdd/m^2)	SINGHALS'S specific capacity index (lpm/mdd/m^2)	LIMAYE'S specific capacity index (lpm/mdd/m^2)
1	Vellore	86.04	48.56	4.35	3.081	1.803
2	Piravom	188.26	90.08	8.51	5.405	3.306
3	Ilanji	224.47	107.40	10.15	6.444	3.942
4	Chambamala	4.35	7.00	1.87	1.293	0.764
5	Maradi	5.47	1.24	1.51	0.184	0.164
6	Kizhimuri	34.83	19.35	6.93	2.434	1.801
7	Valakom	58.15	25.25	1.67	1.210	0.704
8	Kizhillam	44.41	25.24	0.81	0.958	0.439
9	Kozhipalli	6.17	12.59	0.87	1.336	0.528
10	Adivad	35.54	5.47	1.78	0.345	0.289
11	Avoli	66.84	85.14	1.53	3.626	1.072
12	Kolani	23.32	13.55	26.82	4.098	3.555
13	Chamattom	41.49	34.87	0.76	1.330	0.480
14	Nagapuzha	274.31	120.55	4.17	4.413	2.140
15	Moolamattom	6.54	1.02	1.51	0.138	0.127
16	Elamdesam	58.48	17.42	2.97	1.097	0.797
17	Kaliyar	32.08	27.41	0.97	1.341	0.551

where

C = specific capacity of the well in lpm /mdd.

A = area of cross-section of the well in sq.m

t' = time since pumping stopped in minutes

s = draw down in m just before pumping stopped and

s" = residual drawdown in m at any time t' after pumping stopped.

This formula is valid for wells penetrating in a poorly permeable formations where the recovery is low and may not hold good for such aquifers where the inflow is equal to or more than outflow. Further this formula does not account for the duration of pumping prior to the shut down of the pump. Slichter's (1906) formula has been used to compare the recovery performance of dug wells. It is a linear function of time and logarithmic function of drawdown. It provides a useful basis for comparison of wells of similar types in similar geological environment.

Slichter's (1906) specific capacity values cannot be used directly for the purpose of comparison with other indices. Therefore, Walton (1962) has obtained the specific capacity by dividing the Slichter's (1906) specific capacity (average) with the saturated thickness of the aquifer. Narasimhan (1965) has proposed the unit area specific capacity by dividing the Slichter's (1906) specific capacity with the cross sectional area of the well and this has been successfully adopted by Summers (1972), Subramanian (1975), Viswanathiah et al., (1978) and many others to describe the hydrological characteristics of hard rock areas. Singhal (1973) has suggested that since both diameter and saturated thickness of an aquifer tapped vary much, it would be better if the Slichter's (1906) specific capacity values were divided by the total contributing surface area of the aquifer tapped by the well. On the other hand Limaye (1973) has suggested that instead using the total contributing surface area of the aquifer tapped, it should be the sum of the total surface area of the well under the study. In the present work only Slichter's (1906) and Limaye's (1973) specific capacity indexes have been followed, as these indexes are best suited for hard rock terrains (Venugopal, 1988; Aravindan, 1999; Rajesh, et al., 1999).

In this study Slichter's (1906) specific capacity (Table 3.4) ranges from 4.35 lpm/mdd/m (st.4 - Chambamala, western part of the Muvattupuzha sub basin) to 274.31 lpm/mdd/m (st.14 - Nagapuzha, the northern part of the Thodupuzha sub basin) with an average value of 70.04 lpm/mdd/m. The variation of Slichter's (1906) specific capacity is shown by contour map (Fig. 3.14). The Fig. 3.14 shows that in addition to Nagapuzha, another high specific capacity zone is found around Ilanji on the southwestern part of the Muvattupuzha sub basin. Limaye's (1973) specific capacity index varies from 0.127 lpm/mdd/m^2 (st.15 – Moolamattom, eastern part of the Thodupuzha sub basin) to 3.942 lpm/mdd/m^2 (st.3 – Ilanji, southwestern part of the Muvattupuzha sub basin) as shown in Table 3.4 and the average value being 1.321 lpm/mdd/m^2 .

Singhal and Gupta (1999) have indicated that an increase in the radius of well results in the increase of specific capacity values. Likewise the statistical

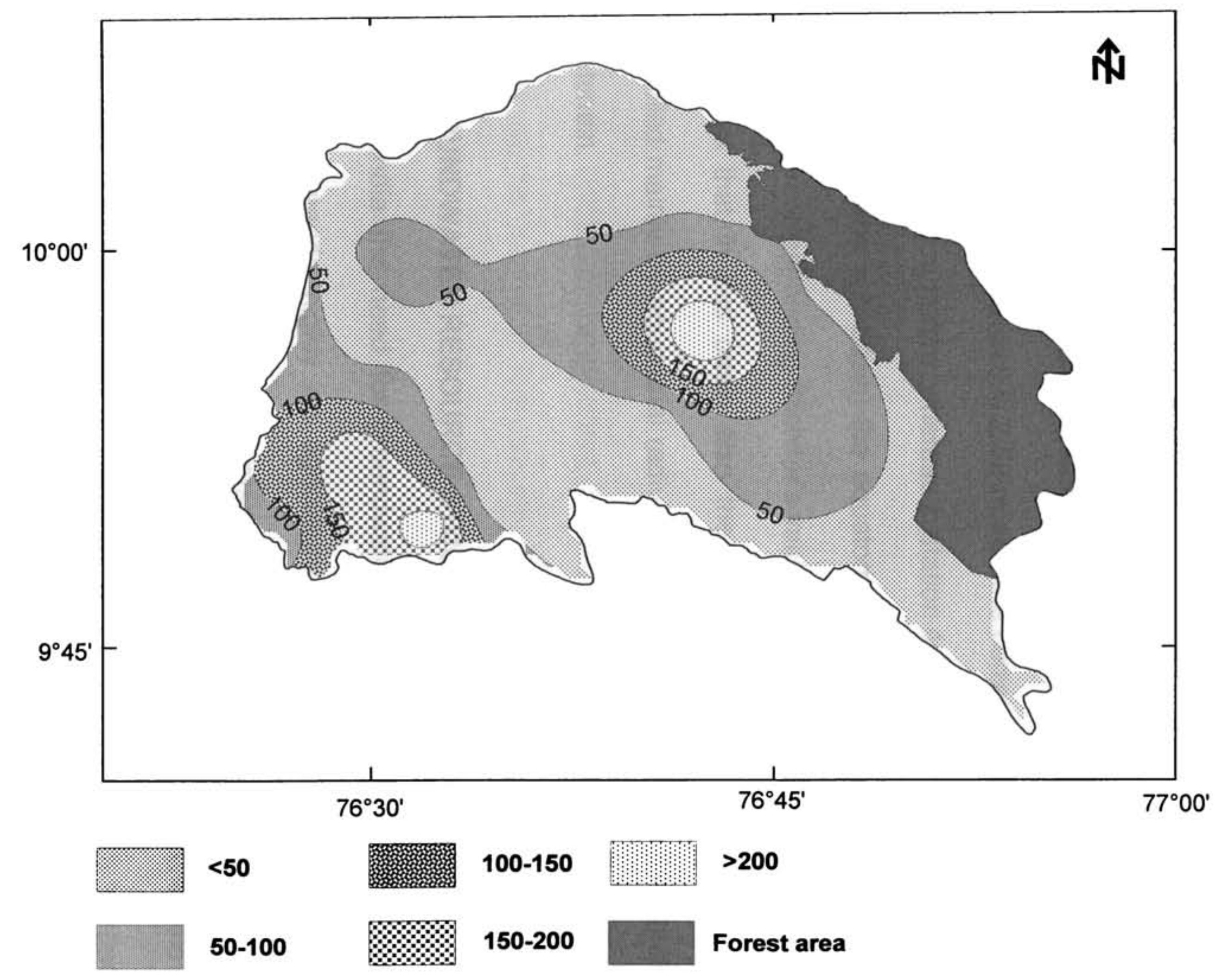


Fig. 3.14 Map showing Slichter's specific capacity indices

analysis of a large number of specific capacity data from a variety of fractured rocks in Pennsylvania, USA, indicates that the main factors which control the specific capacity are well diameter and duration of pumping with lithology contributing to a comparatively smaller extend (Knopman and Hollyday, 1993) and observed elsewhere (Singhal and Gupta, 1999). In this basin also it is found that an increase in well radius leads to an increase in specific capacity. In station 14 (Nagapuzha, northern part of the Thodupuzha sub basin) the equatorial radius of the well is 2.50 m and the corresponding Slichiter's (1906) value is 274.31 lpm/mdd/m, whereas in station 4 (Chambamala, western part of the Muvattupuzha sub basin) the equatorial radius of the well is just 0.86 m, whereas the corresponding Slichiter's value is just 4.35 lpm/mdd/m. From this it is evident that in this basin also the specific capacity of the dug well is controlled mainly by equatorial radius of the wells rather than the lithology of the terrain.

3.5 GROUNDWATER RESOURCE STUDY

In India the need for groundwater is enormous since the Country's economy depends highly on agriculture. Hence there is always a grater demand for water even under diverse conditions such as topography, climate, geology and hydrological conditions. The distribution of available water resources, both surface and groundwater is highly uneven both in space and time. Rainfall is the primary source of groundwater recharge. The vast alluvial plains in the northern part of India form the most productive zone (in terms of agriculture activities) where groundwater has been extensively used for irrigation (Singhal and Gupta, 1999). Out of the 1140 km^3 of annual utilizable water in India (Table 3.5) the utilization in 1990 was worked out to be 572 km^3, which composed of 382 km^3 from surface water and 190 km^3 from groundwater (Singhal and Gupta, 1999). The increasing population always threaten the availability of water for various uses. The utilisation of water for various purposes during 2000 has been estimated as 750 km^3 comprising 500 km^3 of surface water and 250 km^3 of groundwater. Thus in a ten year period the utility of both surface and groundwater has been doubled. Table 3.5 further shows that by 2025 the total utilisable surface water and replenishable groundwater will be entirely exploited for various purposes. Therefore, the ever increasing population is the main threat to available surface and ground water.

The groundwater resources of the Muvattupuzha river basin (mainly occupying Ernakulam and Idukki districts) have been estimated block wise based on the norms of Groundwater Estimation Committee (GEC), as on March 1999 (CGWB, 2002). The net annual availability of groundwater resources of the Ernakulam district has been estimated as 565 MCM, while the gross groundwater draft of this districts is computed as 284 MCM. Hence, the stage of groundwater development in Ernakulam district is worked out to be only 50.26% (CGWB, 2002). The four blocks, which come under the Muvattupuzha river basin, namely Kothamangalam, Muvattupuzha, Pampakuda and Vazhakulam (Table 3.6) are having groundwater development respectively 43.66%, 54.27%, 77.41% and 55.58%. In Idukki district, the stage

Table 3.5 The status of water resources of India (IWRS, 1996)

(a)	For the year 1990	
1	Annual precipitation	4000 km^3
2	Average available surface water	1870 km^3
3	Utilizable surface water	690 km^3
4	Replenishable groundwater	450 km^3
	Total Utilizable water	1140 km^3
(b)	Water Utilization in 1990	
1	Irrigation	460 km^3
2	Domestic	25 km^3
3	Industries	15 km^3
4	Energy	19 km^3
5	Other	53 km^3
	Total	572 km^3
	Out of this 572 km^3 382 km^3 is from surface water and 190 km^3 from groundwater	
(c)	Projected demands for the year 2000	
1	Surface water	500 km^3
2	Ground water	250 km^3
	Total	750 km^3
(d)	Projection of water utilisation for the year 2025	
1	From surface water	700 km^3
2	From ground water	350 km^3
	This includes	
(a)	Irrigation	770 km^3
(b)	Domestic	52 km^3
(c)	Industries	120 km^3
(d)	Energy	71 km^3
(e)	Other uses	37 km^3
	Total (a) to (e)	**1050 km^3**

Table 3.6 Groundwater resources of the Muvattupuzha river basin

No.	Name of block	Total annual GW recharge *	Natural loss *	Net annual GW availa-bility *	Gross GW draft for irrigation *	Gross GW Draft for domestic & Industry *	Allocation for domestic & Industrial use for next 25 years *	Net GW availability for future irrigation development *	Stage of develo-pment %	Category
1	Kothamangalam	57.73	6.48	51.25	16.98	5.40	12.24	22.03	43.66	safe
2	Muvattupuzha	46.47	6.28	40.19	13.73	8.08	11.14	15.32	54.27	safe
3	Pampakuda	46.09	4.43	41.65	24.40	7.85	11.77	5.48	77.41	semi- critical
4	Vazhakulam	53.20	5.27	47.93	18.65	7.99	14.78	14.5	55.58	safe
5	Thodupuzha	18.95	0.94	18.00	4.39	2.89	3.95	20.38	40.44	safe
6	Elamdesam	21.54	2.14	19.39	7.01	4.78	6.47	5.91	60.80	safe
7	Idukki	31.98	3.19	28.78	3.18	5.19	7.11	18.49	29.08	safe

GW = groundwater
* = Million Cubic Meters (MCM)

of groundwater development in the blocks of Idukki, Thodupuzha and Elamdesam are found to be 29.08%, 40.44% and 60.80% respectively. As per the norms of GEC all the seven blocks except the Pampakuda block are categorised as safe zone (Table.3.6). The Pampakuda block, being situated in mid land region, extensive agricultural activities are going on for the past several decades and therefore the groundwater utility has crossed 77% thus reached a semi critical condition. On other hand the Idukki block being located in the upstream/hilly region and with a low population density, the stage of groundwater development is just 29.08%. Therefore, the utility of groundwater is rather very less. In Elamdesam, which is again located in mid land region where the agricultural activities are widespread, the groundwater utility is more than double than in the Idukki block (60.8%). Therefore, ample measures have to be taken up in the midland region for the groundwater management.

CHAPTER 4

GEOPHYSICAL PROSPECTING

4.1 INTRODUCTION

Geophysics, as it name indicates, has to do with the physics of the earth and its surrounding atmosphere (Telford et al., 1990) Geophysics has been enjoying a long history of success in the groundwater exploration and delineation. It also addresses the solution of groundwater related problems goes by the names environmental, groundwater and near-surface geophysics. The recent technological breakthrough, mainly in microprocessors and associated numerical modelling, has greatly boosted the potential of geophysical investigation (Johansen, 1975; Palacky and Jagodis, 1975).

Geophysical survey is necessary to ascertain the subsurface geological and hydrogeological conditions. Various physical properties employed in geophysical exploration include electrical conductivity, magnetic susceptibility, density, elasticity and radioactivity. Depending upon the scale of operations, geophysical surveys can help to delineate regional hydrogeological features and in pinpointing locations for drilling of bore wells. The proper use of geophysical techniques reduces the risk of drilling poor yield wells. It can also supplement the geological evaluation of proposed well locations. Often groundwater models are used to simulate subsurface flow for a more quantitative hydrogeological analysis of the effect of proposed water-supply wells and for planning purposes in highly urbanized regions, which depend heavily on groundwater (Zohdy et al., 1974; Palacky et al., 1981; Stewart et al., 1983). In an area of saltwater intrusion, resulting from over pumping, geophysical techniques can provide additional data to improve the accuracy of groundwater models, which in turn can be used to determine the extent of the non-saline groundwater resource (Singh and Merh, 1982; Sathiyamoorthy and Banerjee, 1985; Ahmed et al., 1987; Basak and Nazimuddin, 1987).

The application of geophysical methods in groundwater exploration has been reviewed by a number of workers (Zohdy et al., 1974; Palacky et al., 1981; Beeson and Jones, 1988; Ward, 1990; deStadelhofen, 1994). Geophysical surveys for groundwater exploration are generally restricted to the upper 1000 feet (300 m) of the earth's surface. Major groundwater problems addressed are: mapping the depth to basement, thickness of the saturated zone, continuity of granular aquifers and the confining beds separating them. Other applications include mapping of fractured-rock aquifers, individual bedrock fractures or fracture zones, saltwater intrusion in the coastal aquifers and buried valleys. Physical property contrasts implied by these specific problems are exploited by the various geophysical techniques available. Electrical resistivity methods are widely used for both regional and detailed surveys for groundwater exploration because of their greater resolving powers, low expense and wide range of field applicability (Kellor and Frischnecht, 1966; Balakrishna et al., 1978; Chandra and Athavale, 1979; Kefoed, 1979, Chandrasekhran, 1988). In the present study electrical resistivity- Vertical Electrical Soundings (VES) - is followed.

4.2 RESISTIVITY OF GEOLOGICAL FORMATIONS

The resistivity of geological formations varies very widely and it depends on

1) density, porosity, pore size and shape of the aquifer materials,
2) quality of the water encountered in the aquifer,
3) distribution of water in the rocks due to structural and textural characteristics and
4) the temperature of the subsurface environment.

Gilkeson and Wright (1983) have found that the porous geological formations, saturated with groundwater of high ionic strength, are characterised by very low resistivity. However, a low resistivity value need not always a water bearing zone. For example the delineation of Archean- Cretaceous contact that was not exposed at the surface of earth has been well interpreted by the geoelectrical section in the Cretaceous of Tiruchirappalli region (Ballukraya et al., 1981). By carrying out offset soundings in the above area which is underlained by charnockites (Ballukraya et al., 1981), a clear cut low resistivity anomaly has been observed in the VES curves and is inferred as horizontal discontinuity. It is possible that such anomaly/ discontinuity can be mistaken for water bearing zone at depth and in those cases it is necessary to carry out a detailed geophysical survey. A resistivity range from 10.0 to 46.8 Ohm-m may be attributed to water bearing zone either a gravel or weathered /fractured granite (Singhal and Gupta, 1999). Apparent resistivity maps and profiles are commonly used to delineate potential groundwater source (Zohdy et al., 1974; Todd, 1980). Ballukraya (2001), while conducting hydrogeophysical survey in

Table 4.1 Representative resistivity values for Earth materials (Mooney, 1980)

Low resistivity materials	< 100 ohm- m
Medium resistivity materials	100 to 1000 ohm- m
High resistivity materials	> 1000 ohm- m
1. Regional soil resistivities	
Wet regions	50 - 200 ohm- m
Dry regions	100 – 500 ohm- m
Arid regions	200 – 1000 ohm- m
(Some times as low as 50 ohm- m if the soil is saline)	
2. Waters	
Soil water	1 – 100 ohm- m
Rain water	30 – 100 ohm- m
Sea water	order of 0.2 ohm- m
Ice	10^5 - 10^8 ohm- m
3. Rock types below the water table	
Igneous and metamorphic	100 to 10,000 ohm- m
Consolidated sediments	10 to 1000 ohm- m
Unconsolidated sediments	1 to 100 ohm- m
4. Ores	
Massive sulphides	10^{-4} to 1 ohm- m
Non-metallic	order of 10^{10} ohm- m

Table 4.2 Hydrogeological significance of bulk resistivity values

Bulk resistivity (Ohm-m)	Aquifer characteristics or significance	Source
< 1	Clay/ sand saturated with salt water	Zohdy et al. (1974)
15 – 600	Sand and gravel saturated with fresh water	Zohdy et al. (1974)
< 10	Delineates sediments enriched with salt water	Steward et al. (1983)
< 20	Indicates a chloride ion concentration of 250 ppm (aquifer fine sand and limestone)	Steward et al. (1983)
20 – 30	Pore fluid conductivity dominant	Steward et al. (1983)
30 – 70	Affected by both water quality and lithology	Steward et al. (1983)
50 – 70	Porosity is the principal determinant of resistivity	Steward et al. (1983)
< 19	Clay / clay mixed with kankar	Singhal (1984)
64- 81	Weathered sandstone	Singhal (1984)
57-111	Weathered granite	Singhal (1984)
< 10	Saline coastal zone sand (sedimentary)	Balasubramanian et al. (1985)
10 – 20	Clay with or without diffused water	Balasubramanian et al. (1985)
20 - 60	Freshwater zones	Balasubramanian et al. (1985)
0.2 – 0.8	Clay	Sathiyamoorthy and Banerjee (1985)
0.6 – 5	Dry sand (contaminated)	Sathiyamoorthy and Banerjee (1985)
0.3 – 3	Brine bearing sand	Sathiyamoorthy and Banerjee (1985)
3 – 6	Red clay	Sathiyamoorthy and Banerjee (1985)

Source: Sakthimurugan and Balasubramanian (1991).

Namagiripettai area, Namakkal district, Tamil Nadu, found that the buried pediment and bazada at the foothill (on the eastern margin) are having low apparent resistivity.

Bhimashankaram and Gour (1977), Patangay and Muali (1984) and Telford et al. (1990), have given comprehensive lists of resistivity values of various rock types, minerals and soils. Mooney (1980) has also given representative resistivity values for different kinds of earth materials (Table 4.1). Sakthimurugan and Balasubramanian (1991) have tabulated the range of resistivity values of common hard rocks (Table 4.2) and their water bearing weathered products of Peninsular India. The electrical resistivity of a dry formation is much higher than that of the same formation when it is saturated with water. Singhal and Gupta (1999) have given a range of resistivity values of common rocks/materials under dry and saturated conditions (Table 4.3).

Table 4.3 Ranges of resistivity values (ohm-m) of common rocks/ material (Singhal and Gupta, 1999)

Rocks/material	Almost dry	Saturated with water
Quartzite	$4.4\text{x } 10^3$ - $2\text{x}10^8$	50 – 500
Granite	10^3- 10^8	50 – 300
Limestone	600 - 10^7	50 –1000
Basalt	$4\text{x}10^4$- $1.3\text{x } 10^8$	10 – 50
Gneiss	$6.8\text{x}10^4$ - $3\text{x}10^8$	50 – 350
Sand	150 - $2\text{x}10^3$	10 – 100

4.3 INTERPRETATION OF VES DATA

The distribution of 40 well stations used for the study is given in Fig. 4.1 and the results are presented in Table 4.4. The results are analysed both qualitatively and quantitatively in the light of the available geological and hydrogeological information in order to locate groundwater potential zones.

4.3.1 Qualitative interpretation

The qualitative interpretation of VES is done by analysing the iso-apparent resistivity maps (Venugopal, 1998; Aravindan, 1999). This method helps in learning the general information about the geological structure and the changes in geoelectrical section of an area. The ρ1 (resistivity of the first layer) of this basin ranges from 60 ohm-m (station 4) to as high as 6889 ohm-m (station 38). In majority of the stations, the top most layer (average thickness ≅ 2m; Table 4.4) is characterised by hard laterite capping; thus the resistivities of over 30 stations are more than 500 ohm-m of which stations 5, 12, 15-17, 20-23, 25-27, 31-33, 35, 37 and 38 show resistivity values of over 1000 ohm-m.

The resistivity of the second layer (ρ2) ranges from 27 to 9598 ohm-m (Table 4.4; Fig. 4.2) and generally consists of weathered/ fractured rocks and may or may not be saturated with water. From the iso- apparent resistivity map of the second layer, (Fig. 4.2) it is observed that a low resistivity zone is found (<500 ohm-m) in most of the Muvattupuzha sub basin (except the western part) and two small pockets in the Kaliyar sub basin. These areas can be correlated to a smaller extend with storage coefficient (Fig. 3.11) and to a grater extend with the optimum yield (Fig. 3.12). Hence resistivity values below 500 ohm-m

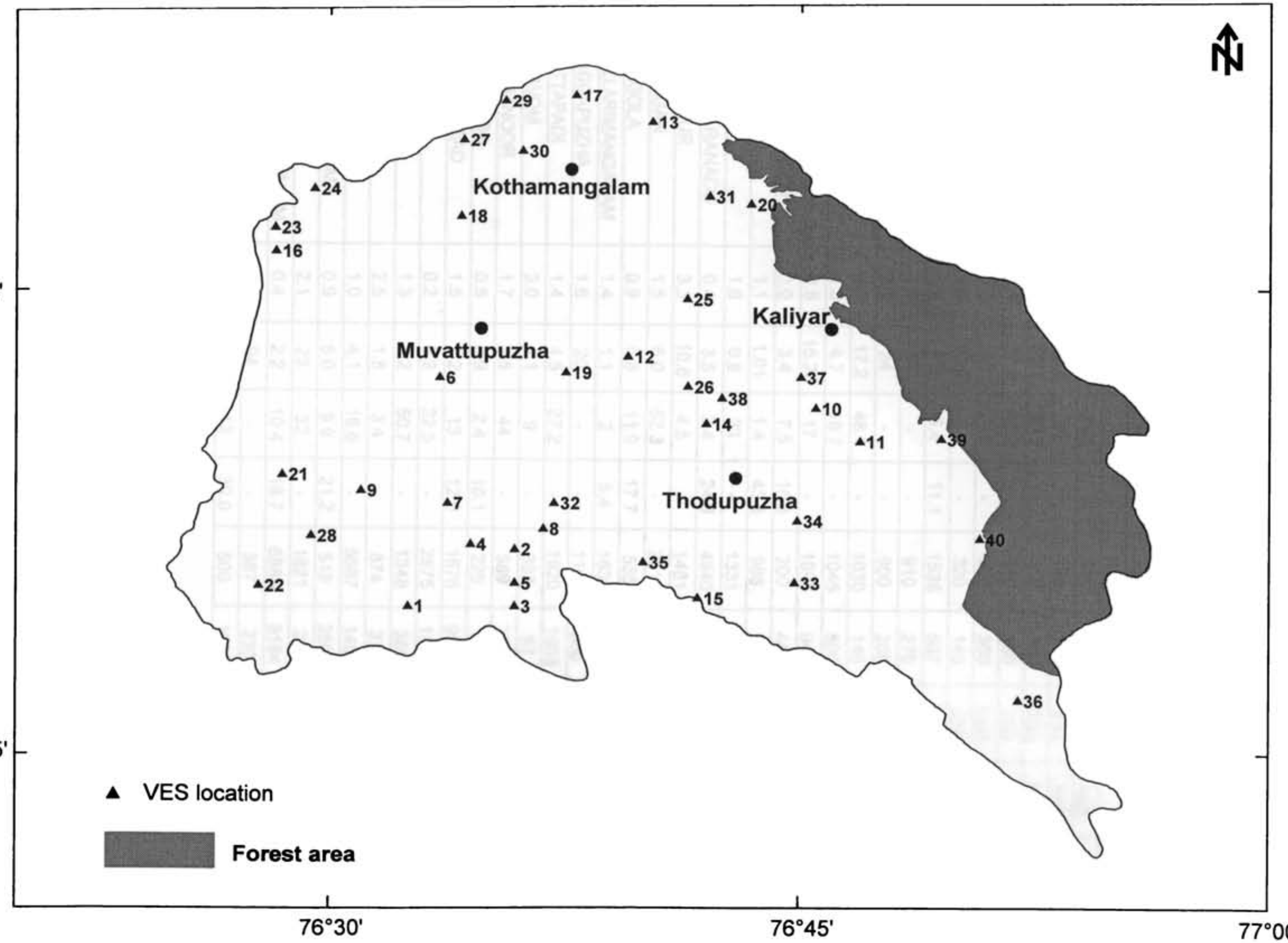


Fig. 4.1 Vertical electrical sounding (VES) locations of the Muvattupuzha river basin

Table 4.4 Analaysed vertical electrical sounding (VES) data of the Muvattupuzha river basin.

S.No.	LOCATION	h1 (m)	h2 (m)	h3 (m)	h4 (m)	ρ1	ρ2	ρ3	ρ4	ρ5	CURVE TYPE
1	ILANJI*	2.3	38.1	-	-	437	200	high	-	-	H
2	KUTTATUKULAM*	3.1	76.3	22.3	-	395	110	200	-	-	H
3	PUDUVELI*	1.8	20	-	-	800	300	high	-	-	H
4	KIZHAKOMBU*	2.1	30	-	-	60	500	high	-	-	A
5	NARIKARA*	1.7	19	-	-	1000	290	high	-	-	H
6	VADAKKUMARADI*	3.1	30	21.1	-	970	300	890	high	-	HA
7	OLIYAPURAM*	0.8	80.6	61	-	180	153	230	high	-	HA
8	KOZIPPALLI*	1.3	58.1	60.8	-	510	183	230	high	-	HA
9	ONAKKUR*	1.1	57.3	62.2	-	310	180	220	high	-	HA
10	VANDAMATTOM*	1.5	30	-	-	500	300	high	-	-	H
11	KARIMANNNUR*	1.8	53.2	25	-	320	140	230	high	-	HA
12	KALURKAD*	1.4	4.0	6.4	11.1	1538	507	4165	269	high	HKH
13	NADUKANI*	1.2	50	-	-	910	270	high	-	-	H
14	PALAKUZHI	2.0	24	-	-	900	200	high	-	-	H
15	PIZHAKU	2.9	17.2	48.1	-	1630	146	292	high	-	HA
16	PUKOLMUKKU	1.3	4.7	19.7	-	1045	590	163	high	-	QH
17	PADAMALI	0.8	15.26	17	-	1993	949	711	735	-	QH
18	ELLUMALAPADDY	3.0	3.4	7.5	15.8	200	484	625	190	high	AKH
19	NALLIPALLI	1.1	1.01	1.4	43.8	986	126	675	109	high	HKH
20	OONUKAL	1.6	0.8	33	-	1331	391	2297	3776	-	HA
21	EZHAKKARANADU	0.4	3.5	3.4	24.6	4940	970	187	1321	high	QHA
22	KAIPATHUR	3.3	10.6	4.5	-	1481	133	631	high	-	HA
23	VILANGAN	1.5	6.0	52.3	-	2611	1174	514	high	-	QH
24	VENGOLA	0.9	0.8	11.9	17.7	535	117	1031	200	high	HKH
25	PALLARIMANGALAM	1.4	1.1	2	5.4	1636	599	1254	49	high	HKH
26	NAGGAPUZHA	1.6	20	-	-	1100	300	high	-	-	H
27	KOTTAPADI	1.4	4.5	27.2	-	1920	1038	439	high	-	QH
28	PIRAVOM	3.0	4.1	9	-	383	97	1150	50	-	HK
29	ASAMANOOR	1.7	2.5	44	-	589	3169	261	high	-	KH
30	NELLIKUZHI	0.5	0.9	2.4	16.1	226	27	3391	182	high	HKH
31	KAVALANGAD	1.5	1.2	13	12.0	1676	9598	810	173	high	KQH
32	VAZITTALA	0.2	3.9	22.5	-	2875	1517	69	high	-	QH
33	MUTTOM	1.3	1.2	50.7	-	1348	388	1679	high	-	HA
34	KARIKODE	2.5	1.8	3.4	-	874	372	4395	595	-	HK
35	KARIMKUNNAM	1.0	4.1	16.6	-	5587	1496	148	high	-	QH
36	MOOLAMATTOM	0.9	8.0	9.9	21.2	518	2500	188	high	-	KH
37	MYLACOMBU	2.1	23	32	-	1821	224	134	high	-	QH
38	KUMARAMANGALAM	0.4	2.2	10.4	18.7	6889	3194	367	48	high	QQH
39	KADALIKAD	1.1	94	-	-	387	230	high	-	-	H
40	CHINIKUZHY	1.1	10	12	30.0	500	1600	200	high	-	KH

h = thickness

ρ = resisistivity

* CGWB data

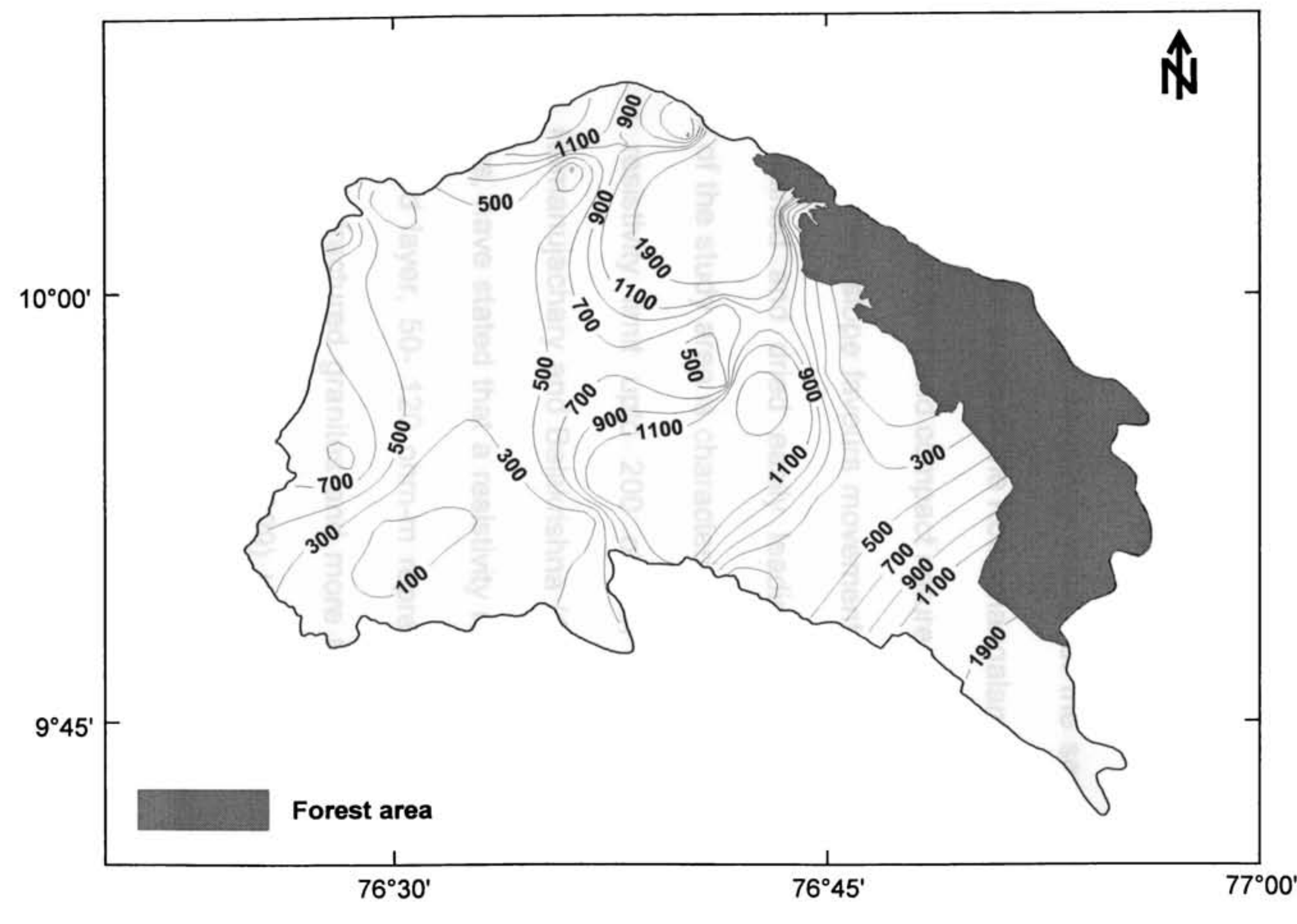


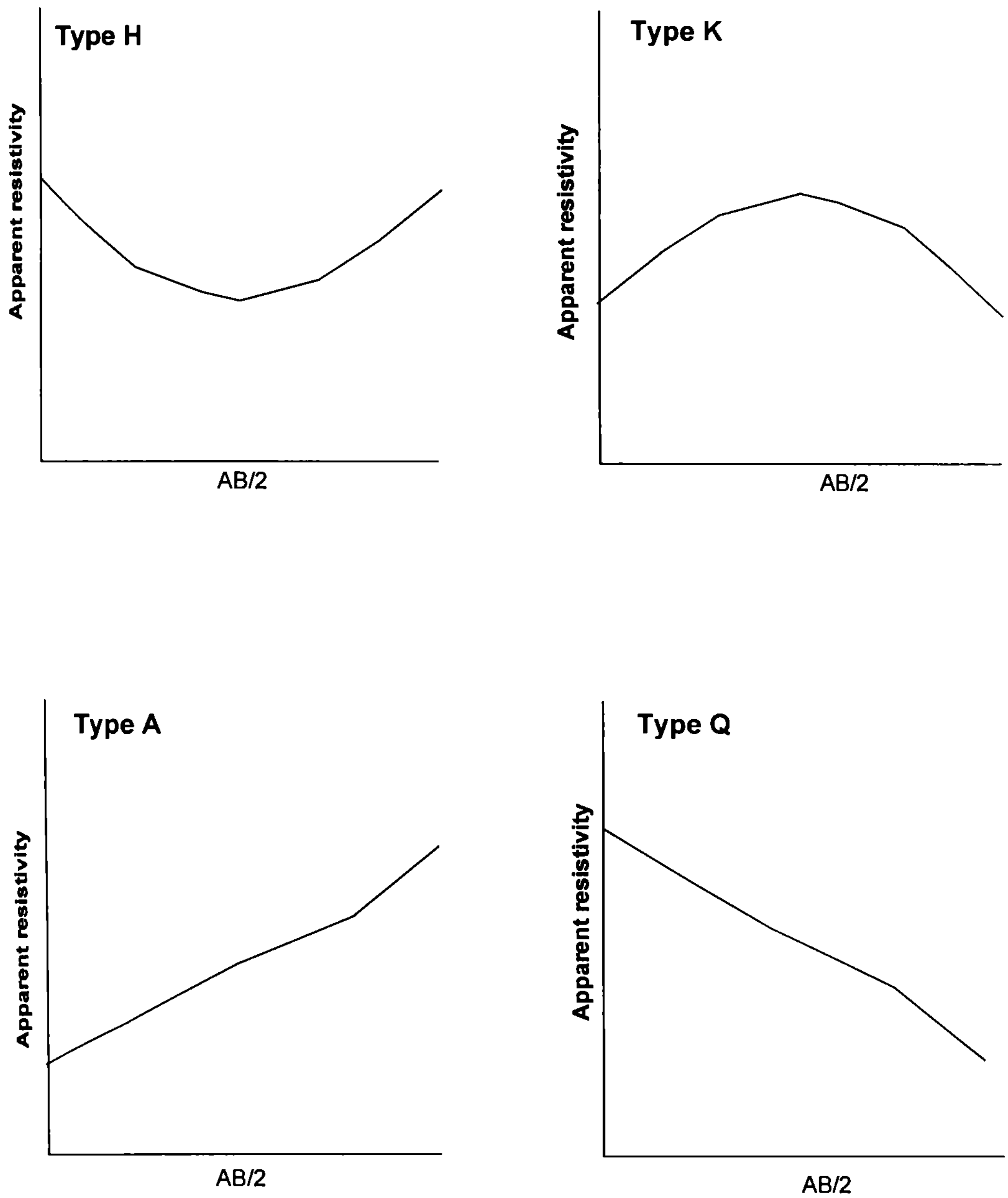
Fig. 4.2 Iso- apparent resistivity of the second layer of the Muvattupuzha river basin

are considered here as potential phreatic aquifer zone as the area is being lateritic nature. Earlier Ramanujachary and Balakrishna (1985) while conducting resistivity survey in and around Goa, have observed very high resistivity of the order of several hundreds of ohm-m in areas covered with laterite. In laterites, resistivity values ranging from 500 to a few thousand ohm-m are considered favourable ground for tapping groundwater (Ramanujachary and Balakrishna, 1985) as laterites are usually porous and can accumulate enormous water. The very high resistivity values of the second layer (>1000 ohm-m) observed in certain areas of the Kothamangalam and Thodupuzha sub basins may be due to the hard and compact nature of laterites accompanied by steep slopes. The steep slope favours movement of water down slope so that the layer get drained and dried easily leading to high resistivity. As the basement rock of the study area is characterised by charnockites and Archean gneiss, so a resistivity limit upto 200 ohm-m is taken for groundwater development. Ramanujachary and Balakrishna (1985) during resistivity survey in granitic terrains, have stated that a resistivity range of 20-50 ohm-m relates to highly weathered layer, 50- 120 ohm-m represents semi-weathered layer, 120-200 ohm-m for fractured granites and more than 200 ohm-m for jointed granite. Unlike this study Aravindan (1999) have used a resistivity value of <500 ohm-m for the development of groundwater in hard rock terrain of the Gadilam river basin, Tamil Nadu.

4.3.2 Quantitative interpretation

The two geoelectrical parameters used in this computation are resistivity (ρ) and thickness (h) of layer. In the case of two-layered ground surface, the simplest sounding curves are the ascending and descending types. An ascending type curve ($\rho1 < \rho2$) is characterised by either topsoil or weathered layer followed by hard compact basement and designated as resistive basement. In descending type curve ($\rho1 > \rho2$), a compact top layer is overlained by a thick clay layer or saline water aquifer and is called conductive basement.

In a three layered ground surface, four types of sounding curves are possible (Fig. 4.3). If $\rho1$, $\rho2$ and $\rho3$ are resistivities of three successive layers from surface, the possible sounding curves are 'A' type ($\rho1<\rho2< \rho3$), 'Q' type ($\rho1>\rho2> \rho3$), 'H' type ($\rho1>\rho2< \rho3$) and 'K' type ($\rho1<\rho2> \rho3$). 'A' type curve is obtained in typical hard rock terrain having a thin conductive topsoil and therefore the resistivities of the layers continuously increase with depth. A sounding curve with a continuously decreasing resistivity is called 'Q' type and such curves are usually obtained in coastal areas where saline waters predominate. 'H' type curves are obtained generally in hard rock terrains consisting of dry top soil (first layer) of high resistivity followed by either a water saturated or weathered layer of low resistivity and then a compact hard rock of very high resistivity at the bottom. Sounding curves of 'K' type show a maximum peak flanked by a low resistivity values. Such curves are obtained in basaltic areas, where compact and massive traps exist between top black



AB/2 = Electrode spacing

Fig. 4.3 Common types of sounding curves in three layered formation

cotton soil and bottom vesicular basalt. In coastal areas also these types of curves will be encountered due to the freshwater aquifer occurring in between clayey layer at the top and a saline zone in the bottom.

The different layer thickness and apparent resistivity values obtained from 40 VES stations are given in Table 4.4 along with curve types. The spatial distribution of various types of sounding curves of the Muvattupuzha river basin is shown in Fig. 4.4. A few sounding curves of the study area (stations 21 and 31) are given in Figs. 4.5a & b. In the southern part of the Muvattupuzha sub basin (Fig. 4.4) most of the sounding curves are found to be H and HA types; a few curves representing HK, A and QHA types are also obtained. In the rest of the Muvattupuzha sub basin curves such as QH, HA and HKH are obtained. In the central Kaliyar sub basin H, HKH, HA, QQH and QH are present. The Kothamangalam sub basin is characterised by a combination of curve types which include QH, AKH, HKH, KH, H, KQH and HA. The Thodupuzha sub basin is characterised by QH on the west, HA/ HK in the central region and KH on the eastern part. The occurrence of a significant typical H type curve (22%) in the entire basin (Fig. 4.4) revels the presence of highly resistive top lateritic soil followed by saturated zone and then the basement topography. So also the wide spread distribution of different combinations of H types (HA-22%, HKH-12% and QH-17%) is an additional indication of a top resistive layer and thus it is predicted here that a water saturated zone is overlained by a top hard layer and underlained by another resistive layer possibly the basement.

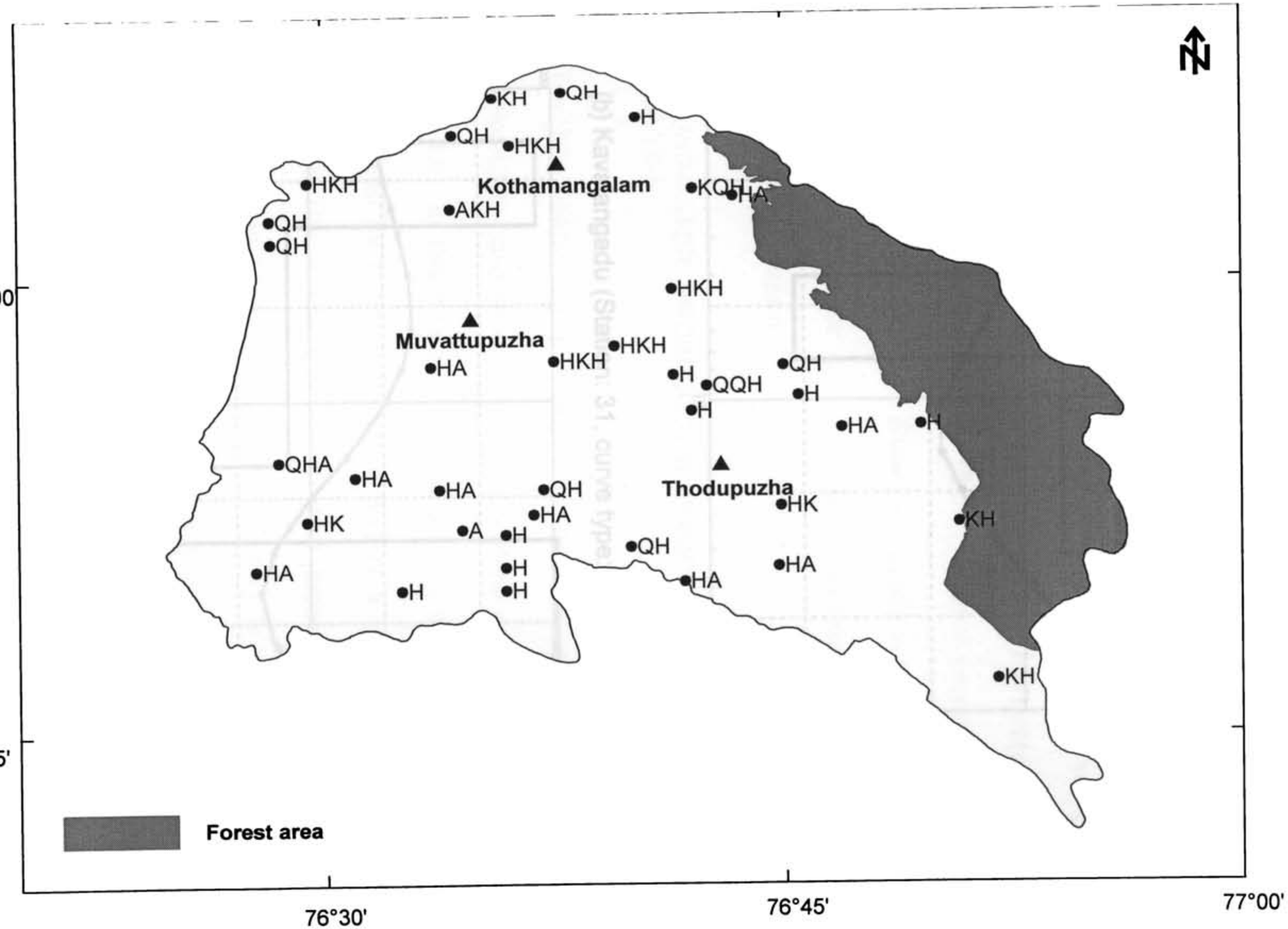
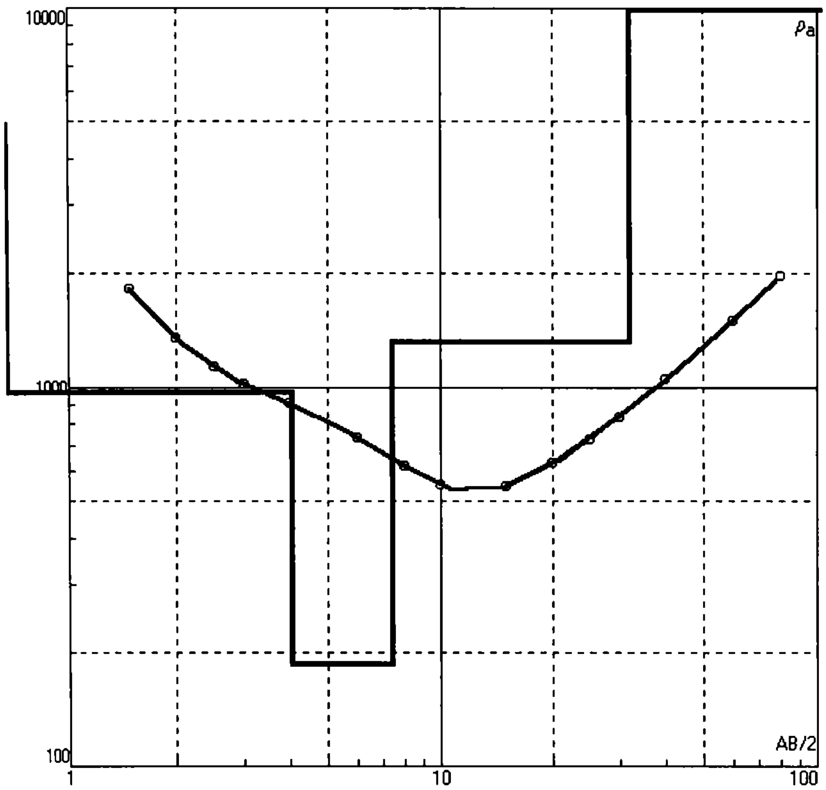


Fig. 4.4 Geoelectric curve types of the Muvattupuzha river basin

(a) Ezhakkaranadu (Station: 21, curve type: QHA)



(b) Kavalangadu (Station: 31, curve type: KQH)

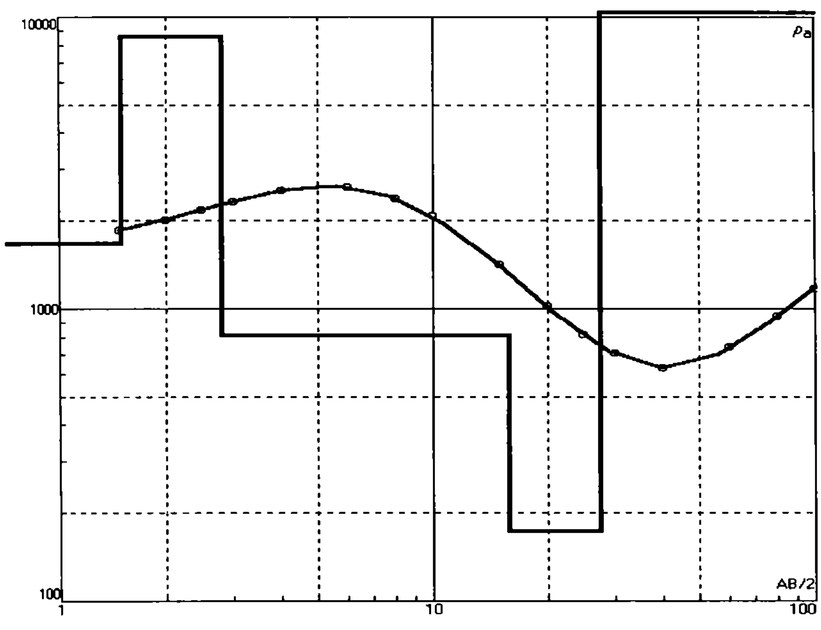


Fig. 4.5 Interpretation of VES data and selected curve pattern of the Muvattupuzha river basin (a) Ezhakkaranadu and (b) Kavalangadu

Based on the depth to bedrock of the basin (Fig. 4.6), the basin is classified into four depth zones namely <5 mbgl, 5-10 mbgl, 10-15 mbgl and >15 mbgl and found that the depth to bedrock steadily increases westward. It is well evident that in most of the Kothamangalam and Thodupuzha sub basins the depth to bedrock is less than 5 m while in the Kaliyar the depth to bedrock is 5 to 10 m. On the other hand in most of the Muvattupuzha sub basin the depth to bedrock is more than 10 m and particularly the entire western part show that the depth to bedrock is over 15 m. Two small pockets on the eastern part of the Kaliyar sub basin also show high depth to bedrock (>10 m). The above depth characteristics give an idea in planning and development of phreatic aquifer in this basin.

4.4 GROUNDWATER PROSPECTING ZONES BASED ON RESISITIVITY ANALYSIS

The information on the depth to bedrock of a basin can help hydrogeologists to have an idea of the depth of the well to be drilled in phreatic zone (Fig. 4.6). In this basin more than 90% of the area is having laterite capping followed by a weathered zone and or a fractured zone above the basement rock. The thickness of the first layer (topsoil) of this basin (Fig. 4.7) ranges from 0.4m to 3.3m (Table 4.4 and Fig. 4.7). In most of the eastern part of the terrain i.e. the sub basins of Kothamangalam, Kaliyar and Thodupuzha, the thickness of the top soil is 1 to 2 m while in the western part of the basin (Muvattupuzha sub basin) the thickness ranges from 1 to 3 m. The top soil is characterised by high resistivity, values ranging from 60 ohm-m to 6889 ohm-m

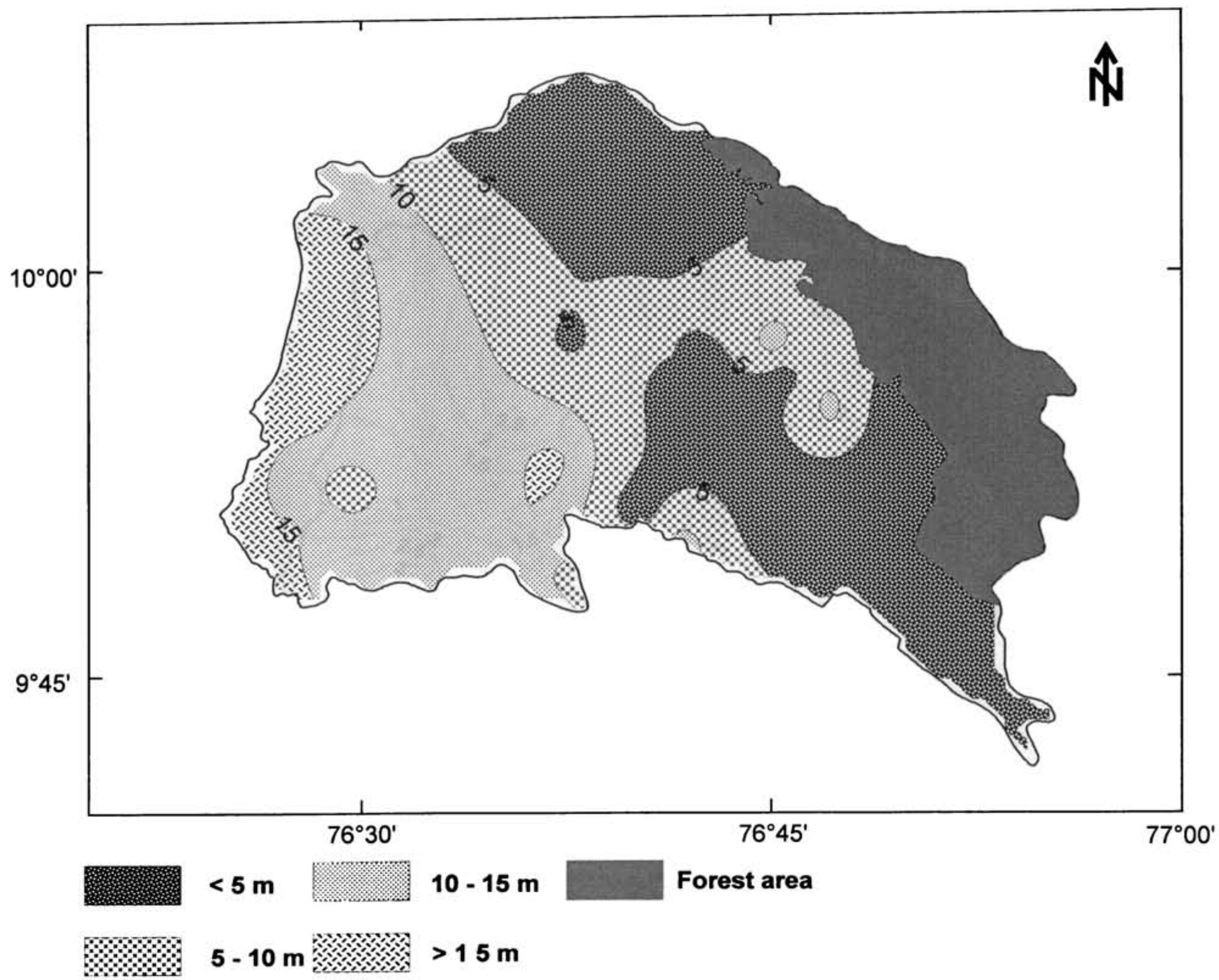


Fig. 4.6 Depth to bed rock of the Muvattupuzha river basin

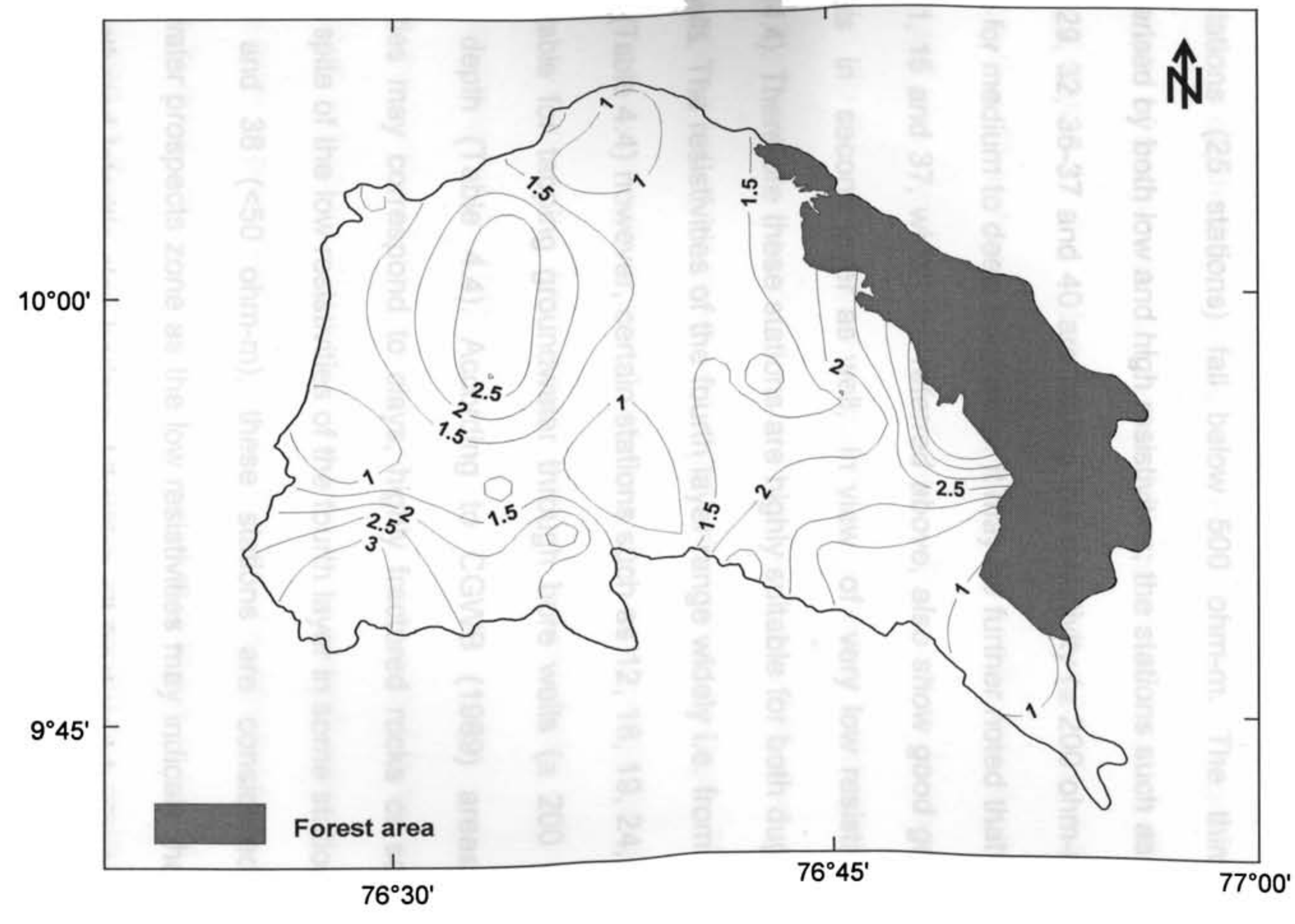


Fig. 4.7 Thickness of top soil of the Muvattupuzha river basin

(Table 4.4). Considering the meagre thickness but high resistivity of the first layer it may be concluded that except a few locations, the top layer is not a prospective zone for groundwater extraction. On the other hand the second layer is considered as a potential zone for phreatic aquifer as the resistivities in most stations (25 stations) fall below 500 ohm-m. The third layer is characterised by both low and high resistivities; the stations such as 2, 7-9, 11, 15, 16, 29, 32, 35-37 and 40 are having low resistivity (≅ 200 ohm-m) and are suitable for medium to deep bore wells. It may be further noted that stations 2, 7 - 9, 11, 15 and 37, which are referred above, also show good groundwater potentials in second layer as well, in view of very low resistivity values (Table 4.4). Therefore these stations are highly suitable for both dug wells and bore wells. The resistivities of the fourth layer range widely i.e. from 48 ohm-m to high (Table 4.4) however, certain stations such as 12, 18, 19, 24, 30 and 31 are suitable for tapping groundwater through bore wells (≅ 200 ohm-m) of varying depth (Table 4.4). According to CGWB (1989) areas with low resistivities may correspond to clays, highly fractured rocks or saline sand. Thus in spite of the low resistivities of the fourth layer in some stations such as 25, 28 and 38 (<50 ohm-m), these stations are considered as poor groundwater prospects zone as the low resistivities may indicate the presence of a weathered lateritic clay horizon. Likewise all fractured horizons need not be water-bearing zones. For example the bore hole lithology at Ilanji (Fig. 1.5) show a very thick fracture zone extending up to 150 m, however, the VES indicate low resistivities only up to a depth of 40 m beyond which the resistivities is recorded as high (Table 4.4). This is a clear indication that the recorded fractures at Ilanji (station1) can be either horizontal type or that the fractures have not been interconnected with other potential fracture zones and therefore below the depth of 40 m at station1 the productivity is rather low.

As the depth of the existing dug wells of this basin ranges from 1 to 18 m, the depth of the phreatic aquifer is rather restricted to 20 m. The depth to bedrock at station 21 (Fig. 4.5a) is 15 m while at station 31 (Fig. 4.5b) depth to bedrock is 2 m. Therefore, the limiting of phreatic aquifer at a depth of 20 m is justified and the resistivity value of below 500 ohm-m is considered for discussion. So the criteria for demarcating groundwater prospects of phreatic zone of this basin are based on resistivity values below 500 ohm-m (fractured and weathered saturated zone) and extent of depth to bedrock. Thickness of layers and low resistivity horizons are taken for demarcating the groundwater potential zones over hard rock terrain (Balakrishnan et al., 1984; Balasubramanian et al., 1985).

A comparison of the resistivity values of the second layer (Fig. 4.2) with that of depth to bedrock (Fig. 4.6) is made and the groundwater prospect of the phreatic zone is presented in Fig. 4.8. The criteria adopted to subdivide the basin in to good, moderate and poor are also present in Fig. 4.8. As the southern part of the Muvattupuzha sub basin is having low resistivity (<300 ohm-m) and depth to bed rock is more than 10 m the area is designated as good groundwater prospects. Further a narrow zone, extending up to the north of the Muvattupuzha sub basin, show as resistivity value ranging from 300 to

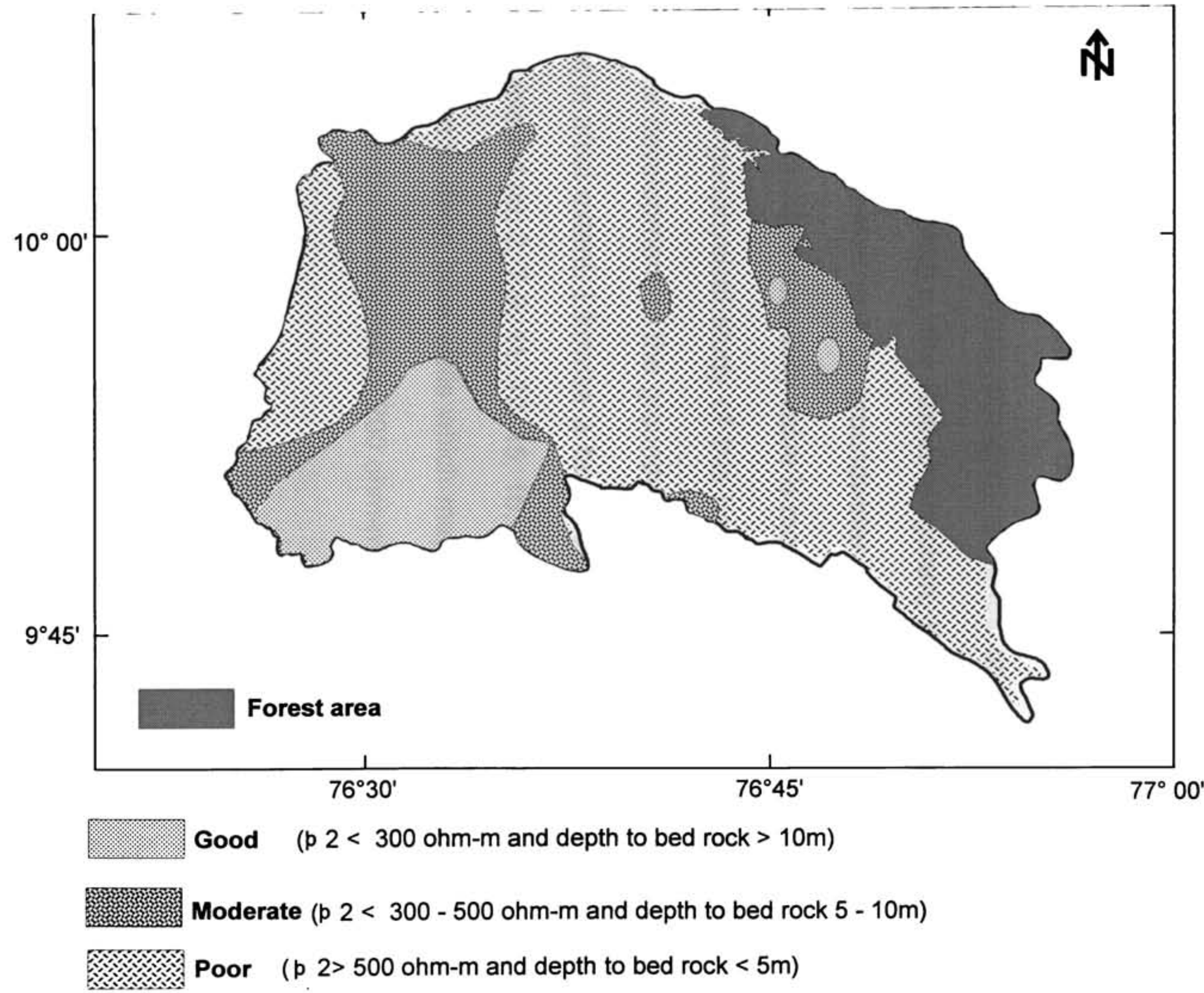


Fig. 4.8 Groundwater potential of phreatic zones of the Muvattupuzha river basin

500 ohm-m while depth to bed rock is 5 -10 m and therefore the groundwater prospecting of this stretch is moderate. On the other hand the western part of the Muvattupuzha sub basin, in spite of having grater depth to bedrock (>15 m) the area is categorized as poor category of groundwater prospects as the resistivity is high (>500 ohm-m). In spite of above observation the water level fluctuation is rather low and therefore detailed study is necessary with additional control points. The rest of the Muvattupuzha basin, (except a few isolated good and moderate prospecting zones on the eastern part of the Muvattupuzha basin (i.e. the Kothamangalam, Kaliyar and Thodupuzha sub basins), is designated as poor groundwater prospects as the depth to bedrock is less than 5 m while resistivity value is more than 500 ohm-m.

Thus geophysical study of this basin has given the probable potential zones for development of the groundwater in phreatic aquifer, which is rather limited in areal extent. Likewise a few promising stations has been identified from Table 4.4 (st. 2, 7-9, 11, 12, 15, 16, 18, 19, 24, 29, 30- 32, 35-37 and 40) for medium to deep bore wells which may be made up to 3rd or 4th layers in view of moderate resistivities ($\cong$ 200 ohm-m)

CHAPTER 5

HYDROGEOCHEMISTRY

5.1 INTRODUCTION

The quality of groundwater has equal importance as the quantity and this has been recognised only a couple of decades ago. The characteristics of groundwater (hard or soft; mineralised or non-mineralised) depend on the extent of reactions it made with the country rock (Edmunds, 1994). At this juncture it is important to know the mineral characteristics of the country rock, which will vary from place to place. Therefore, an understanding of the various geochemical processes, which control the groundwater quality, should form the starting point while conducting hydrogeological investigations and other applied studies. The natural chemistry of groundwater can often has an important bearing on human health or on livestock. A detailed analysis of major, minor and trace constituents (including organics) of groundwater is a prerequisite while commissioning public supply of water. Various international bodies such as the World Health Organization (WHO), European Economic Community (EEC) and Indian Standard Institution (ISI) have given certain standards for drinking water. For a hydrogeologist, an understanding of the geochemical characteristics of groundwater systems is very important in determining the physical properties of flow system. Hydrochemical data can help to estimate such properties like the amount of recharge, the extent of mixing, the circulation pathways, maximum circulation depth, temperature at depth and residence time of groundwater (Edmunds, 1994).

The type and concentration of salts in groundwater depend on the geological environment and movement of groundwater (Raghunath, 1987). Generally, high concentrations of dissolved constituents are found in groundwater than in surface water because of its greater exposure to soluble minerals of the geological formations (Todd, 1980). Bicarbonates, which are the primary anion in groundwater, are derived from carbon dioxide released by organic decomposition in soil (Langmuir, 1997). Groundwater passing though igneous, rocks dissolve only a very small quantity of mineral matter because of the relative insolubility of the rock composition (Todd, 1980). The average chemical composition of rocks (igneous, metamorphic and carbonates rocks) and groundwater (Chebotarev, 1950; Hem, 1959) are given in Table 5.1a while the sources of various ions in water (Hem, 1959) are given in Table 5.1b.

5.2 QUALITY CRITERIA FOR VARIOUS USES

Groundwater is mainly used for domestic, irrigation and industrial purposes. The quality criteria depend on the use of water for a particular purpose and quality standards have to be maintained in water supply for different uses to avoid deleterious effects. Hence in this study an evaluation of groundwater for domestic, irrigational and industrial purposes is made. Groundwater samples collected from 55 dug wells during pre and post monsoon periods (Fig. 5.1) were analysed for physical parameters, major

Table: 5.1a Average chemical composition (mg/l) of three major rock types and groundwater (after Chebotarev, 1950; Hem, 1959)

Constituents	Igneous rocks	Sandstone	Carbonates	Groundwater
SiO_2	285000	359000	34	1-30
Al	79500	32000	8970	1-2
Fe	42200	18600	8190	0-5
Ca	36200	22	272000	10-200
Mg	17600	400	45300	1-100
Na	28100	8100	393	1-300
K	25700	13200	2390	1-20
Sr	368	28	617	<10
HCO_3	-	-	-	80-400
SO_4	-	-	-	10-100
Cl	200	150	-	1-150
F	715	220	112	0.1-2
Br	2.4	1	606	<0.5
B	7.5	90	16	<2
TDS	-	-	-	100-1000

Table 5.1b Various sources of ions in water (Hem, 1959)

Major ions (> 1 mg/l)	Sources
Calcium Ca_2^+	Carbonates, gypsum
Magnesium Mg^{2+}	Olivine, pyroxene, amphibole
Sodium Na^+	Clays, feldspars, evaporates, industrial waste
Potassium K^+	Feldspar, fertilizers, K-evaporates
Bicarbonate HCO_3^-	Soil and atmospheric CO_2, carbonates
Chloride Cl^-	Windborne rain water, sea water and natural brines, evaporates deposits; pollution
Sulphate SO_4^{2-}	Gypsum and anhydrite, sea water, windborne, oxidation of pyrite
Nitrate NO_3^-	Windborne, oxidation of ammonia or organic nitrogen, contamination
Silica, SiO_2	Hydrolysis of silicates
Minor ions (1 to 0.1 mg/l)	
Iron Fe_2^{2-}	Oxides and sulphides, e.g. heamatite and pyrite; corrosion of iron pipes
Manganese Mn_2^{2-}	Oxides and hydroxides,
Boron B	Tourmaline, evaporates, sewage, sea water
Flouride F^-	Flourine-bearing minerals, viz. fluorite, biotite
Trace elements (<0.1 mg/ 1)	
As	Arsenic minerals, eg arsenopyrite, arsenic insecticides
I	Marine vegetation, evaporates
Zn	Sphalerite, industrial waste
Heavy metals (Hg, Pb, Cd, Cr)	Industrial waste and igneous rock weathering, under mild reducing conditions
Radioactive elements (U, Ra, etc.)	Uraniferous minerals, nuclear tests and nuclear power plants.

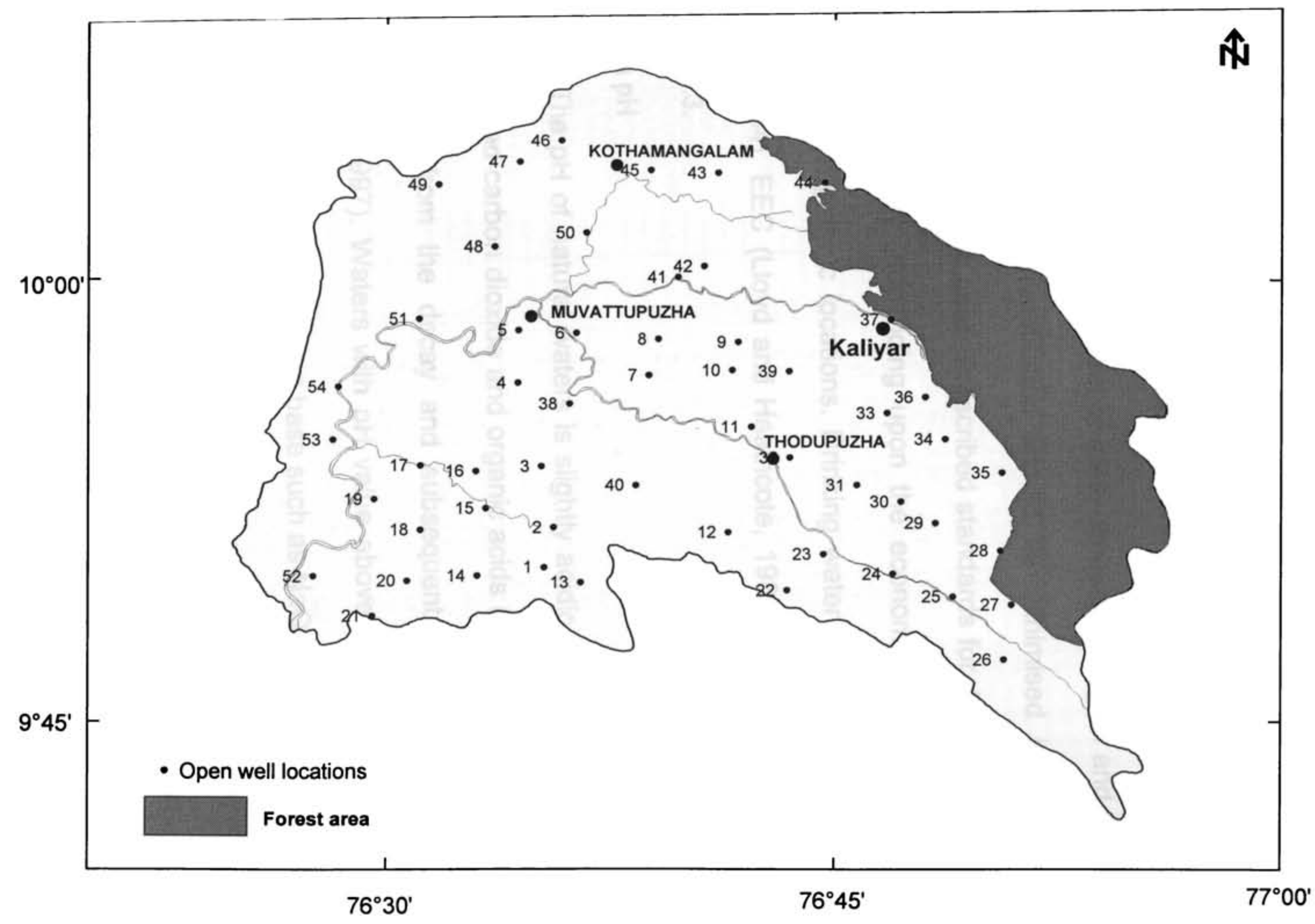


Fig. 5.1 Location map of open wells in the Muvattupuzha river basin

cations and anions, fluoride, total iron and total hardness (as $CaCO_3$). The results are given in Tables 5.2a & b.

5.2.1 Evaluation of groundwater for domestic uses

As groundwater is mainly used for drinking and other domestic purposes, a detailed chemical analysis of water is very much important, as certain chemical constituents became toxic beyond particular concentrations, although they may be beneficial at lower amounts (Singhal and Gupta, 1999). So also bacterial contamination should be minimised in groundwater for drinking and domestic uses. Prescribed standards for drinking water vary from country to country, depending upon the economic condition, climate, food habits and geographic locations. Drinking water standards as prescribed by WHO (1984), EEC (Lloyd and Heathcote, 1985) and ISI (1983) are given in Table 5.3.

5.2.1a pH

The pH of natural waters is slightly acidic (5.0 –7.5) and is caused by the dissolved carbon dioxide and organic acids (fulvic and humic acids), which are derived from the decay and subsequent leaching of plant materials (Langmuir, 1997). Waters with pH value above 10 are exceptional and may reflect contamination by strong base such as NaOH and $Ca(OH)_2$. The range of desirable limit of pH of water prescribed for drinking purpose by ISI (1983) and WHO (1984) is 6.5-8.5 while that of EEC (Lloyd and Heathcote, 1985) is 6.5-9.0.

Table 5.2a Chemical analysis of groundwater of the Muvattupuzha river basin (pre monsoon)

Well No.	Location	µS/cm		mg/l										
		EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T. Fe	TDS	TH
1	Puthuvely	166	6.5	9.62	3.37	9.30	1.10	22.00	6.85	14.99	0.34	BDL	70	38
2	Pampakada	210	7.5	20.84	4.00	19.00	9.00	31.90	9.05	32.99	0.10	BDL	130	68
3	Karimbara	55	8.0	4.01	1.07	4.20	1.00	15.40	3.44	5.00	0.07	BDL	35	14
4	Thekkumaradi	137	6.5	16.83	0.73	7.40	2.90	30.80	5.60	15.99	0.15	BDL	87	45
5	Vadakkumaradi	112	6.3	6.41	5.32	13.00	1.20	17.60	5.55	18.99	0.22	0.20	71	38
6	Adoorparambu	64	6.6	4.01	0.20	7.70	1.00	23.10	5.55	6.00	BDL	0.39	41	11
7	Vazhakulam	73	7.5	4.01	1.95	5.90	1.00	23.10	4.91	13.99	0.17	BDL	47	18
8	Vazhakulam	68	6.7	6.41	0.49	5.10	0.70	24.20	4.91	8.00	BDL	BDL	43	18
9	Thazhuramkunnu	72	6.8	0.80	3.90	5.50	1.30	17.60	4.91	10.00	0.17	BDL	48	18
10	Nagapuzha	54	6.4	0.80	2.15	4.90	1.30	9.90	4.91	9.00	BDL	BDL	34	11
11	Vengallur	57	7.3	4.81	1.46	3.40	1.20	22.00	4.91	5.00	BDL	BDL	36	18
12	Karimkunnam	271	6.8	12.02	4.98	18.00	16.50	92.40	7.76	29.99	0.08	BDL	173	50
13	Veliyannur	153	7.3	8.02	2.15	21.00	3.50	60.50	5.83	8.00	0.31	0.39	99	29
14	Elanji	142	7.3	20.84	2.24	3.00	1.90	48.40	9.24	6.00	0.11	BDL	90	61
15	Idayar	52	6.6	4.01	1.51	3.20	0.70	15.40	6.20	7.00	0.07	BDL	33	16
16	Tirumaradi	52	6.3	0.80	3.02	3.80	0.90	20.90	5.55	9.00	BDL	BDL	35	14
17	Onakkur	53	7.1	6.41	0.05	4.90	1.10	17.60	7.31	5.00	0.04	BDL	34	16
18	Illikamukkada	40	5.9	1.60	0.78	4.10	0.70	14.30	6.38	8.00	BDL	0.14	25	7
19	Piravam	55	5.7	3.21	0.68	5.20	0.40	12.10	5.55	7.00	0.24	BDL	35	11
20	Aborma	56	6.7	4.01	1.51	4.20	1.10	16.50	4.91	5.00	0.12	BDL	36	16
21	Peruva	124	7.2	14.43	0.44	5.20	5.50	59.40	4.91	5.00	BDL	BDL	80	38
22	Thudanganad	45	6.3	1.60	1.22	2.30	0.70	11.00	6.39	2.00	0.04	BDL	28	9
23	Muttam	55	6.2	4.01	0.63	3.40	1.00	13.20	4.36	7.00	BDL	BDL	35	13
24	Kolapra	47	6.1	3.21	1.12	3.80	0.90	16.50	6.39	6.00	BDL	BDL	30	13
25	Kanjar	59	6.7	5.61	0.54	3.70	1.30	12.10	4.45	4.00	0.18	BDL	37	16
26	Manappadi	119	6.7	11.22	0.20	9.70	3.60	23.10	6.20	15.99	0.08	0.08	76	29
27	Karippilangadu	79	6.4	4.01	0.20	2.90	1.40	30.80	6.94	1.00	0.08	2.40	50	11
28	Pannimattam	67	6.8	6.41	2.68	3.60	1.60	26.40	6.20	2.00	0.09	0.08	42	27
29	Ilamdesam	98	6.3	8.02	0.39	7.60	2.70	11.00	5.60	12.99	0.17	BDL	62	22
30	Kontalappali	78	6.7	4.81	1.46	5.50	3.40	18.70	5.60	10.00	BDL	0.08	49	18
31	Alakkodu	99	6.7	0.80	7.41	8.00	1.60	23.10	5.83	10.00	0.04	0.76	63	32
32	Karikode	156	6.6	11.22	3.27	11.40	7.90	59.40	8.97	9.00	0.04	BDL	99	41
33	Kurumpalamattam	53	7.6	4.81	0.15	4.60	1.40	12.10	4.08	9.00	BDL	BDL	33	13
34	Udambannur	49	6.3	2.40	1.17	4.50	0.90	22.00	3.44	9.00	0.18	BDL	31	11
35	Chinikkuzhi	61	6.3	5.61	0.98	5.60	2.50	19.80	5.16	10.00	BDL	0.14	39	18
36	Molappuram	103	6.6	3.21	0.24	6.20	6.80	22.00	6.85	12.00	0.08	0.39	66	9
37	Kaliyar	124	6.5	6.41	1.37	13.80	7.00	14.30	6.39	25.99	0.22	0.24	78	22
38	Arakuzha	69	7.3	5.61	0.54	3.20	0.80	22.00	5.60	6.00	0.35	0.14	43	16
39	Ezhallur	94	6.0	6.41	0.93	5.80	6.70	6.60	7.30	13.99	0.31	BDL	60	20
40	Vazathala	40	6.0	3.21	1.56	2.50	0.70	16.50	5.83	8.00	0.29	BDL	26	14
41	Pulinthanam	46	6.7	1.60	0.78	2.80	1.50	27.50	5.55	2.00	0.15	1.76	30	7
42	Pottanikad	170	6.1	16.83	0.29	12.00	4.30	24.20	6.66	22.99	0.02	0.00	108	43
43	Nellimattom	57	6.1	1.60	2.98	3.20	1.00	13.20	7.39	9.00	BDL	BDL	37	16
44	Tallakode	136	6.3	1.60	0.78	3.10	1.50	61.60	6.85	8.00	0.10	0.14	87	7
45	Kuthikuzhi	161	6.3	16.03	1.66	19.00	8.20	34.10	6.94	29.99	BDL	BDL	103	47
46	Nellikuzhi	89	6.1	8.02	0.83	11.80	3.00	15.40	5.60	9.00	BDL	BDL	56	23
47	Iramallur	121	7.0	9.62	1.61	9.70	7.30	11.00	7.30	17.99	0.08	0.18	77	31
48	Pezhakapalli	134	6.6	7.21	0.44	16.00	1.40	12.10	6.85	11.00	0.03	0.08	85	20
49	Kizhillam	356	7.3	38.48	0.29	27.00	3.90	127.60	13.57	38.98	0.07	4.74	227	97
50	Karukadam	107	6.3	6.41	0.05	8.60	5.60	13.20	7.30	12.00	0.36	0.40	68	16
51	Valakam	80	6.1	5.61	0.10	6.80	2.30	9.90	6.94	10.00	BDL	BDL	51	14
52	Piravam Road	186	7.4	16.03	2.98	6.00	0.70	62.70	7.95	11.00	0.09	1.02	119	52
53	Nechur	44	7.0	1.60	0.78	3.60	1.30	19.80	5.83	5.00	0.05	1.33	28	7
54	Ramamangalam	87	6.6	1.60	0.34	7.60	3.50	12.10	6.39	17.99	0.04	0.39	55	5
55	Arayankavu	52	6.2	4.08	1.50	6.80	1.00	25.10	4.10	24.76	0.40	BDL	33	16

BDL - Below detection level, T.Fe- Total Iron, TH- Total Hardness

Table 5.2b Chemical analysis of groundwater of the Muvattupuzha river basin (post monsoon)

Well No.	Location	µS/cm		(mg/l)										
		EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T.Fe	TDS	TH
1	Puthuvely	77	6.4	6.53	1.00	7.00	1.48	33.95	6.84	5.00	0.24	0.66	49	20
2	Pampakada	139	6.9	16.32	0.00	12.00	8.58	33.95	8.39	15.00	0.09	0.18	88	40
3	Karimbara	42	6.4	1.63	1.50	5.00	2.01	38.80	BDL	5.00	0.07	0.06	26	10
4	Thekkumaradi	95	6.7	10.61	2.00	5.50	6.55	48.95	4.65	10.00	0.11	BDL	60	34
5	Vadakkumaradi	87	6.8	5.71	1.00	11.50	2.20	29.10	2.75	16.99	0.19	0.07	55	18
6	Adoorparambu	44	6.2	3.26	0.50	5.80	1.12	19.40	2.90	4.00	BDL	BDL	28	10
7	Vazhakulam	52	6.4	4.08	1.50	6.80	0.93	29.10	2.75	8.00	0.15	BDL	33	16
8	Vazhakulam	48	6.4	4.90	1.00	5.10	1.48	24.25	3.29	6.00	BDL	0.07	30	16
9	Thazhuramkunnu	30	6.4	2.45	2.50	2.80	0.93	29.10	2.60	2.00	0.16	BDL	19	16
10	Nagapuzha	41	6.1	4.08	0.50	5.90	1.83	19.40	3.29	8.00	BDL	0.19	26	12
11	Vengallur	42	7.0	3.26	0.50	2.10	0.90	10.00	3.15	4.00	BDL	BDL	27	10
12	Karimkunnam	125	7.1	11.42	0.50	8.20	7.65	43.65	3.59	9.00	BDL	0.28	80	30
13	Veliyannur	29	6.4	4.90	0.50	4.80	1.48	29.10	2.60	8.00	0.30	0.13	19	14
14	Elanji	86	7.4	13.87	1.00	5.20	1.48	53.35	2.60	3.00	0.09	BDL	54	38
15	Idayar	45	6.6	4.08	1.00	5.00	0.58	24.25	2.60	4.00	0.05	0.07	27	14
16	Tirumaradi	43	6.4	3.26	1.00	5.00	1.12	33.95	BDL	6.00	BDL	BDL	28	12
17	Onakkur	46	6.6	4.08	1.50	6.50	1.31	33.95	3.29	6.00	BDL	0.35	29	16
18	Illikamukkada	41	5.9	2.45	0.50	6.20	2.20	29.10	2.90	12.00	BDL	BDL	26	8
19	Piravam	54	5.6	3.26	0.50	6.40	1.12	24.25	2.75	11.00	0.19	BDL	35	10
20	Aborma	45	7.1	3.26	0.50	5.80	1.68	29.10	2.60	5.00	0.10	0.67	28	10
21	Peruva	55	6.8	4.08	1.50	7.40	2.54	33.95	2.75	9.00	BDL	0.06	35	16
22	Thudanganad	25	6.1	2.45	1.00	3.40	0.93	29.10	3.82	5.00	BDL	0.13	16	10
23	Muttam	39	6.2	1.63	2.00	5.20	2.01	24.25	BDL	4.00	BDL	0.07	24	12
24	Kolapra	32	6.5	2.45	0.50	4.30	1.48	24.25	2.60	6.00	BDL	BDL	20	8
25	Kanjar	46	6.0	4.08	3.00	5.00	1.12	33.95	2.60	5.00	0.11	BDL	30	22
26	Manappadi	56	6.8	6.53	0.50	5.20	2.39	29.10	3.52	4.00	BDL	BDL	35	18
27	Karippilangadu	29	6.6	1.63	0.50	3.90	1.83	29.10	2.75	3.00	BDL	BDL	18	6
28	Pannimattam	27	6.2	2.45	1.00	2.60	0.93	33.95	3.29	2.00	BDL	0.28	17	10
29	Ilamdesam	74	6.4	1.63	0.50	8.30	3.64	24.25	3.06	8.00	0.06	BDL	47	6
30	Kontalappali	73	6.1	6.53	0.50	7.80	4.76	24.25	2.75	10.00	BDL	BDL	46	18
31	Alakkodu	48	6.6	5.71	0.50	4.50	1.31	29.10	5.42	6.00	BDL	BDL	30	16
32	Karikode	128	6.8	12.24	0.50	12.20	10.17	63.05	2.90	12.00	BDL	BDL	82	32
33	Kurumpalamattam	36	6.6	2.45	0.50	4.60	3.30	29.10	2.60	3.00	BDL	0.35	24	8
34	Udambannur	41	6.4	2.45	1.00	5.10	2.01	24.25	2.75	7.00	0.09	0.18	27	10
35	Chinikkuzhi	71	6.3	5.71	0.50	8.50	5.84	24.25	2.60	12.00	BDL	0.11	45	16
36	Molappuram	94	6.9	8.16	1.50	8.60	10.53	33.95	2.75	13.00	BDL	0.26	60	26
37	Kaliyar	138	6.4	10.61	1.50	13.80	7.81	19.40	2.75	22.99	0.21	BDL	88	32
38	Arakuzha	61	7.0	7.34	0.50	4.60	2.01	38.80	2.75	6.00	0.31	0.19	39	20
39	Ezhallur	86	6.2	2.45	0.60	1.40	0.60	14.10	2.90	10.18	0.31	BDL	55	12
40	Vazathala	34	6.2	2.45	0.50	3.20	0.76	33.95	3.06	3.00	0.25	0.06	22	8
41	Pulinthanam	40	6.7	4.90	1.00	4.20	0.76	29.10	2.60	2.00	0.15	0.28	26	16
42	Pottanikad	88	6.1	8.98	1.00	7.60	4.57	24.25	3.52	11.00	BDL	0.28	57	26
43	Nellimattom	49	7.4	6.53	0.50	4.00	4.76	29.10	2.75	5.00	BDL	BDL	32	14
44	Tallakode	55	6.4	4.08	1.50	5.30	2.20	29.10	3.29	6.00	0.10	0.06	36	16
45	Kuthikuzhi	180	6.4	17.95	1.50	15.40	7.29	24.25	9.16	21.99	BDL	0.06	115	50
46	Nellikuzhi	71	6.5	6.53	1.00	12.00	4.03	29.10	2.60	16.99	BDL	0.06	45	20
47	Iramallur	48	6.7	2.45	1.50	5.20	2.20	29.10	3.59	4.00	BDL	0.14	31	12
48	Pezhakapalli	114	6.3	5.71	1.50	13.70	2.20	24.25	8.70	16.00	BDL	0.13	72	20
49	Kizhillam	254	8.1	34.27	9.50	16.00	4.91	155.20	3.52	15.00	BDL	1.00	162	122
50	Karukadam	137	7.0	2.45	0.50	14.40	10.03	38.80	3.52	22.99	0.33	0.11	87	8
51	Valakam	50	6.3	2.45	1.50	5.50	10.01	24.25	3.06	9.00	BDL	BDL	32	12
52	Piravam Road	97	7.4	16.32	1.50	5.70	0.58	63.05	2.75	5.00	0.09	1.20	63	46
53	Nechur	37	6.6	3.26	0.50	4.80	1.48	29.10	4.21	5.00	BDL	BDL	23	10
54	Ramamangalam	110	6.2	3.26	3.00	13.40	5.32	24.25	2.90	22.99	BDL	0.11	70	20
55	Aryankavu	72	6.1	3.26	0.50	7.90	2.20	19.40	3.29	10.00	0.35	BDL	46	10

BDL - Below detection level, T.Fe- Total Iron, TH- Total Hardness

Table 5.3 Ranges/ upper limits of various constituents (mg/l) in drinking water

Parameters	WHO (1984)	EEC (1985)	ISI (1983)
TDS	1000	1500	500
pH	6.5-8.5	6.5-9.0	6.5-8.5
Total hardness ($CaCO_3$)	500	2-10 meq/l	300
Ca	75-200	75-200	75
Mg	-	50	30
Na	200	150	No limit
Cl	250	250	250
SO_4	400	250	150
NO_3	45	50	45
Fe	0.3	0.2	0.3
F	1.5	1.5	0.6-1.2
Pb	0.05	0.05	0.1
Hg	0.001	0.001	0.001
Zn	5.0	5.0	5.0
Cu	1.0	0.05	0.05
Cd	0.005	0.005	0.01
As	0.01	0.05	0.05
Cr (hexavalent)	0.05	0.05	0.05
CN (Cyanides)	0.05	0.05	0.05
Overall radioactivity (α)	3 pCi/l	3 pCi/l	1 pCi/l
Overall radioactivity (β)	30 pCi/l	30pCi/l	10 pCi/l
Coliforms	No fecal coliforms	No fecal coliforms	100 coliforms/litre

WHO- World Health Organisation
EEC-Europeans Economic Community
ISI-Indian Standard Institutions

The pH distribution of the groundwater of the basin for both seasons are given in Table 5.2a & b and presented in thematic maps (Figs. 5.2a & b). The pH is classified into five zones, viz. (i) 5.5-6.0, (ii) 6.0-6.5, (iii) 6.5-7.0, (iv) 7.0 - 7.5 and (v) >7.5 (Figs. 5.2a & b). In this study, pH value as low as 6.5 is recorded in a considerable part of the study area (1/3 of the basin). In general the pH distribution does not show any specific trend within the basin (Figs. 5.2a & b). It is found that the eastern parts of Thodupuzha and Kaliyar sub basins, the pH distribution does not show any variation between the monsoons. On the other hand the Kothamangalam sub basin shows an increase in pH values during post monsoon, while the southern part of Muvattupuzha sub basin there is a decrease of pH during post monsoon. In an unconfined aquifer system (like that of the present study) the pH will be often below 7 (Langmuir, 1997). The acidic nature of the groundwater can be attributed to the dissolution of CO_2, which is being incorporated into the groundwater system by bacterial oxidation of organic substances (Matthess and Pekdeger, 1981) and addition of CO_2 through rainwater. Moreover, the low pH of the groundwater of the basin is related to the wide distribution of lateritic soil whose pH is always acidic (CESS, 1984). Further, the study area also encompasses extensive agricultural fields and therefore one of the main reasons for the observed low pH could be related to the use of acid producing fertilizers like ammonium sulphate and super phosphate of lime as manure for agriculture purpose (Rajesh et al., 2001).

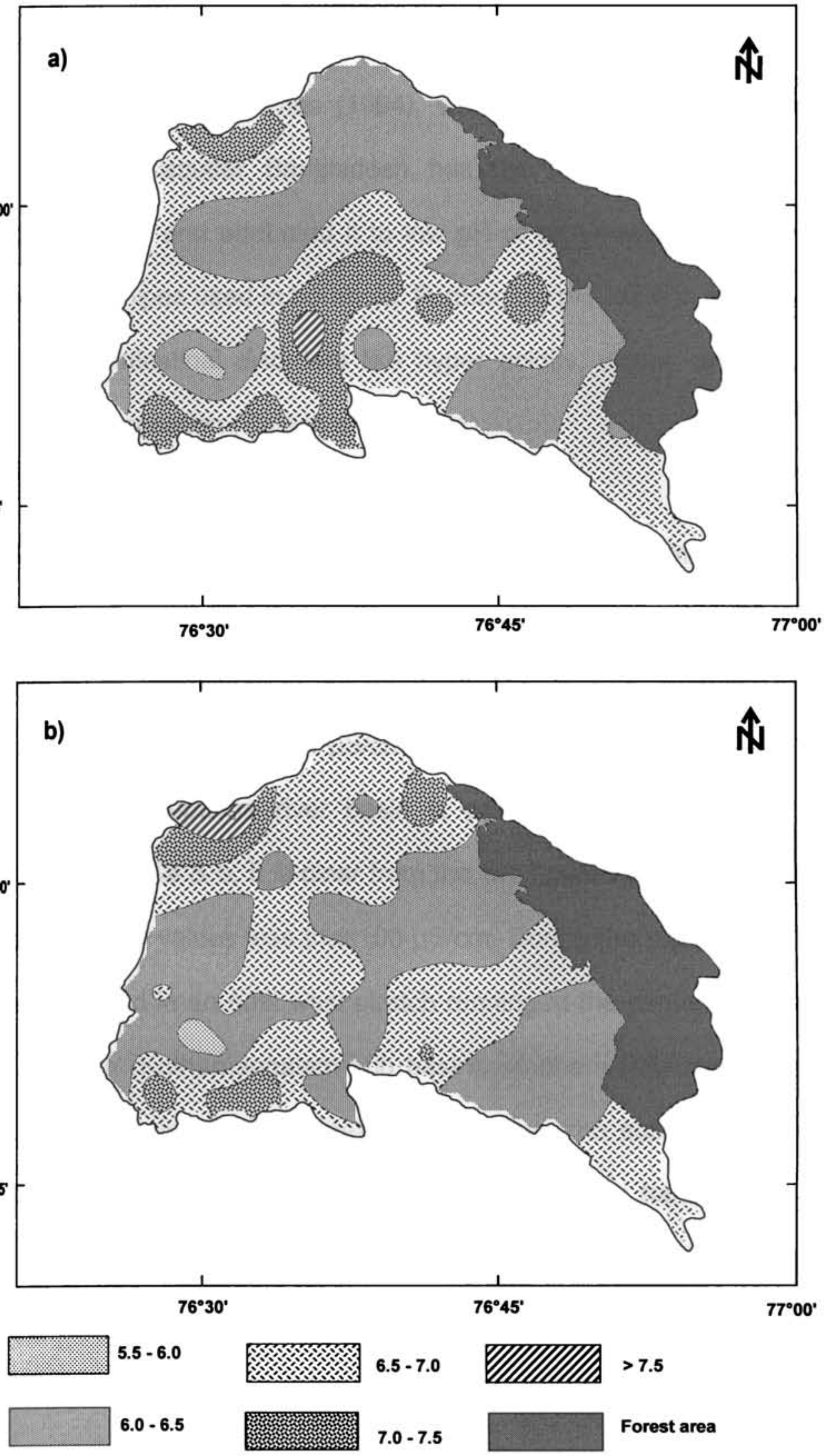


Fig. 5.2 Distribution of pH in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

A low pH of below 6.5 can cause corrosion to water carrying metal pipes thereby releasing toxic metals such as zinc, lead, cadmium, copper etc. (Trivedy and Goel, 1986). Davies (1994), while carrying out hydrochemical studies of Madhupur aquifer, Bangladesh, has also found a moderately high concentration of zinc and attributed it to low pH of groundwater. The low pH can corrode metal pipes used in borehole. Further low pH value in groundwater can cause gastrointestinal disorders like hyper acidity, ulcers, and stomach pain with burning sensation (Rajesh et al., 2001).

5.2.1b Electrical Conductivity (EC)

EC is measured in microsiemens/cm (µS/cm) and is a measure of salt content of water in the form of ions (Karanth, 1987). In this study EC values ranges from 40 to 356 µS/cm in pre monsoon (Table 5.2a) whereas in post monsoon it ranges from 25 to 254 µS/cm (Table 5.2b). The distribution of EC values of the Muvattupuzha river basin is presented (both pre and post monsoons) in Figs.5.3a & b. It is clear from the two figures that a vast majority of the area show EC values less than100 µS/cm. During the pre monsoon low EC values are found in an east west stretch running at the centre of the basin while the northern (Kothamangalam sub basin), southern (Muvattupuzha and Thodupuzha sub basins) and southeastern (Thodupuzha sub basin) parts of the basin show high EC values (>100 µS/cm). On other hand during post monsoon most of the basin except the northern part (Muvattupuzha and Kothamangalam sub basins) of the Muvattupuzha basin show low EC values. The high EC values (Fig. 5.3b) on the northwestern part of the study area might

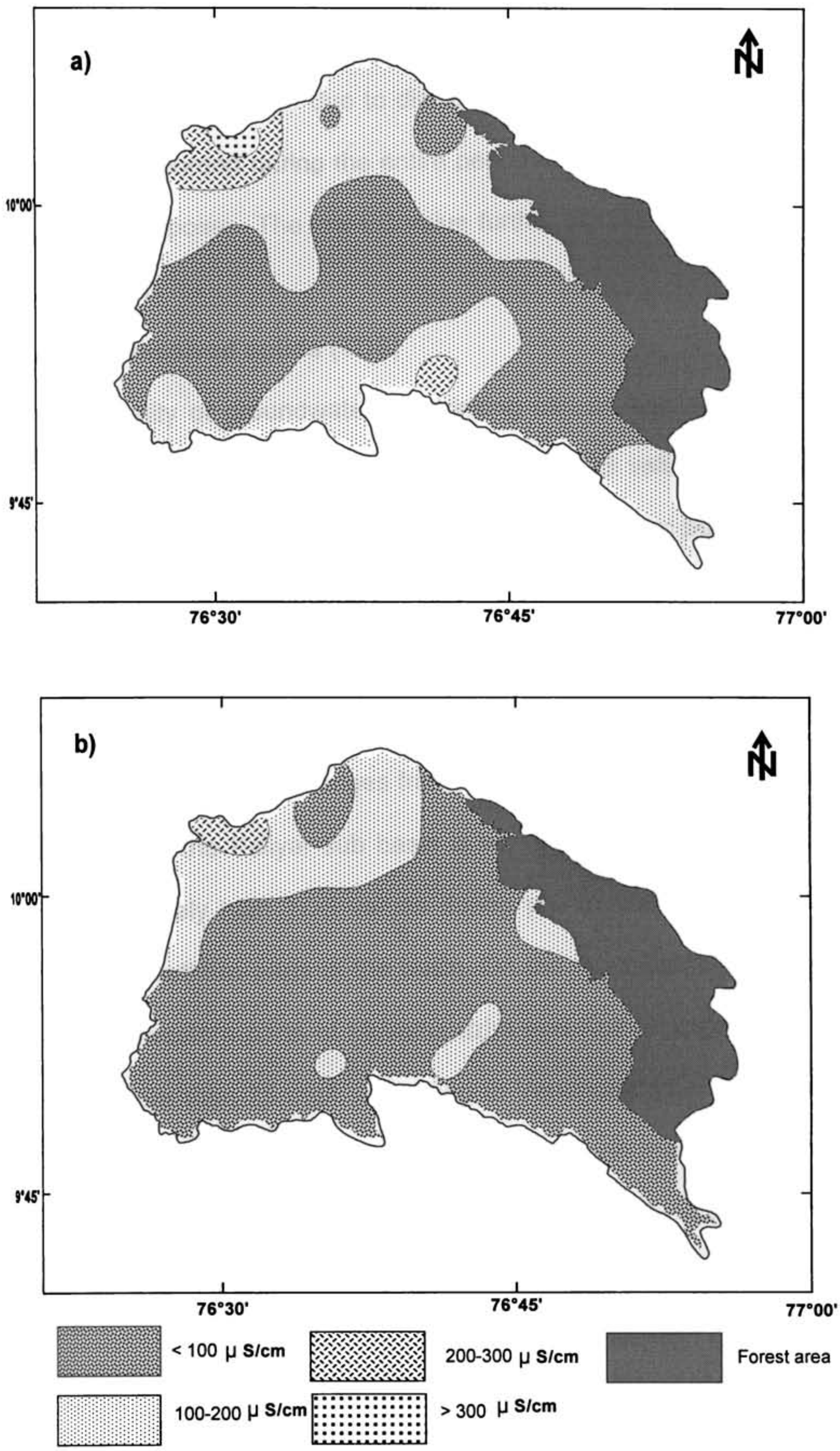


Fig. 5.3 Distribution of electrical conductivity in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

be due to addition of some salts through agricultural practice. Comparatively areas with low EC values (<100 μS/cm) are more during post monsoon than pre monsoon period and are due to dilution of soluble salts by rainfall. As low EC values are recorded during the entire period, the water is good for drinking and domestic purposes. The low EC value further signifies anoxic condition of the groundwater.

5.2.1c Total dissolved solids (TDS)

The quality of groundwater for drinking can be expressed in terms of total dissolved solids (TDS). Groundwater with a TDS value of less than 300 mg/l (Table 5.4) can be considered as excellent for drinking purpose according to WHO (1984). The distributions of TDS values for both seasons (Figs. 5.4a & b) clearly show that the entire basin falls within the desirable limit (< 300 mg/l). In pre monsoon, values ranges from 25 to 227 mg/l, (Table 5.2a) whereas in post monsoon it ranges from 16 to 162 mg/l (Table 5.2b). The TDS value of most of the Kaliyar sub basin is very low (<75 mg/l) during both the seasons. Relatively high TDS values during pre monsoon are found on the northern and southern parts of the basin. On the other hand in post monsoon only the northwestern parts of Muvattupuzha and Kothamangalam sub basins show TDS more than 75 mg/l. According to Venugopal (1998) and Aravindan (1999) the TDS values are higher during pre monsoon than the post monsoon season. However, this basin is encountered with low TDS values and is due to the prolonged leaching of topsoil under the existing anoxic condition.

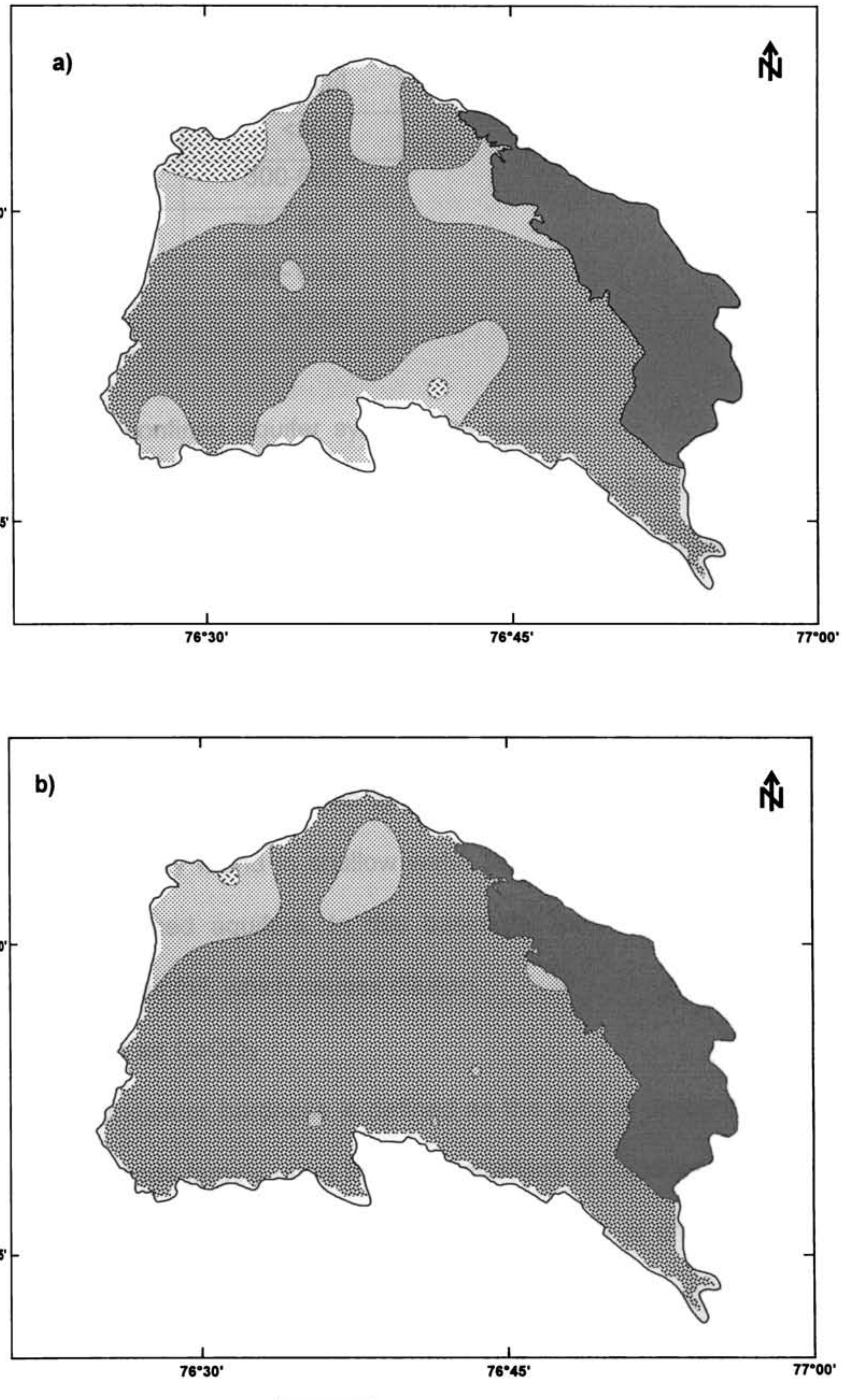


Fig. 5.4 Distribution of total dissolved solids in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

Table 5.4 The potability of water in terms of TDS (mg/l) as per WHO (1984)

Water class	TDS mg/l
Excellent	<300
Good	300-600
Fair	600-900
Poor	900-1200
Unacceptable	>1200

Usually unconfined aquifer system has relatively low TDS (Langmuir, 1997). The hydrogeological properties of rocks will have a strong influence on the extent of water/rock reaction. Areas with high groundwater-flow velocities usually have relatively low dissolved solids because of the shorter groundwater- rock contact time and high water/rock ratios, and vice-versa (Langmuir, 1997). Typical high groundwater velocities are found in highly fractured or weathered near-surface igneous and metamorphic rocks. Such conditions are usually found in shallow water table (unconfined) aquifers but not in deep, confined aquifers. In this basin the low TDS values can be attributed to high rainfall, which causes dilution.

5.2.1d Hardness as $CaCO_3$

The groundwater hardness is defined as the sum of divalent cations in solution but depends largely upon the concentrations of aqueous calcium and magnesium (Taylor and Howard, 1994). The hard water is unsatisfactory for household cleansing purposes and hence, water-softening processes are needed for the removal of hardness. The hardness of water has been classified as soft, moderately hard, hard and very hard (Table 5.5) by Sawyer and

McCarty (1967). Following the above classification, the spatial distributions of hardness of this basin during pre and post monsoons are shown in Figs. 5.5a & b. The hardness of water in terms of $CaCO_3$ content for pre monsoon samples ranges from 5 to 97 mg/l while in post monsoon a minimum value of 6 and maximum value of 122 mg/l are observed (Tables 5.2a & b). In general pre monsoon samples show higher hardness values compared to post monsoon. In both seasons the northwestern part of the study area (Muvattupuzha sub basin) show hardness values greater than 75 mg/l while the rest of the area has been categorised as soft (Figs. 5.5a & b).

Table 5.5 Classification of the degree of hardness in water (Sawyer and McCarty, 1967)

Water class	Hardness, mg/l as $CaCO_3$
Soft	0-75
Moderately hard	75-150
Hard	150-300
Very hard	> 300

A low pH of groundwater favours the dissolution of carbonate mineral, which in turn enhances the hardness by dissolving carbonate minerals in the country rock (Todd, 1980). But such a equilibrium system is not prevailing in this basin in view of low hardness. Studies in U.S.A, Canada, Japan indicate that the incidence of cardiovascular diseases is more in areas where drinking water is extremely soft (Hem, 1959). However, no such definite relationship exists between hardness of water and cardiovascular diseases as per WHO (1984) report.

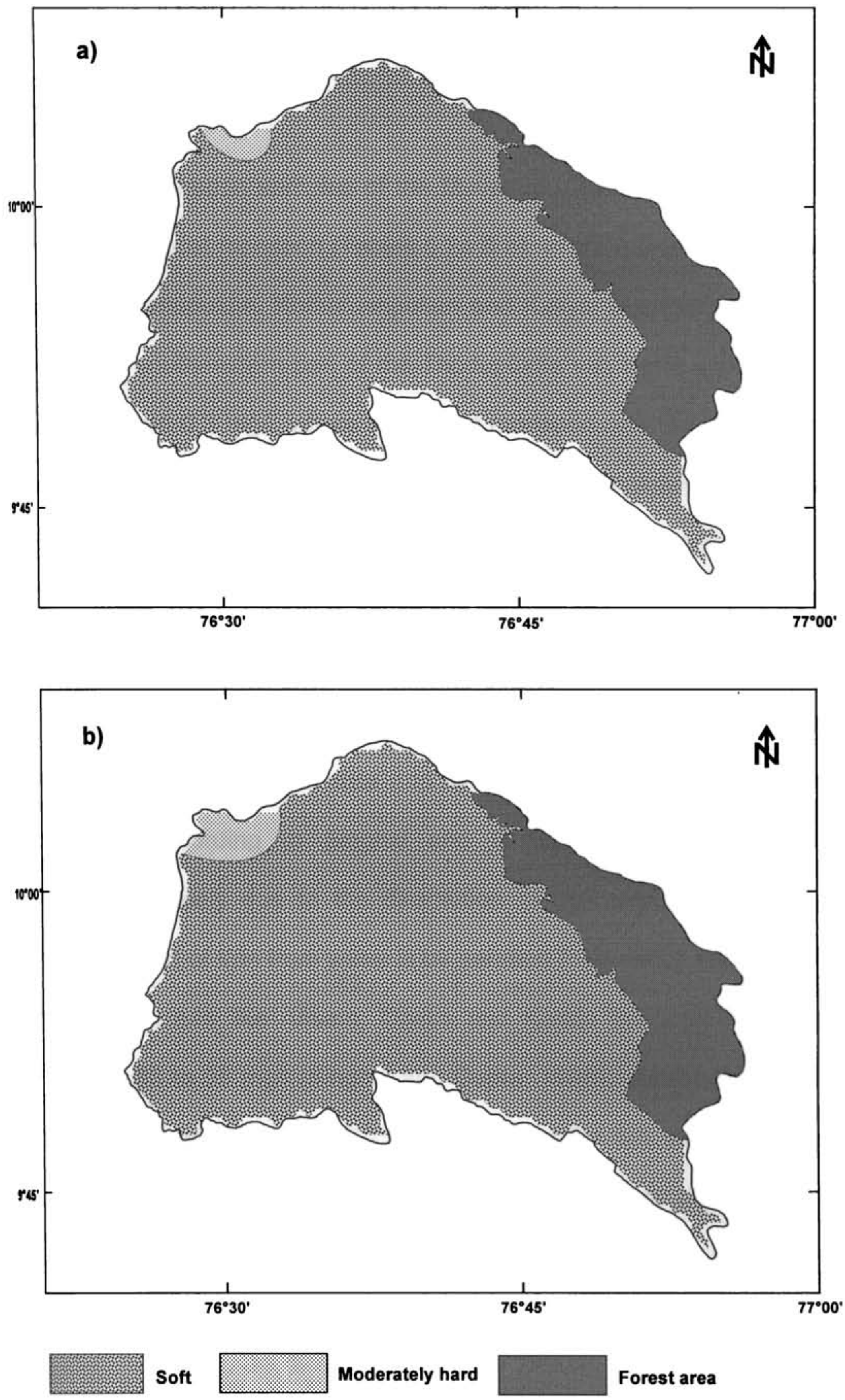


Fig. 5.5 Distribution of total hardness in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

5.2.1e Total Iron

The pre monsoon samples of the Muvattupuzha basin show high total iron content than post monsoon (Tables 5.2a & b). In pre monsoon the western part of the Muvattupuzha, Kothamangalam and Kaliyar sub basins and small patches in the southeastern part of the Thodupuzha sub basin show total iron values grater than 0.3 mg/l, where as in post monsoon only the north western and south western parts of the Muvattupuzha sub basin show more than 0.3 mg/l of total iron (Figs. 5.6a & b). The concentration of iron in groundwater will be higher under more reducing conditions due to bacteriological attack on organic matter which leads to the formation of various humic and fluvic compounds (Applin and Zhao, 1989; White et al. 1991). Under reducing condition, the iron from biotite mica and laterites are leached into solution in ferrous state. According to Singhal and Gupta (1999) iron content in groundwater is mainly due to the dissolution of iron oxides. The common method of removal of iron from water is by aeration followed by sedimentation. In high rainfall areas like Assam, Orissa and Kerala the total iron content ranges from 6.83 to 55 mg/l (Singhal and Gupta, 1999). As the study area is primarily covered with laterites (70%), leaching of Fe will take place easily under the existing anoxic condition and thus the high concentration of total iron in groundwater of this basin above the contamination level (Table 5.3).

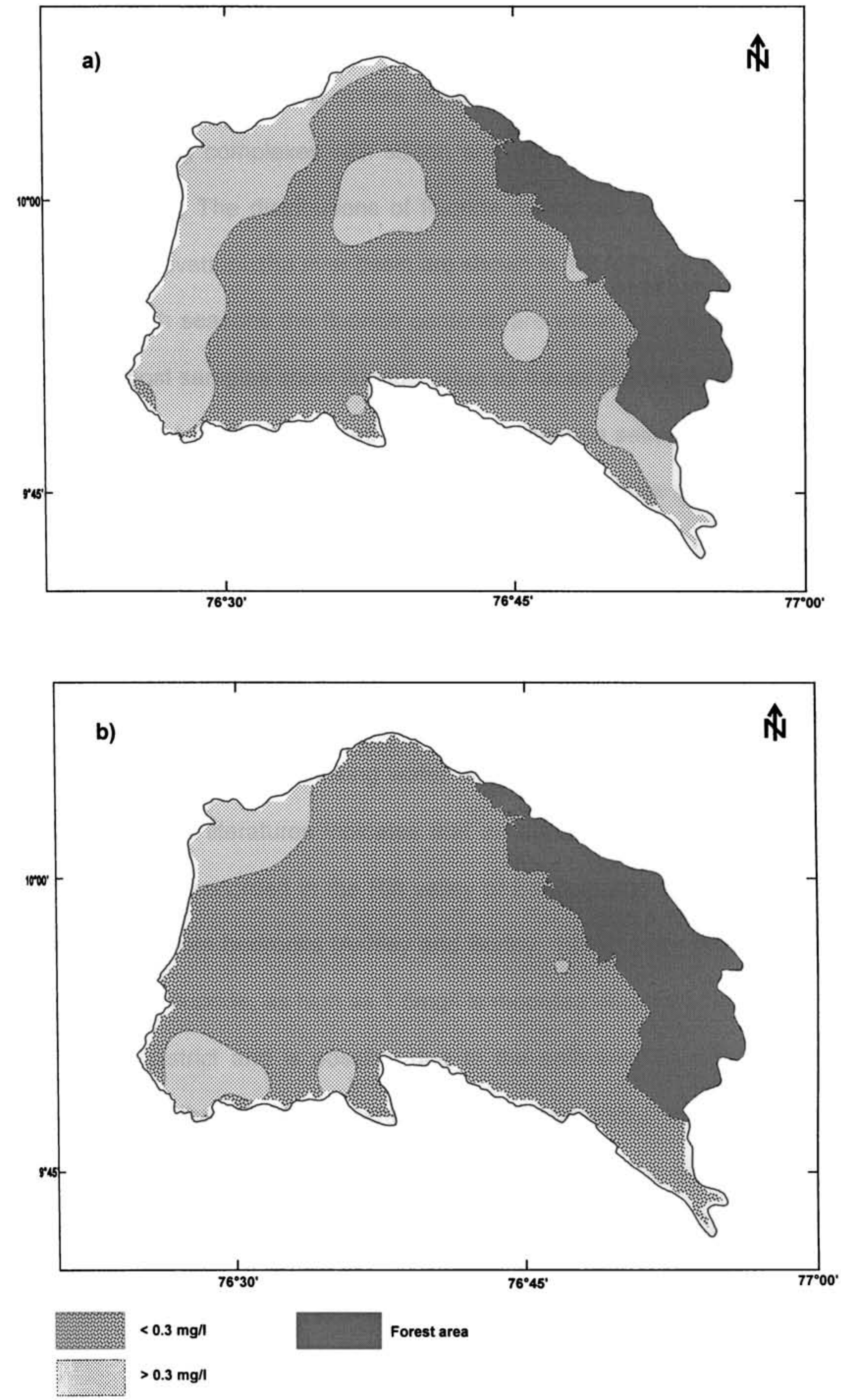


Fig. 5.6 Distribution of total iron in the Muvattupuzha river basin
(a) pre monsoon and (b) post monsoon

5.2.1f Fluoride

In groundwater, fluorine occurs mainly as the simple fluoride ion. It is capable of forming complexes with silicon and aluminium, and is believed to exist at a pH < 7. The distributions of fluoride during pre and post monsoon periods of the Muvattupuzha river basin are shown in Tables 5.2a & b and Figs. 5.7a & b. In both seasons the fluoride contents are within the permissible limit (Table 5.3); most samples show fluoride value as traces (Tables 5.2a & b). The highest value (0.4 mg/l) is recorded during pre monsoon season (Table 5.2a). The distribution of fluoride (Figs. 5.7a & b) for both seasons shows more or less an identical pattern.

Fluoride is beneficial when present in small concentrations (0.8 to 1 mg/l) in drinking water for calcification of dental enamel but it causes dental and skeletal fluorosis if present in higher amount (Table 5.6). High concentration of fluoride in drinking water is also linked with cancer (Smedly, 1992). A review of literatures indicates that an abnormal concentration (>1.5 mg/l) of fluoride is recorded in the Rift valley of Ethiopia and is due to calcium fluoride derived from bedrocks (Ashley and Burley, 1995). Even in Kerala high concentration of fluoride, as high as 1.5mg/l is recorded in certain coastal areas of Alappuzha district and is possibly due to the saltwater intrusion (CGWB, 2003). However, the fluoride concentration in the study area is very negligible and this is related to non-fluoride bearing basement rock. The concentration of fluoride in groundwater will only be in traces in crystalline rocks (Goldschmidt, 1958).

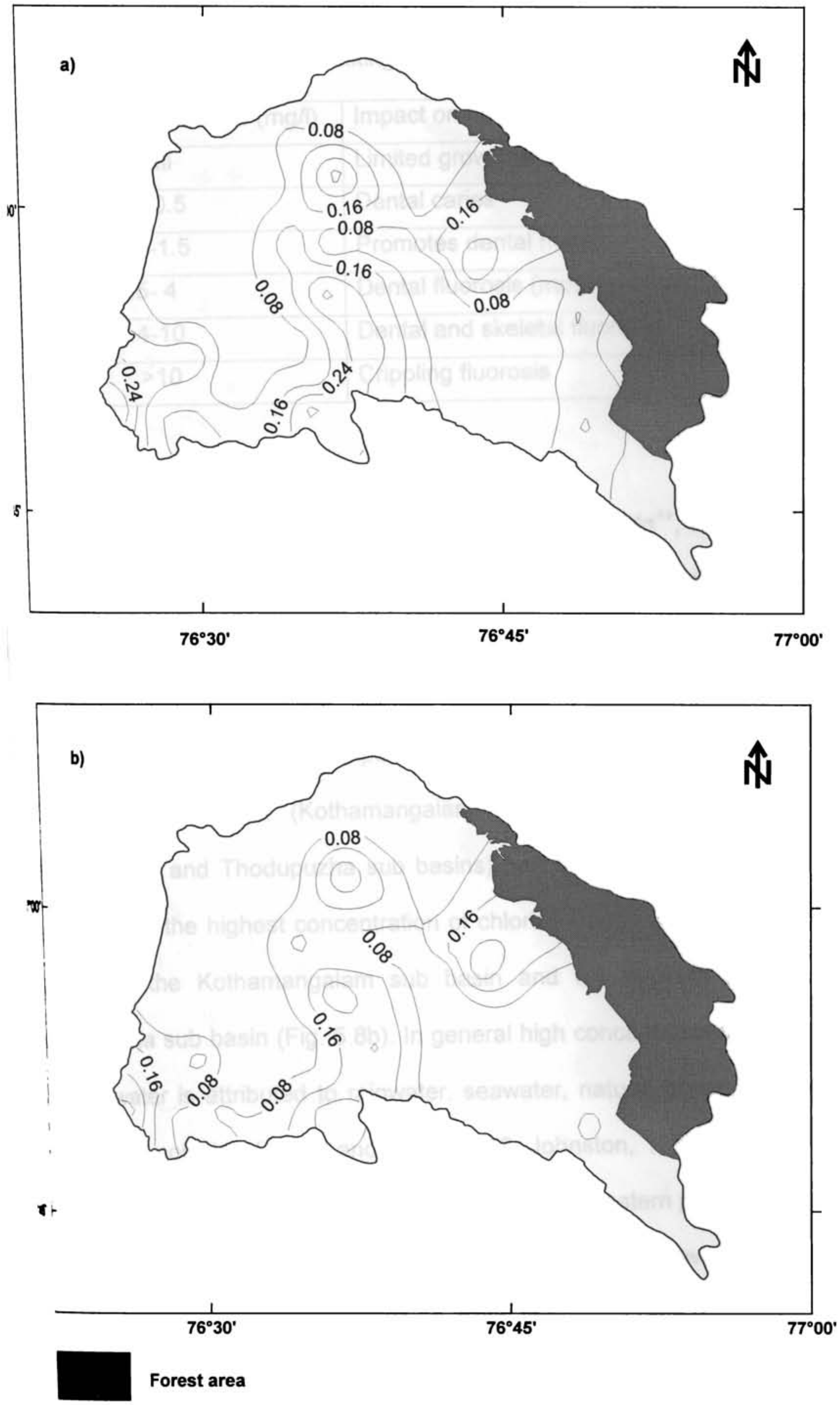


Fig. 5.7 Isocone map of fluoride in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

Table 5.6 Impact of fluoride in drinking water on health (Dissanayake, 1991)

Concentration of fluoride (mg/l)	Impact on health
Nil	Limited growth and fertility
0-0.5	Dental caries
0.5-1.5	Promotes dental health
1.5- 4	Dental fluorosis (mottling of teeth)
4-10	Dental and skeletal fluorosis
>10	Crippling fluorosis

5.2.1g Major cations and anions

Major cations and anions such as Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, CO_3^{--}, SO_4^{--} and Cl^- (Tables 5.2a & b) were plotted in hydrochemical pattern and facies diagrams. The distribution of chloride during pre monsoon (range 1.0-38.98 mg/l) shows that the highest concentration is recorded on the northwestern part of the Muvattupuzha sub basin while moderate values are found on the northern (Kothamangalam sub basin) and the southern (Muvattupuzha and Thodupuzha sub basins) part of the basin (Fig. 5.8a). In post monsoon the highest concentration of chloride (range 2.0 – 23.0 mg/l) is recorded in the Kothamangalam sub basin and the western part of the Muvattupuzha sub basin (Fig. 5.8b). In general high concentrations of chloride in groundwater is attributed to rainwater, seawater, natural brines, evaporate deposits and pollution (Junge and Wrby, 1958; Johnston, 1987). In this study the high concentration of chloride on the northern and western part of this basin may be related to pollutant through the use of fertilisers. However the chloride concentration of this basin is found to be within the permissible limit (Table 5.3)

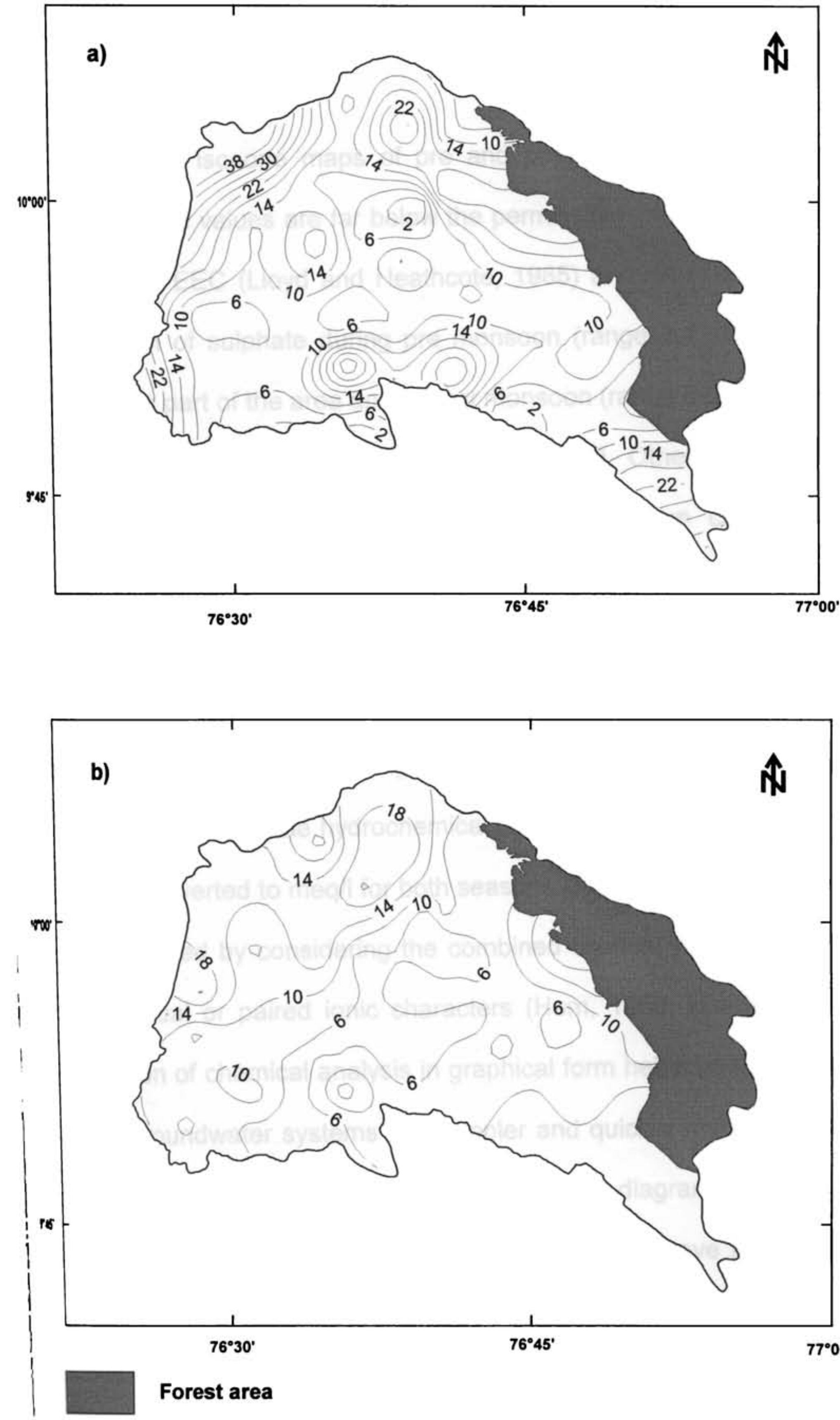


Fig. 5.8 Isocone map of chloride in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

as prescribed by WHO (1984), EEC (Lloyd and Heathcote, 1985) and ISI (1983).

Sulphate isocone maps of pre and post monsoons (Figs. 5.9a & b) indicate that the values are far below the permissible values recommended by WHO (1984), EEC (Lloyd and Heathcote, 1985) and ISI (1983). The highest concentration of sulphate during pre monsoon (range 3.4 -13.57 mg/l) is on northwestern part of the area and in post monsoon (range 0.0 - 9.16 mg/l) there is low concentration of sulphate (Figs. 5.9a & b). Other major cations and anions (including chloride and sulphate), their relative concentration and environment are discussed below.

Hydrochemical pattern diagram: The purpose of constructing hydrochemical pattern diagram is to depict the absolute or relative concentration of cations and anions in terms of either mg/l or meq/l. For plotting the concentration of anions and cations in the hydrochemical pattern diagram the original values in mg/l were converted to meq/l for both seasons (Tables 5.7a & b). Better results can be obtained by considering the combined chemistry of all the ions rather than individual or paired ionic characters (Hem, 1959; Handa, 1964, 1965). Presentation of chemical analysis in graphical form helps us to understand the complex groundwater systems in a simpler and quicker manner. Methods like radiating vectors, parallel and horizontal axes diagram (Stiff, 1951), bar diagram (Hem, 1959) are used widely, however they have limited application and hence are not followed in this study.

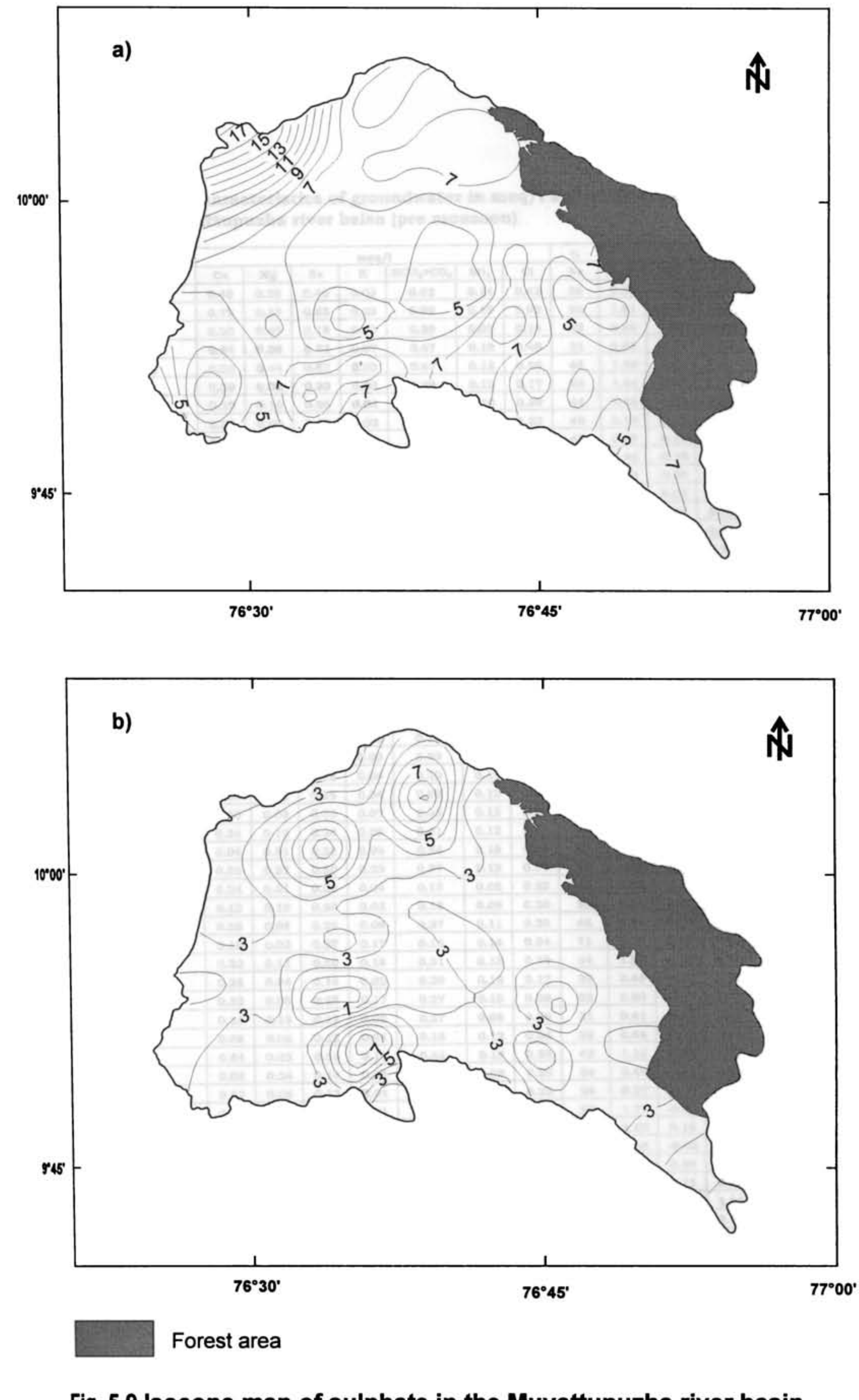


Fig. 5.9 Isocone map of sulphate in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

Table 5.7a Chemical characteristics of groundwater in meq/l and various ratio/ percentage in the Muvattupuzha river baisn (pre monsoon)

Well No.	Locations	meq/l							%	Ratios				
		Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	Na	SAR	RSC	CR	$Cl/(Cl+HCO_3)$	Na/(Na+Ca+K)
1	Puthuvely	0.48	0.28	0.40	0.03	0.62	0.14	0.42	36	0.93	-0.13	1.18	0.40	0.47
2	Pampakada	0.72	0.33	0.83	0.23	0.99	0.19	0.93	50	1.61	-0.06	1.51	0.48	0.59
3	Karimbara	0.20	0.09	0.18	0.03	0.29	0.07	0.14	42	0.68	0.00	0.94	0.33	0.51
4	Thekkumaradi	0.84	0.06	0.32	0.07	0.67	0.12	0.45	31	0.68	-0.23	1.12	0.40	0.32
5	Vadakkumaradi	0.32	0.44	0.57	0.03	0.67	0.12	0.54	44	1.30	-0.09	1.30	0.44	0.65
6	Adoorparambu	0.20	0.02	0.33	0.03	0.29	0.12	0.17	63	1.44	0.07	1.23	0.37	0.64
7	Vazhakulam	0.20	0.16	0.26	0.03	0.15	0.10	0.39	44	0.85	-0.21	4.41	0.73	0.59
8	Vazhakulam	0.32	0.04	0.22	0.02	0.25	0.10	0.23	40	0.74	-0.11	1.66	0.47	0.43
9	Thazhuramkunnu	0.04	0.32	0.24	0.03	0.25	0.10	0.28	43	0.80	-0.11	1.98	0.53	0.87
10	Nagapuzha	0.04	0.18	0.21	0.03	0.11	0.10	0.25	53	0.92	-0.10	4.06	0.69	0.86
11	Vengallur	0.24	0.12	0.15	0.03	0.31	0.10	0.14	33	0.49	-0.05	0.97	0.31	0.43
12	Karimkunnam	0.60	0.41	0.78	0.42	1.02	0.19	0.87	54	1.56	0.02	1.39	0.46	0.67
13	Veliyannur	0.40	0.18	0.91	0.09	0.99	0.12	0.45	63	2.41	0.42	0.76	0.31	0.71
14	Elanji	1.04	0.18	0.13	0.05	0.79	0.19	0.39	13	0.24	-0.43	0.94	0.33	0.15
15	Idayar	0.20	0.12	0.14	0.02	0.15	0.13	0.20	33	0.49	-0.18	2.73	0.57	0.44
16	Tirumaradi	0.04	0.25	0.17	0.02	0.15	0.07	0.25	39	0.62	-0.14	2.88	0.63	0.82
17	Onakkur	0.32	0.00	0.21	0.03	0.29	0.15	0.14	43	0.75	-0.04	1.22	0.33	0.43
18	Illikamukkada	0.32	0.06	0.18	0.02	0.25	0.10	0.20	34	0.58	-0.13	1.51	0.44	0.38
19	Piravam	0.16	0.06	0.23	0.01	0.15	0.12	0.20	52	0.97	-0.07	2.64	0.57	0.60
20	Aborma	0.20	0.12	0.18	0.03	0.31	0.10	0.14	39	0.64	-0.01	0.97	0.31	0.51
21	Peruva	0.72	0.04	0.23	0.14	0.79	0.12	0.20	33	0.52	0.04	0.50	0.20	0.34
22	Thudanganad	0.08	0.10	0.10	0.02	0.11	0.13	0.06	40	0.47	-0.07	1.96	0.34	0.60
23	Muttam	0.20	0.05	0.15	0.03	0.15	0.09	0.20	41	0.59	-0.10	2.47	0.57	0.46
24	Kolapra	0.16	0.09	0.17	0.02	0.15	0.13	0.17	43	0.66	-0.10	2.49	0.53	0.54
25	Kanjar	0.28	0.04	0.16	0.03	0.31	0.09	0.11	37	0.57	-0.01	0.81	0.27	0.41
26	Manappadi	0.56	0.02	0.42	0.09	0.50	0.13	0.45	47	1.11	-0.07	1.51	0.47	0.48
27	Karippilangadu	0.20	0.02	0.13	0.04	0.20	0.14	0.03	43	0.54	-0.02	0.92	0.12	0.45
28	Pannimattam	0.32	0.22	0.16	0.04	0.53	0.13	0.06	27	0.43	-0.01	0.39	0.10	0.38
29	Ilamdesam	0.40	0.03	0.33	0.07	0.33	0.12	0.37	48	1.01	-0.10	1.92	0.53	0.50
30	Kontalappali	0.24	0.12	0.24	0.09	0.31	0.12	0.28	48	0.80	-0.05	1.66	0.48	0.58
31	Alakkodu	0.04	0.61	0.35	0.04	0.54	0.19	0.28	37	0.86	-0.11	1.09	0.34	0.91
32	Karikode	0.56	0.27	0.50	0.20	0.97	0.19	0.37	46	1.09	0.14	0.72	0.27	0.55
33	Kurumpalamattam	0.24	0.01	0.20	0.04	0.15	0.08	0.25	48	0.80	-0.10	2.97	0.63	0.50
34	Udambannur	0.12	0.10	0.20	0.02	0.15	0.09	0.20	50	0.84	-0.07	2.49	0.57	0.65
35	Chinikkuzhi	0.28	0.08	0.24	0.06	0.27	0.11	0.28	46	0.81	-0.09	1.89	0.51	0.52
36	Moolappuram	0.16	0.02	0.27	0.17	0.18	0.14	0.34	71	1.27	0.00	3.43	0.65	0.73
37	Kaliyar	0.32	0.11	0.60	0.18	0.31	0.13	0.73	64	1.83	-0.12	3.76	0.70	0.71
38	Arakuzha	0.28	0.04	0.14	0.02	0.20	0.12	0.17	33	0.49	-0.13	1.79	0.46	0.36
39	Eshallur	0.32	0.08	0.25	0.17	0.27	0.15	0.39	52	0.80	-0.13	2.65	0.60	0.57
40	Vazathala	0.16	0.13	0.11	0.02	0.27	0.08	0.06	31	0.41	-0.02	0.61	0.17	0.44
41	Pulinthanam	0.08	0.06	0.12	0.04	0.15	0.12	0.06	53	0.64	0.00	1.31	0.27	0.67
42	Pottanikad	0.84	0.02	0.52	0.11	0.62	0.19	0.65	42	1.12	-0.24	1.77	0.51	0.43
43	Nellimattom	0.08	0.24	0.14	0.03	0.22	0.08	0.20	34	0.49	-0.11	1.68	0.48	0.67
44	Tallakode	0.48	0.06	0.13	0.04	0.33	0.14	0.23	24	0.37	-0.21	1.40	0.41	0.27
45	Kuthikuzhi	0.80	0.14	0.83	0.21	0.79	0.19	0.93	53	1.71	-0.15	1.91	0.54	0.56
46	Nellikuzhi	0.40	0.07	0.51	0.08	0.62	0.12	0.28	56	1.50	0.16	0.82	0.31	0.60
47	Iramallur	0.48	0.13	0.42	0.19	0.59	0.15	0.51	50	1.08	-0.02	1.47	0.46	0.56
48	Pezhakapalli	0.36	0.04	0.70	0.04	0.79	0.14	0.20	65	2.21	0.39	0.53	0.20	0.67
49	Kizhillam	1.92	0.02	1.17	0.10	2.09	0.28	1.10	40	1.68	0.15	0.88	0.34	0.40
50	Karukadam	0.32	0.00	0.37	0.14	0.33	0.15	0.34	61	1.31	0.01	1.91	0.51	0.62
51	Valakam	0.28	0.01	0.30	0.06	0.20	0.14	0.28	55	1.10	-0.09	2.73	0.59	0.56
52	Piravam Road	0.80	0.24	0.26	0.02	0.80	0.17	0.31	21	0.51	-0.24	0.75	0.28	0.26
53	Nechur	0.08	0.06	0.16	0.03	0.15	0.12	0.06	57	0.82	0.00	1.35	0.27	0.70
54	Ramamangalam	0.28	0.03	0.33	0.09	0.20	0.08	0.48	58	1.19	-0.11	3.83	0.71	0.60
55	Arayankavu	0.80	0.12	0.30	0.03	0.41	0.09	0.70	26	0.62	-0.51	2.60	0.63	0.29

Table 5.7b Chemical characteristics of groundwater in meq/l and various ratio/ percentage in the Muvattupuzha river basin (post monsoon)

Well No.	Location	meq/l							%	Ratios				
		Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	Na	SAR	RSC	CR	$Cl/(Cl+HCO_3)$	Na/(Na+Ca+K)
1	Puthuvely	0.33	0.08	0.30	0.04	0.48	0.14	0.14	45.62	0.95	0.07	0.73	0.23	0.51
2	Pampakada	0.81	0.04	0.52	0.22	0.90	0.17	0.48	46.43	1.13	0.05	0.95	0.35	0.48
3	Karimbara	0.08	0.12	0.22	0.05	0.34	BDL	0.14	56.76	0.96	0.14	0.58	0.29	0.77
4	Thekkumaradi	0.53	0.16	0.24	0.17	0.76	0.10	0.28	36.96	0.57	0.06	0.66	0.27	0.43
5	Vadakkumaradi	0.29	0.08	0.50	0.06	0.42	0.06	0.48	60.24	1.65	0.06	1.74	0.53	0.66
6	Adoorparambu	0.16	0.04	0.25	0.03	0.29	0.06	0.11	57.93	1.12	0.08	0.78	0.28	0.63
7	Vazhakulam	0.20	0.12	0.30	0.02	0.36	0.06	0.23	49.43	1.03	0.04	1.04	0.38	0.61
8	Vazhakulam	0.24	0.08	0.22	0.04	0.38	0.07	0.17	44.30	0.78	0.05	0.81	0.31	0.52
9	Thazhuramkunnu	0.12	0.21	0.12	0.02	0.36	0.05	0.06	30.75	0.43	0.03	0.37	0.13	0.54
10	Nagapuzha	0.20	0.04	0.26	0.05	0.25	0.07	0.23	55.36	1.04	0.01	1.54	0.47	0.60
11	Vengallur	0.16	0.04	0.09	0.02	0.13	0.07	0.11	35.94	0.40	-0.07	1.73	0.46	0.41
12	Karimkunnam	0.57	0.04	0.36	0.20	0.80	0.07	0.25	47.47	0.91	0.19	0.54	0.24	0.49
13	Veliyannur	0.24	0.04	0.21	0.04	0.29	0.05	0.23	46.35	0.78	0.00	1.31	0.44	0.50
14	Elanji	0.69	0.08	0.23	0.04	0.87	0.05	0.08	25.43	0.51	0.10	0.20	0.09	0.28
15	Idayar	0.20	0.08	0.22	0.01	0.34	0.05	0.11	44.84	0.81	0.06	0.63	0.25	0.53
16	Tirumaradi	0.16	0.08	0.22	0.03	0.34	BDL	0.17	50.10	0.88	0.10	0.69	0.33	0.60
17	Onakkur	0.20	0.12	0.28	0.03	0.39	0.07	0.17	49.17	0.99	0.07	0.79	0.30	0.61
18	Illikamukkada	0.12	0.04	0.27	0.06	0.13	0.06	0.34	66.62	1.33	-0.03	4.11	0.72	0.73
19	Piravam	0.16	0.04	0.28	0.03	0.13	0.06	0.31	60.08	1.23	-0.07	3.79	0.70	0.65
20	Aborma	0.16	0.04	0.25	0.04	0.29	0.05	0.14	59.14	1.12	0.08	0.89	0.33	0.64
21	Peruva	0.20	0.12	0.32	0.06	0.39	0.06	0.25	54.19	1.13	0.07	1.06	0.39	0.66
22	Thudanganad	0.12	0.08	0.15	0.02	0.13	0.08	0.14	45.65	0.65	-0.07	2.15	0.52	0.58
23	Muttam	0.08	0.16	0.23	0.05	0.40	BDL	0.11	53.02	0.91	0.15	0.40	0.22	0.77
24	Kolapra	0.12	0.04	0.19	0.04	0.18	0.05	0.17	57.94	0.93	0.02	1.60	0.48	0.65
25	Kanjar	0.20	0.25	0.22	0.03	0.52	0.05	0.14	35.34	0.65	0.07	0.49	0.21	0.55
26	Manappadi	0.33	0.04	0.23	0.06	0.48	0.07	0.11	43.92	0.75	0.11	0.49	0.19	0.47
27	Karippilangadu	0.08	0.04	0.17	0.05	0.18	0.06	0.08	63.85	0.97	0.06	0.97	0.31	0.73
28	Pannimattam	0.12	0.08	0.11	0.02	0.22	0.07	0.06	40.11	0.50	0.01	0.69	0.21	0.53
29	Ilamdesam	0.08	0.04	0.36	0.09	0.31	0.06	0.23	78.75	2.06	0.19	1.24	0.42	0.85
30	Kontalappali	0.33	0.04	0.34	0.12	0.48	0.06	0.28	55.69	1.12	0.11	0.95	0.37	0.59
31	Alakkodu	0.29	0.04	0.20	0.03	0.29	0.11	0.17	41.28	0.69	-0.04	1.25	0.37	0.45
32	Karikode	0.61	0.04	0.53	0.26	1.03	0.06	0.34	54.81	1.31	0.38	0.52	0.25	0.56
33	Kurumpalamattam	0.12	0.04	0.20	0.08	0.31	0.05	0.08	63.53	0.99	0.15	0.57	0.21	0.70
34	Udambannur	0.12	0.08	0.22	0.05	0.25	0.06	0.20	57.20	0.98	0.05	1.34	0.44	0.69
35	Chinikkuzhi	0.29	0.04	0.37	0.15	0.43	0.05	0.34	61.41	1.29	0.10	1.24	0.44	0.65
36	Molappuram	0.41	0.12	0.37	0.27	0.69	0.06	0.37	54.80	1.03	0.16	0.83	0.35	0.61
37	Kaliyar	0.53	0.12	0.60	0.20	0.69	0.06	0.65	55.07	1.49	0.04	1.41	0.48	0.60
38	Arakuzha	0.37	0.04	0.20	0.05	0.43	0.06	0.17	38.16	0.63	0.02	0.69	0.28	0.41
39	Ezhallur	0.16	0.08	0.11	0.03	0.14	0.05	0.20	37.42	0.46	-0.11	2.46	0.59	0.47
40	Vazathala	0.12	0.04	0.14	0.02	0.18	0.06	0.08	49.28	0.69	0.02	1.01	0.31	0.56
41	Pulinthanam	0.24	0.08	0.18	0.02	0.43	0.05	0.06	38.23	0.64	0.10	0.32	0.12	0.45
42	Pottanikad	0.45	0.08	0.33	0.12	0.60	0.07	0.31	45.77	0.91	0.07	0.86	0.34	0.50
43	Nellimattom	0.33	0.04	0.17	0.12	0.40	0.06	0.20	44.63	0.57	0.03	0.85	0.33	0.48
44	Tallakode	0.20	0.12	0.23	0.06	0.37	0.07	0.17	46.73	0.81	0.04	0.84	0.31	0.58
45	Kuthikuzhi	0.90	0.12	0.67	0.19	1.03	0.19	0.62	45.66	1.33	0.01	1.04	0.38	0.49
46	Nellikuzhi	0.33	0.08	0.52	0.10	0.48	0.05	0.48	60.50	1.63	0.07	1.53	0.50	0.66
47	Iramallur	0.12	0.12	0.23	0.06	0.33	0.07	0.11	53.50	0.91	0.08	0.72	0.26	0.70
48	Pezhakapalli	0.29	0.12	0.60	0.06	0.40	0.18	0.45	61.49	1.87	-0.01	2.07	0.53	0.70
49	Kizhillam	1.71	0.78	0.70	0.13	2.54	0.07	0.42	24.80	0.88	0.05	0.26	0.14	0.32
50	Karukadam	0.12	0.04	0.63	0.26	0.33	0.07	0.65	84.39	3.10	0.17	3.00	0.66	0.88
51	Valakam	0.12	0.12	0.24	0.26	0.40	0.06	0.25	66.85	0.97	0.15	1.07	0.39	0.80
52	Piravam Road	0.81	0.12	0.25	0.01	1.03	0.06	0.14	21.89	0.51	0.10	0.25	0.12	0.24
53	Nechur	0.16	0.04	0.21	0.04	0.22	0.09	0.14	54.73	0.92	0.02	1.31	0.39	0.60
54	Ramamangalam	0.16	0.25	0.58	0.14	0.43	0.06	0.65	63.70	1.82	0.02	2.27	0.60	0.82
55	Arayankavu	0.16	0.12	0.34	0.06	0.32	0.07	0.28	58.30	1.29	0.03	1.47	0.47	0.71

BDL - Below detection level

Durov's diagram: Durov's diagram is also a type of trilinear diagram (Zaporozec, 1972; Lloyd and Heathcote, 1985). In Durov's diagram, the concentrations of major cations and anions are plotted in two separate triangles and projected to a central square field, which represents the overall chemical characteristics of samples. The range of groundwater chemistry (pre and post monsoons) of the present study is shown on the Durov's diagram (Figs. 5.10 a & b). In this diagram the fresh water is distinguished from saline by an arbitrary boundary being placed at 300 mg/l chloride (Lloyd and Heathcote, 1985). The above authors have subsequently used numbering system for classifying water (Table 5.8). The fresh waters are easily classified on the basis of major element chemistry into type I (bicarbonate waters) type II (sulphate waters) and type III and IV representing mixing series (Figs. 5.10a & b; Table 5.8).

Table 5.8 Fresh water types based on Durov's diagram (Lloyd and Heathcote, 1985)

Type	Characteristics	Trace elements Sodium-chloride
I	Bicarbonate waters	-
II	Sulphate waters	-
IIIa	Sodium-chloride	
IIIb	Sodium-chloride with low calcium	With high Sr, F and I
IIIc	Sodium-chloride with high magnesium and sulphate	
IV	Sodium-chloride	With low Sr, F and I is variable

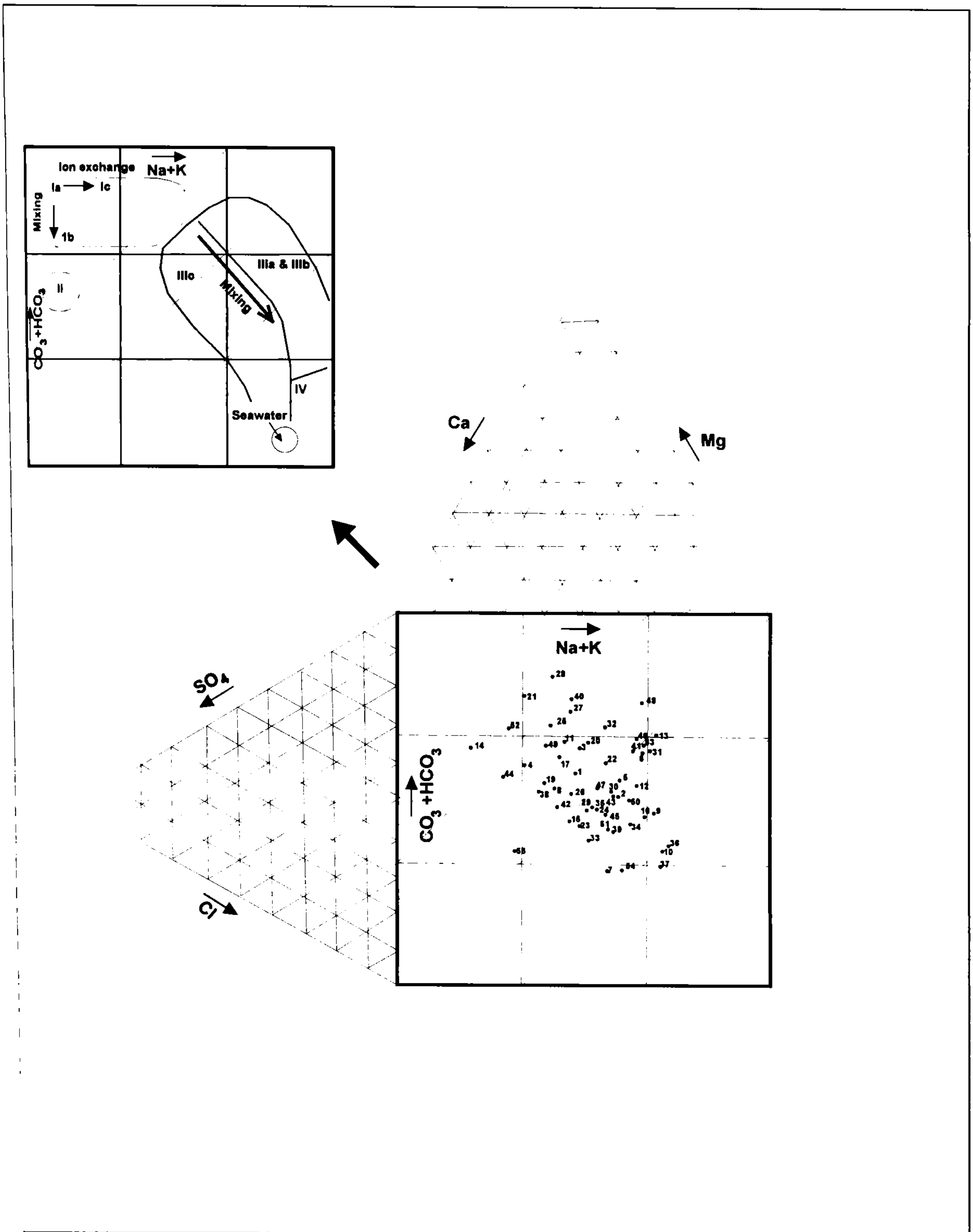


Fig. 5.10a **Durov's diagram of groundwater in the Muvattupuzha river basin (pre monsoon)**

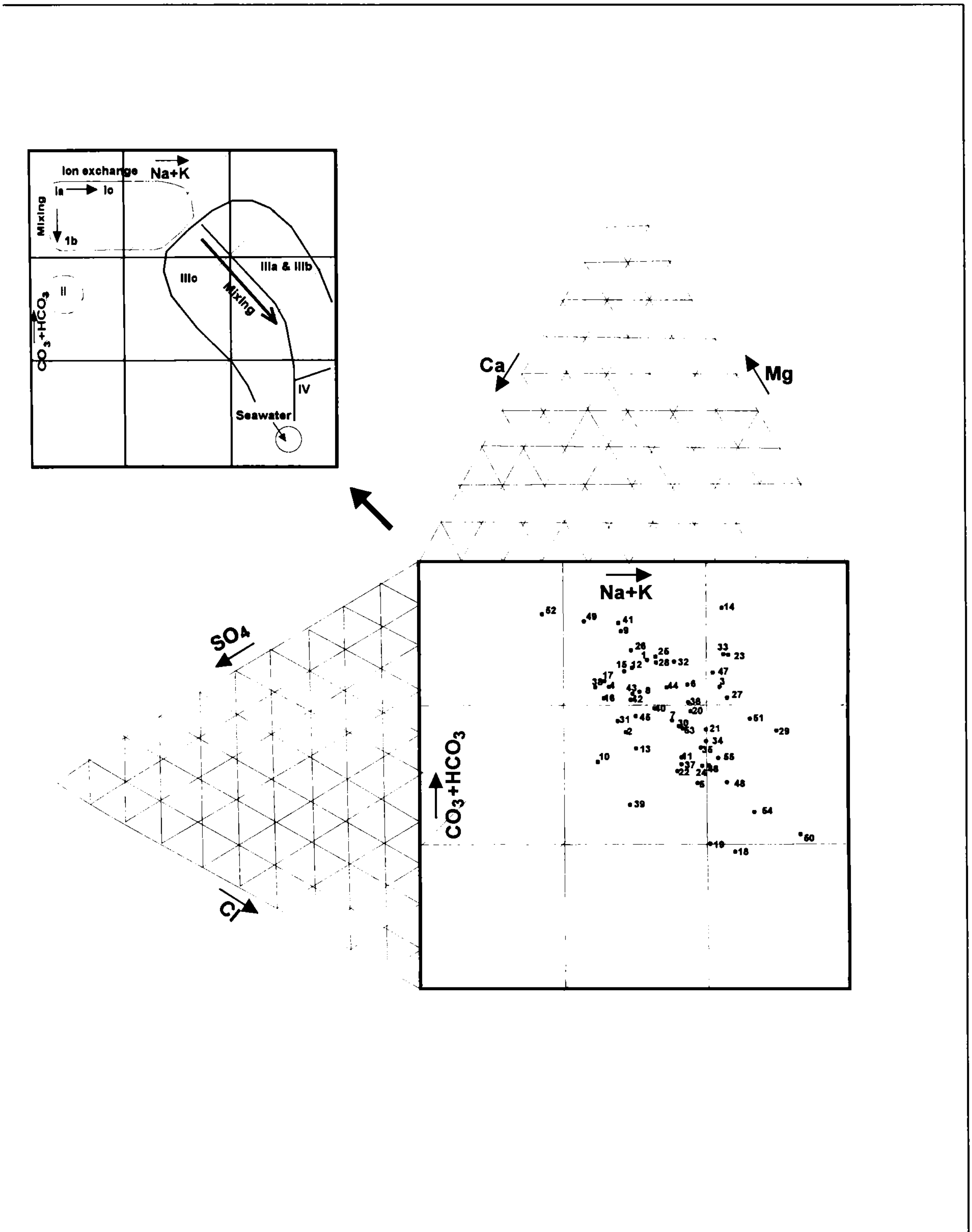


Fig. 5.10b **Durov's diagram of the groundwater in the Muvattupuzha river basin (post monsoon)**

As per the above classification most of the pre monsoon samples fall in type IIIc (Sodium-chloride with high magnesium and sulphate), while in post monsoon in addition to IIIc, considerable number of samples also fall in type IIIa, IIIb and I. This indicates that the groundwater of the basin, which was primarily IIIc type during pre monsoon, has become IIIa, IIIc and I type (Sodium-chloride, Sodium-chloride with low calcium and bicarbonate waters) in post monsoon. Thus an overall shift towards mixing zone from IIIc type is evident.

Hill-Piper diagram: Pattern diagram was convince by Hill (1940) and later improved by Piper (1944). The Hill-Piper trilinear diagram has two triangular fields, one for plotting of cations and other for anions, and in between a central diamond shaped field for projecting the respective cations and anions. The concentration of cations and anions are plotted as percentage in meq/l so that the total of cations (Ca + Mg and Na + K) and anions (Cl, SO_4 and CO_3 + HCO_3) are made to 100 percent. The Hill-Piper system has an advantage of plotting analytical data of a large number of samples in one diagram. It is also used for classification of water samples into various hydrochemical types depending on the relative concentration of major cations and anions. One of the main disadvantages of the Hill-Piper diagram is that it shows only the relative concentration of different ions and not their absolute concentration. The detailed analysis of Hill-Piper trilinear diagram for both seasons (Figs. 5.11a & b) is explained below using facies diagram.

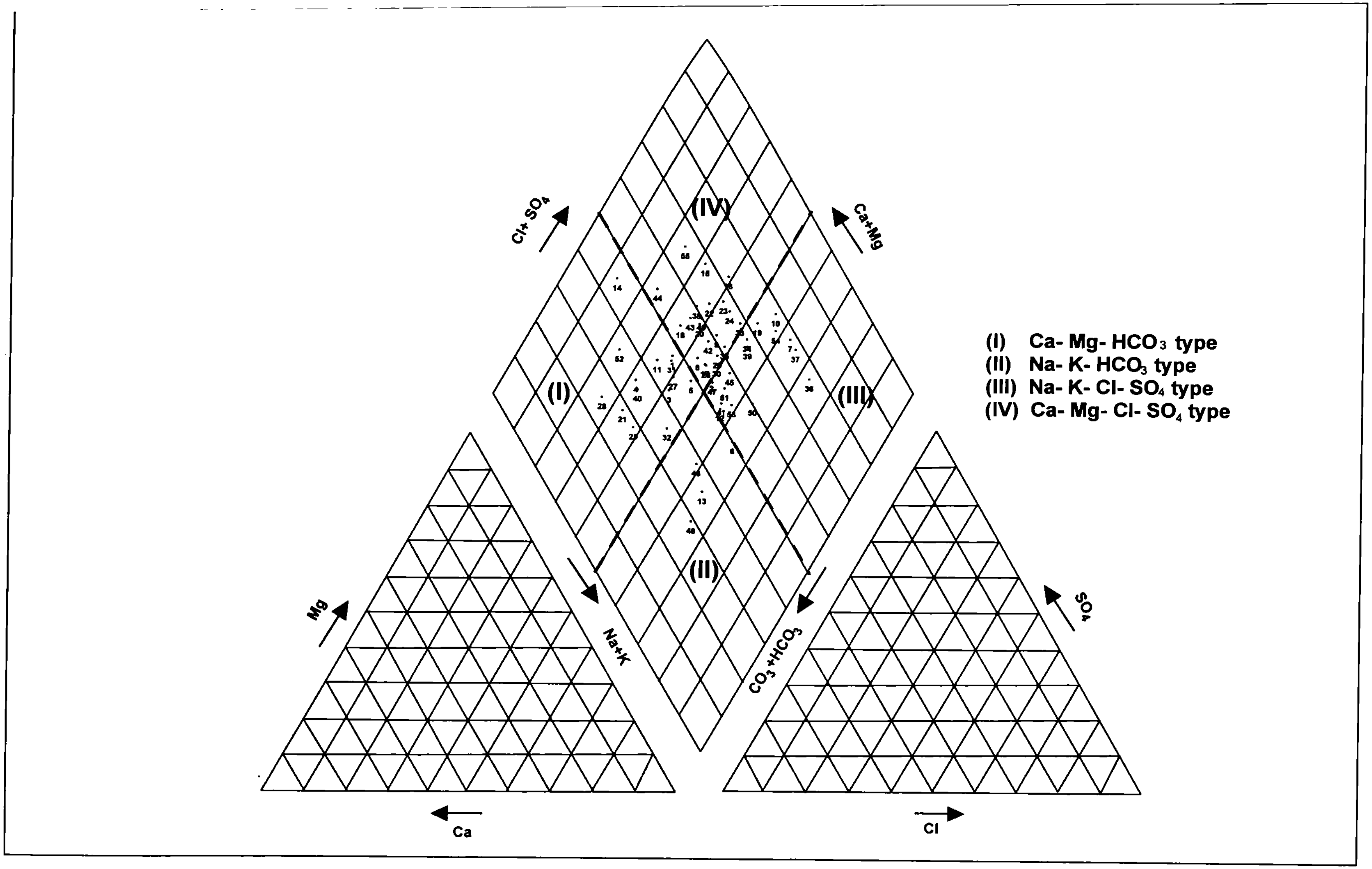


Fig. 5.11a Hill- Piper trilinear diagram of groundwater in the Muvattupuzha river basin (pre monsoon)

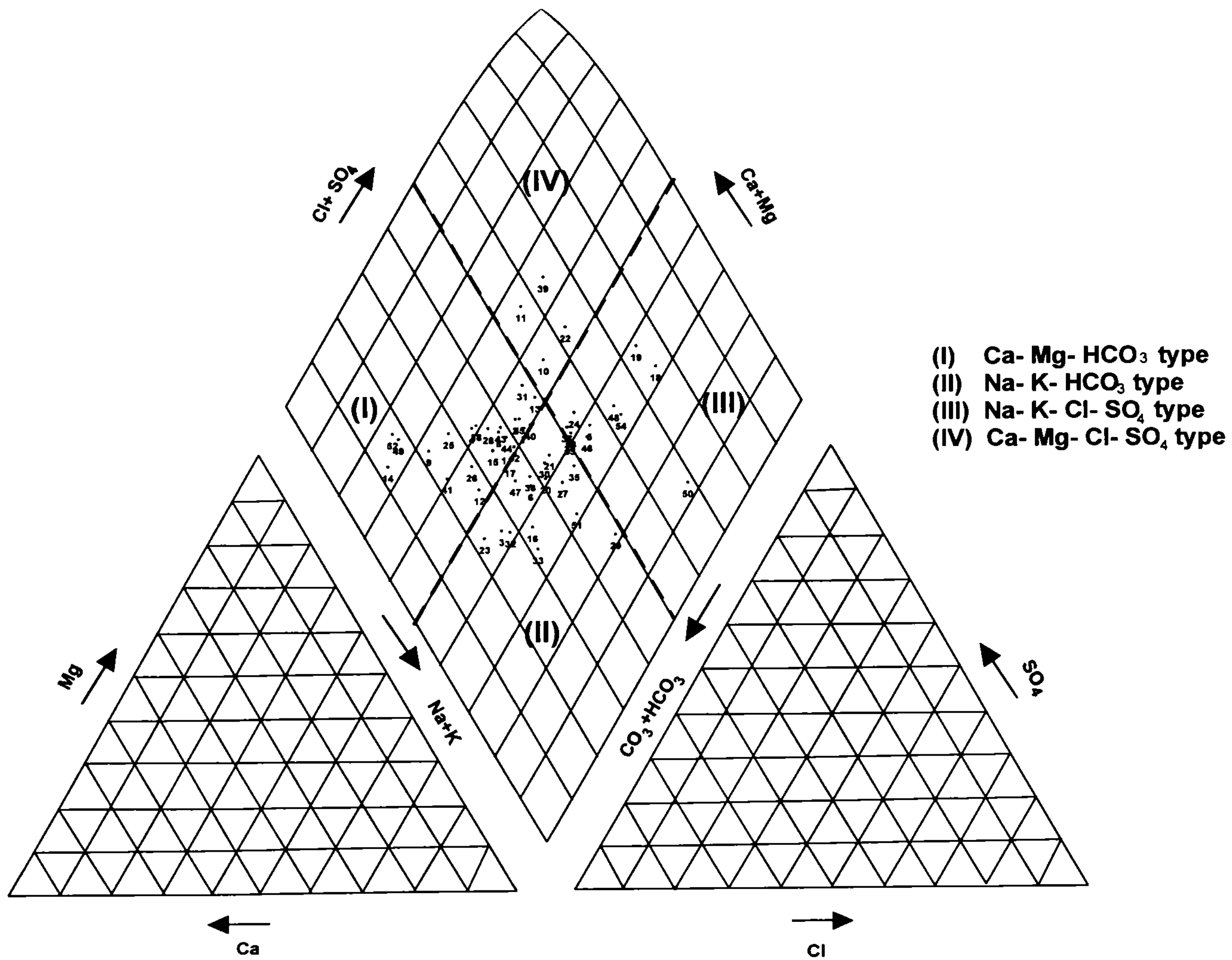


Fig. 5.11b Hill- Piper trilinear diagram of groundwater in the Muvattupuzha river basin (post monsoon)

Hydrochemical facies diagram: The hydrochemical pattern diagram helps in hydrogeochemical facies classification (Back and Hanshaw, 1965). The trilinear diagram of this study is classified into four hydrochemical facies based on the dominance of different cations and anions:

Facies 1: Ca^{++}- Mg^{++} - HCO_3^- type I

Facies 2: Na^+- K^+- Ca^{++}- HCO_3^- type II

Facies 3: Na^+- K^+- Cl^- -SO_4^{--} type III and

Facies 4: Ca^{++}- Mg^{++} - Cl^- - SO_4^{--} type IV.

Figs. 11a & b show that majority of samples, which are in type IV during pre monsoon have shifted to type I (16%), type II (13%) and type III (3%) during post monsoon. The next predominant shift is from type III to type II (13%) and type I and IV (9%). The remaining shifts to other facies are only marginal while 30% of samples do not show any shift at all. This indicates that post monsoon samples are enriched with bicarbonates and sodium types, which are originally types III and IV. From this it is evident that rainfall plays a major role in controlling the groundwater chemistry rather than geology. According to Chandrasekharam (1989), the groundwater from lateritic terrain should be of bicarbonate nature as the groundwaters have high HCO_3 ions than SO_4 and Cl ions. The above conclusion has been drawn by Chandrasekharam (1989) based on experimental and laboratory analyses of groundwater.

The changes in hydrogeochemical facies of the study area for the pre and post monsoons based on Johnson's (1975) modified diagram are shown in the Fig. 5.12. The markings from A to F in the diamond shaped field of the Hill-Piper diagram represent a specific class of water as given below.

i. Sodium chloride (NaCl) brines always fall in the vicinity of point A

ii. Calcium chloride ($CaCl_2$) brines, although rare, are plotted around point B

iii. Waters contaminated with gypsum fall in the region C

iv. Recently recharged waters (high Ca HCO_3) are marked in the region D

v. Sea waters are shown near point E and

vi. Recent dolomite waters are plotted in the region F.

The top half of the diamond shaped diagram further represents unusual waters having high Mg/ $CaCl_2$ and Ca/ $MgSO_4$ contents. The lower half represents normal waters usually found in dynamic basin environments. Based on the above the significant environment of this basin has been deduced below.

From the Fig. 5.12 it is found that most samples of the pre monsoon fall in an area between static and mixing regime, whereas only a very few samples fall in dynamic regime. On the other hand a majority of the post monsoon samples fall between mixing and dynamic regime. So it is found that there is an overall shift during the post monsoon period from static/ dissolution/ mixing regimes to dissolution/mixing/ dynamic regimes. As said above mixing and dissolution of rainwater play a vital role in shifting of water from one facies to another. The facies diagram further attest that the groundwaters of the basin

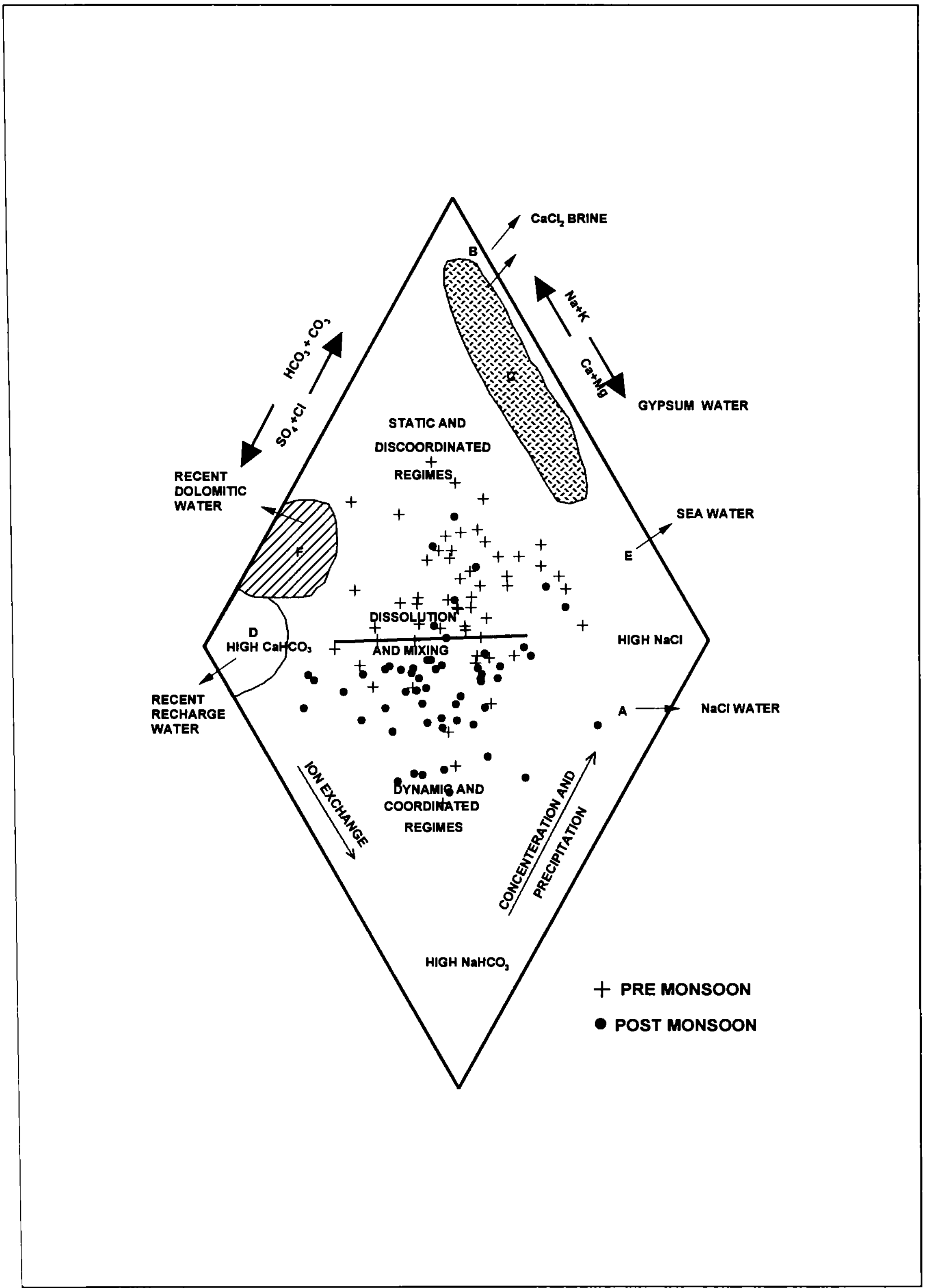


Fig. 5.12 Hydrochemical facies of groundwater in the Muvattupuzha river basin (Johnson, 1975)

have neither too much contact with the country rock nor in a dynamic condition. When comparing the trilinear plot of hydrochemical facies with Johnson's (1975) diamond field, most of the samples fall near the proximity of dissolution and mixing facies.

5.2.1h Bacteriological Quality

Escherichia coli (E. coli): The bacteriological quality is one of the most important aspects in drinking water parameter and the most common and widespread health risk associated with drinking water is the bacterial contamination caused either directly or indirectly by human or animal excreta. E.coli is selected as an indicator parameter of fecal contamination. Fecal contaminated water will lead to enteric diseases. The fecal contamination is mainly due to improper solid waste disposal from farmyard into the soak pits located very near to drinking water wells, which is not having any protecting wall. According to Woods (1990) effluents from point sources such as septic tanks and general farmyard wastes are considered as the main sources of contamination of groundwater. The lack of protecting wall will lead to the entry of contaminated runoff water in to the well from the upstream. Rojas et al. (1993) have studied the contamination of the waters of River Rimac, Peru, and the adjoining groundwater and found that the cause of pollution is due to mining and agricultural activities as well as domestic fecal pollution upstream. It is found here that except a few wells in the upstream, most of the wells contaminated with E.coli are situated in the down stream of the basin (post monsoon groundwater samples) indicating that the down slope movement of groundwater would have led to the contamination of groundwater in the lower levels of the basin (Fig. 5.13). The presence of E.coli in groundwater indicates potentially dangerous situation warrants immediate attention.

5.2.2 Evaluation of groundwater for irrigation

The suitability of groundwater for irrigation depends on the chemical constituents of the water. A relatively high concentration of alkalies and alkaline earths will affect directly the texture, structure, permeability and aeration of soils and indirectly plant growth (Lloyd and Heathcote, 1985). So also high concentration of trace elements such as boron, selenium, cadmium etc. is toxic to the growth of plants (Todd, 1980). The concentration of various ions (expressed in meq/l), their various ratios and percentages are given in Tables 5.7a & b.

5.2.2a Evaluation based on percentage of sodium, EC and TDS

Wilcox (1955) has classified the waters for irrigation purpose, which is based on electrical conductivity (EC), TDS, sodium percent (Na%) and boron concentration (Table 5.9). Sodium concentration is very important in classifying the irrigation waters because sodium reacts with soil easily resulting in the reduction of permeability (Houk, 1951). Sodium saturated soil will support a little or no plant growth. Sodium content is usually expressed in terms of sodium percent (also known as sodium percentage and soluble-sodium percentage) and can be calculated using the formula given below

$$\text{Na\%} = \frac{(\text{Na} + \text{K}) \times 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}$$

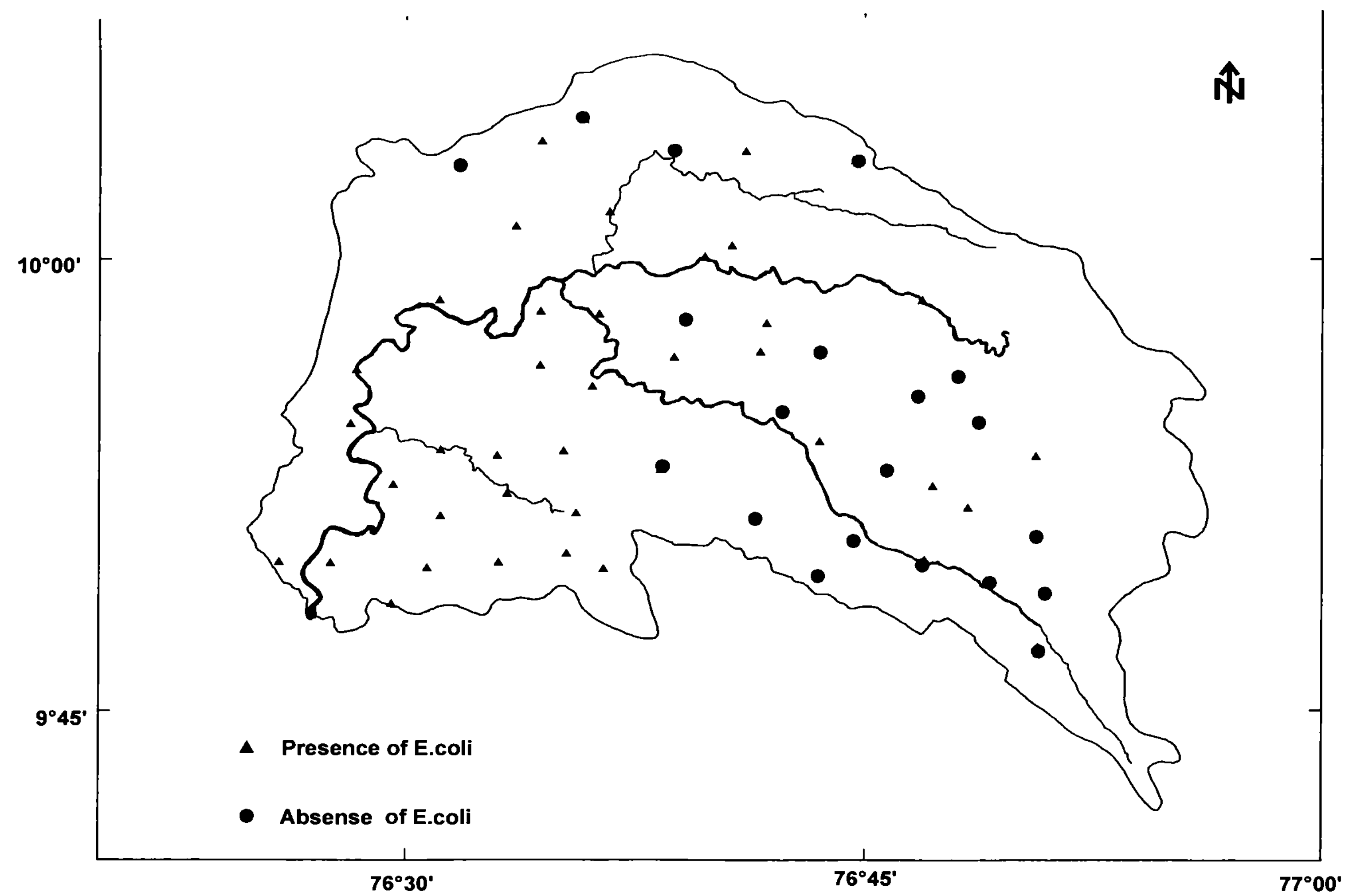


Fig. 5.13 Spatial distribution of E.coli in the groundwater of the study area (post monsoon)

where in all ionic concentrations are expressed in meq/l.

Table 5.9 Classification of groundwater quality for irrigation (after Wilcox, 1955)

Class of water	EC at 25° C (μS/cm)	TDS (mg/l)	Sodium %	Boron (mg/l) (Tolerant crop)
Excellent	<250	<175	<20	< 1
Good	250-750	175-525	20-40	1-2
Permissible	750-2000	525-1400	40-60	2-3
Doubtful	2000-3000	1400-2100	60-80	3-3.75
Unsuitable	>3000	>2100	>80	>3.75

The percentage distribution of sodium indicates that most of the area fall within the excellent, good and permissible limits and some in doubtful area (Figs. 5.14a & b). It is found that during post monsoon, the area coming under 'good zone" has got reduced than in pre monsoon. So also a comparison of the distribution of Na of pre monsoon with that of the post monsoon indicates that area of doubtful zone is slightly more and this is because that the sodium in the soil are being carried by rainfall to groundwater. The fertilizers used for agricultural purpose will also enhance the percent of sodium in groundwater (Paliwal and Yadav, 1976). The electrical conductivity and total dissolved solids are less than 300 μS/cm and 250 mg/l respectively in both seasons. Based on the concentration of Na%, EC and total dissolved solids, it is concluded here that the groundwater is good for irrigation purpose.

5.2.2b Suitability of water through U.S.S.L. diagram

The U.S. Salinity Laboratory (1954), Department of Agriculture, has used salinity and sodium hazards as the two important criteria in the

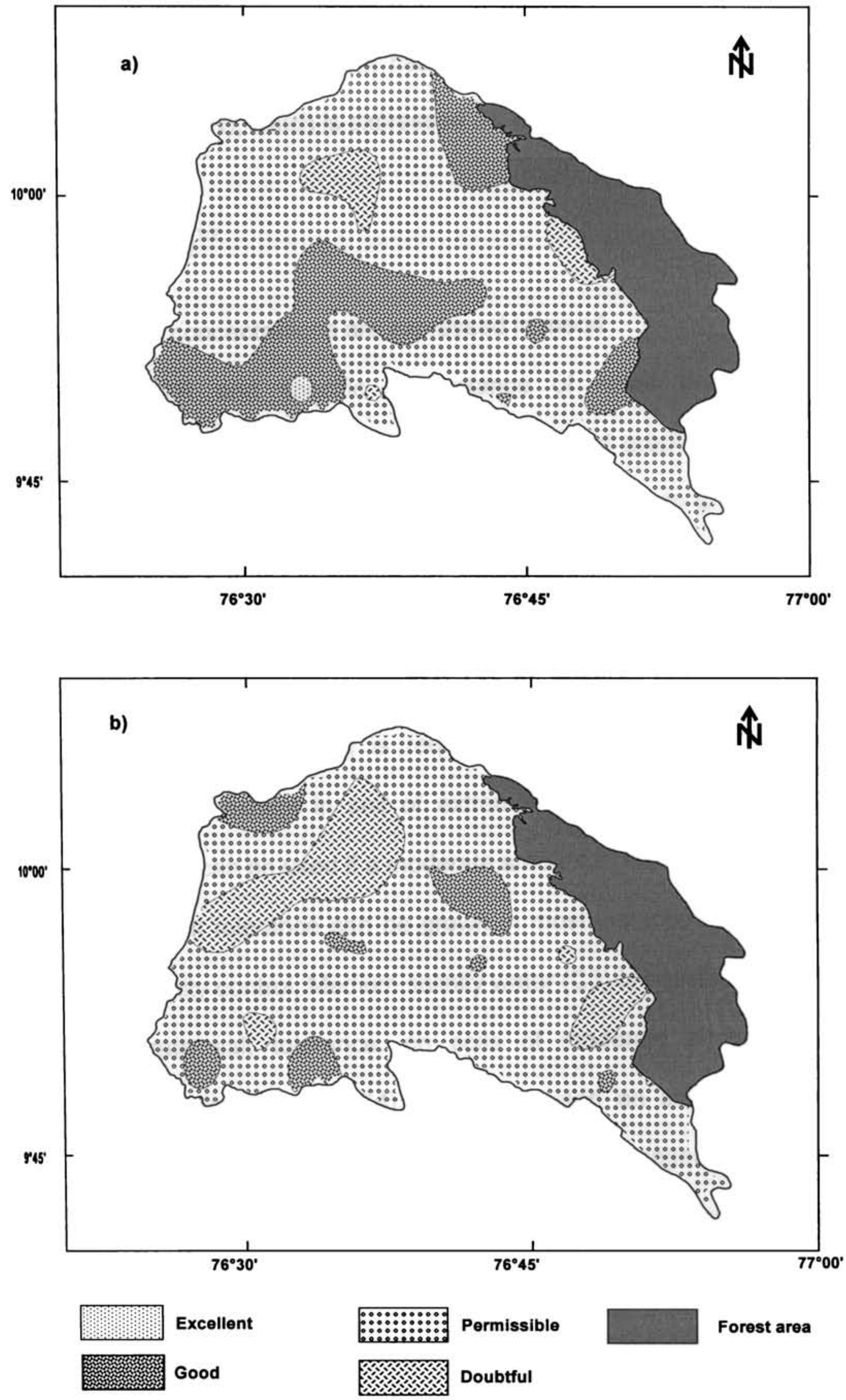


Fig. 5.14 Sodium percentage distribution map of the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

classification of waters for irrigation purpose. Salinity hazard is a measure of electrical conductivity while sodium hazard is expressed in terms of Sodium Adsorption Ratio (SAR), which is expressed as

$$SAR = \frac{Na}{\{(Ca+Mg)/2\}^{1/2}}$$

where in all ionic concentrations are expressed in meq/l.

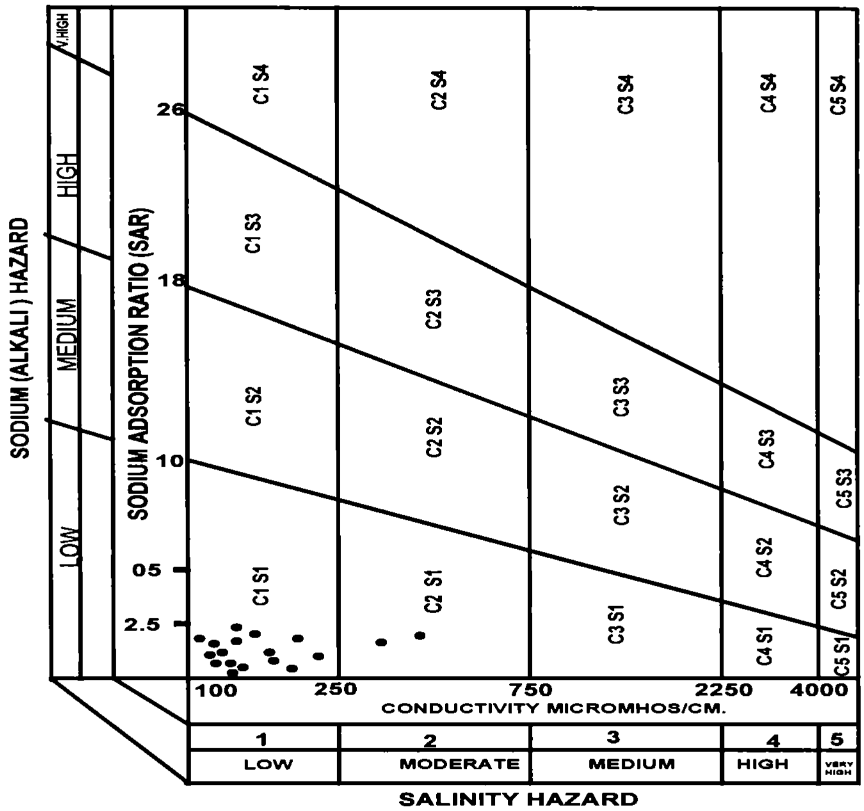
When SAR and specific conductance of water are known, the classification of water for irrigation can be determined graphically by plotting these values on a U.S.S.L. diagram. Waters are divided into C1, C2, C3, C4 and C5 types on the basis of salinity hazard and S1, S2, S3 and S4 types on the basis of sodium hazard (Table 5.10).

Salinity Hazard: Low salinity water (C1) can be irrigated to all kinds of crops on most soils. Some leaching is required, but this occurs under normal irrigation practices, except in soil of extremely low permeability. Moderate salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices of salinity control. Medium salinity water (C3) is satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching. High salinity water (C4) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected. Very high salinity water (C5) is not suitable for irrigation under ordinary conditions, but may be used occasionally, under very special and unavoidable circumstances. In this basin almost all the samples fall in C1 type (EC values <250 μS/cm) and a very few samples in C2 type (Figs. 5.15a & b) and therefore waters are fit for irrigation for most crops.

Sodium Adsorption Ratio (SAR): The classification of irrigation water with respect to SAR is based primarily on the capacity of exchangeable sodium with the soil. Sodium sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissue.

Low sodium water (S1) can be used for irrigation for almost all sorts of soils and plants with a little danger of the development of harmful level of exchangeable sodium. However, sodium sensitive crops, such as Stone-fruit trees and Avocados, may accumulate considerable concentration of sodium. Medium sodium water (S2) may cause an appreciable sodium hazard to fine textured soils, having high cation exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil, this water may be used on coarse textured or organic soils which have good permeability.

High sodium water (S3) may produce harmful level of exchangeable sodium in most soils and will require special soil management like good drainage, high leaching and addition of organic matter. Gypsiferous soils may not develop harmful level of exchangeable sodium from such waters. Very high sodium water (S4) is generally unsatisfactory for irrigation purpose except at low and perhaps medium salinity. Application of gypsum or other amendments may make use of these water feasible. Gypsum application may also increases a)



b)

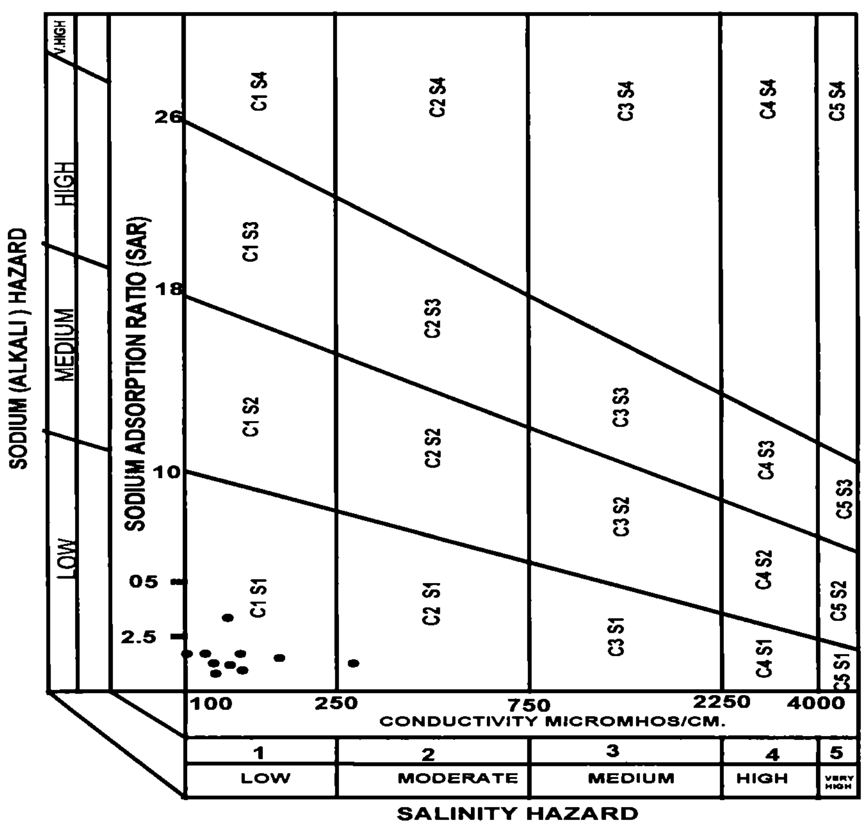


Fig. 5.15 Groundwater classification for irrigation based on U.S.S.L method (a) pre monsoon and (b) post monsoon

the crustal conductive properties of soils as elaborated by Goyal and Jain (1982).

Based on U.S.S.L. diagram of irrigation quality the area can be divided into twenty water classes (C1S1, C2S1, C3S1, C4S1, C5S1, C2S1, C2S2, C2S3, C2S4, C2S5 etc.- Figs. 5.15a & b)

Table 5.10 Classification of water for irrigation based on U.S.S.L. diagram (Wilcox, 1955)

Conductivity classes	Range EC at 25° (µS/cm)	Salinity hazard	SAR classes	Range of values	Sodium alkali hazard
C1	<250	Low	S1	<10	Low
C2	250-750	Moderate	S2	10-18	Medium
C3	750-2250	Medium	S3	18-26	High
C4	2250-4000	High	S4	>26	Very high
C5	>4000	Very high	-	-	-

In general, most of the SAR values of the study area are <2.5 for pre and post monsoon seasons (Table 5.7a & b). Further most of the water samples of this study fall in C1S1 class of (Wilcox, 1955) indicating low salinity- low sodium alkali hazard (Figs. 5.15a & b). Only a very few samples fall in C2S1 class indicating a moderate salinity hazard and low sodium hazard (Figs. 5.15a & b). Based on U.S.S.L. diagram (1954) the groundwater of the Muvattupuzha basin is considered as good for irrigation.

5.2.2c Residual Sodium Carbonate (RSC):

The effect of residual sodium carbonate has been carried by Eaton (1950). The index, which is termed as the residual sodium carbonate (RSC) by Eaton (1950) is given by the equation

$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$

and the units are expressed in meq/l of water. The classification of water based on RSC is given below.

Table 5.11 Limits for residual sodium carbonate values in irrigation water (Lloyd and Heathcote, 1985)

Conditions	RSC (meq/l)
Suitable	<1.25
Marginal	1.5- 2.5
Not suitable	> 2.5

The spatial variation of RSC in both seasons is represented by isocone maps (Figs. 5.16a & b). The concentration of RSC in the groundwater samples of the study area is <1.25 meq/l (Tables 5.7a & b) for both seasons suggesting that the water is suitable for irrigation.

5.2.3 Evaluation of groundwater for industrial purpose

5.2.3a Evaluation based on TDS and Hardness as $CaCO_3$

The quality criteria of water for industrial purposes depend on the type of industry, processes and products. The water for the high-pressure boilers should be free from suspended matter; have low TDS (<1mg/l) and no acid

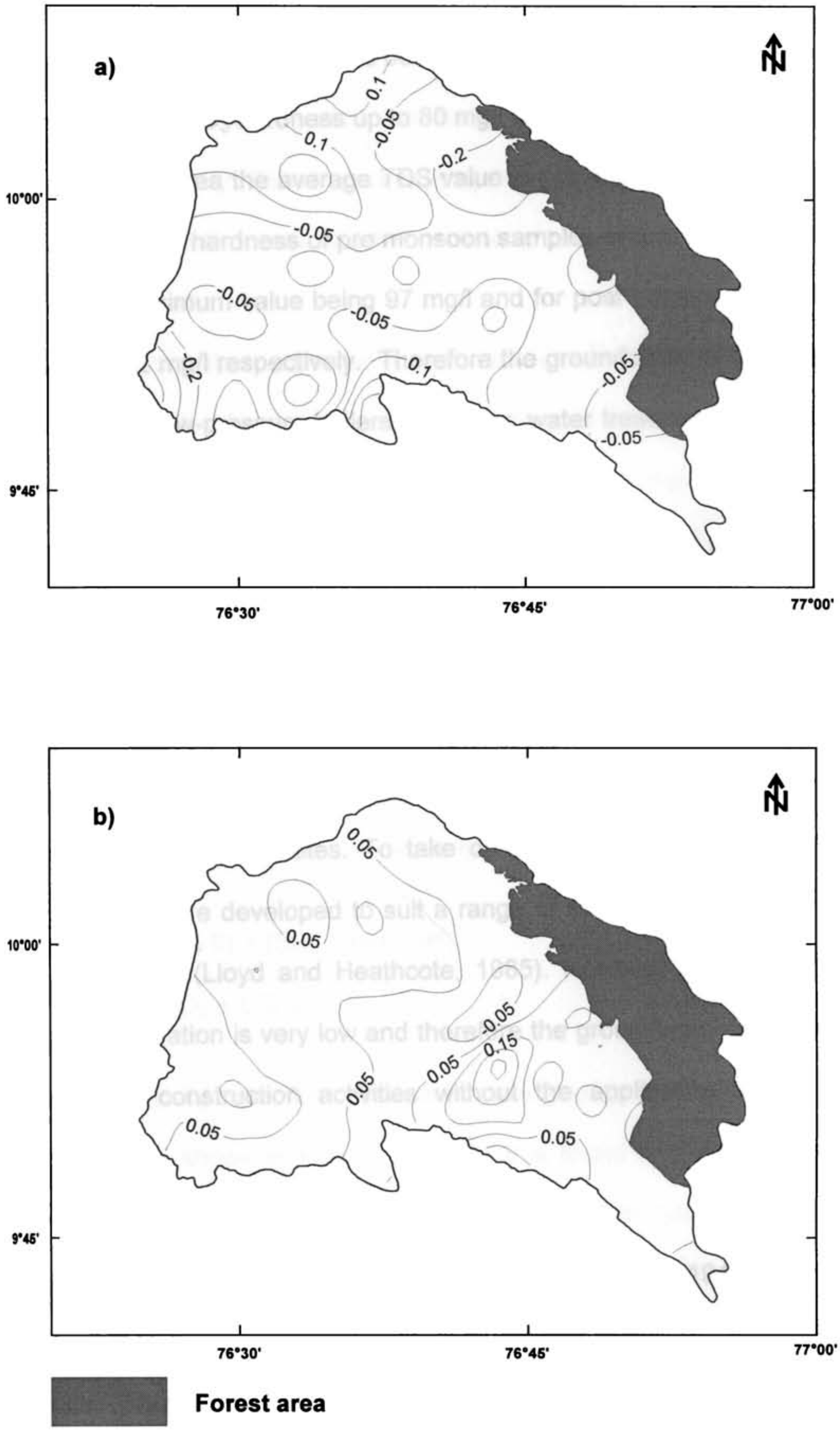


Fig .5.16 Isocone map of residual sodium carbonate in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

reaction. On other hand low-pressure boilers can use water with TDS values up to 5000 mg/l and $CaCO_3$ hardness up to 80 mg/l (Singhal and Gupta, 1999).

In the study area the average TDS value in pre and post monsoons are below 300 mg/l. The hardness of pre monsoon samples shows a minimum of 5 mg/l while the maximum value being 97 mg/l and for post monsoon samples it is 6 mg/l and 122 mg/l respectively. Therefore the groundwater of this basin is most suitable for low-pressure boilers. However, water treatment is necessary if used for high pressure boiler plants.

For the manufacture of pharmaceuticals and high-grade papers, water approaching or water quality should be equal to that of distilled water. High quality water is desirable in nuclear reactors so as to keep the radioactivity caused by neutron activation of dissolved solids as low as possible (Hem, 1959). In the construction industry the sulphate content of water is important to avoid deterioration of concretes. To take care of such problems, sulphate-resisting cements are developed to suit a range of sulphate concentrations in the soil and water (Lloyd and Heathcote, 1985). However in this study the sulphate concentration is very low and therefore the groundwater is very much suitable for all construction activities without the application of sulphate-resisting cements.

5.2.3b Corrosivity Ratio (CR)

The corrosivity ratio was initially proposed by Ryzner (1944). Badrinath et al., (1984) has used this index to evaluate the corrosive tendencies of Sabarmathi river water, Gujarat. Similarly Balasubramanian (1986) and

Rengarajan and Balasubramanian (1990) have studied corrosivity ratio of the groundwater of the Tambaraparani river basin and Nangavalli region Selam, Tamil Nadu respectively. For all practical purposes groundwater is transported by conventional metallic pipes and the corrosivity ratio of the groundwater of this basin is analysed.

Different chemical parameters can be used to identify corrosion potentials. These are pH, dissolved oxygen, hydrogen sulphide, TDS, carbon dioxide, chloride etc. If the water is acidic, corrosion is accelerated as the increased hydrogen ion concentration favours the release of hydrogen and oxygen depolarisation. In addition, a pH value below 6.5 can cause corrosion of metal pipes, thereby releasing toxic metals such as Zn, Pb, Cd, Cu, etc. (Trivedy and Goel, 1986). A corrosivity ratio less than 1 (CR<1) is considered as safe.

The Corrosivity ratio can be determined by the following formula

$$CR = \frac{\{Cl\ (ppm) / 35.5\} + \{SO_4\ (ppm) / 96\}}{2x\ \{HCO_3 + CO\ (ppm)\}}$$

The corrosivity ratios for both seasons are given in Tables 5.7a & b and the variations are shown in Figs. 5.17a & b. It is found that in pre monsoon except three localised pockets respectively on the north (Muvattupuzha and Kothamangalam sub basins), south (Muvattupuzha and Thodupuzha sub basins) and east (Thodupuzha sub basin), most of the other area comes under unsafe zone. On other hand during post monsoon both safe and unsafe zones

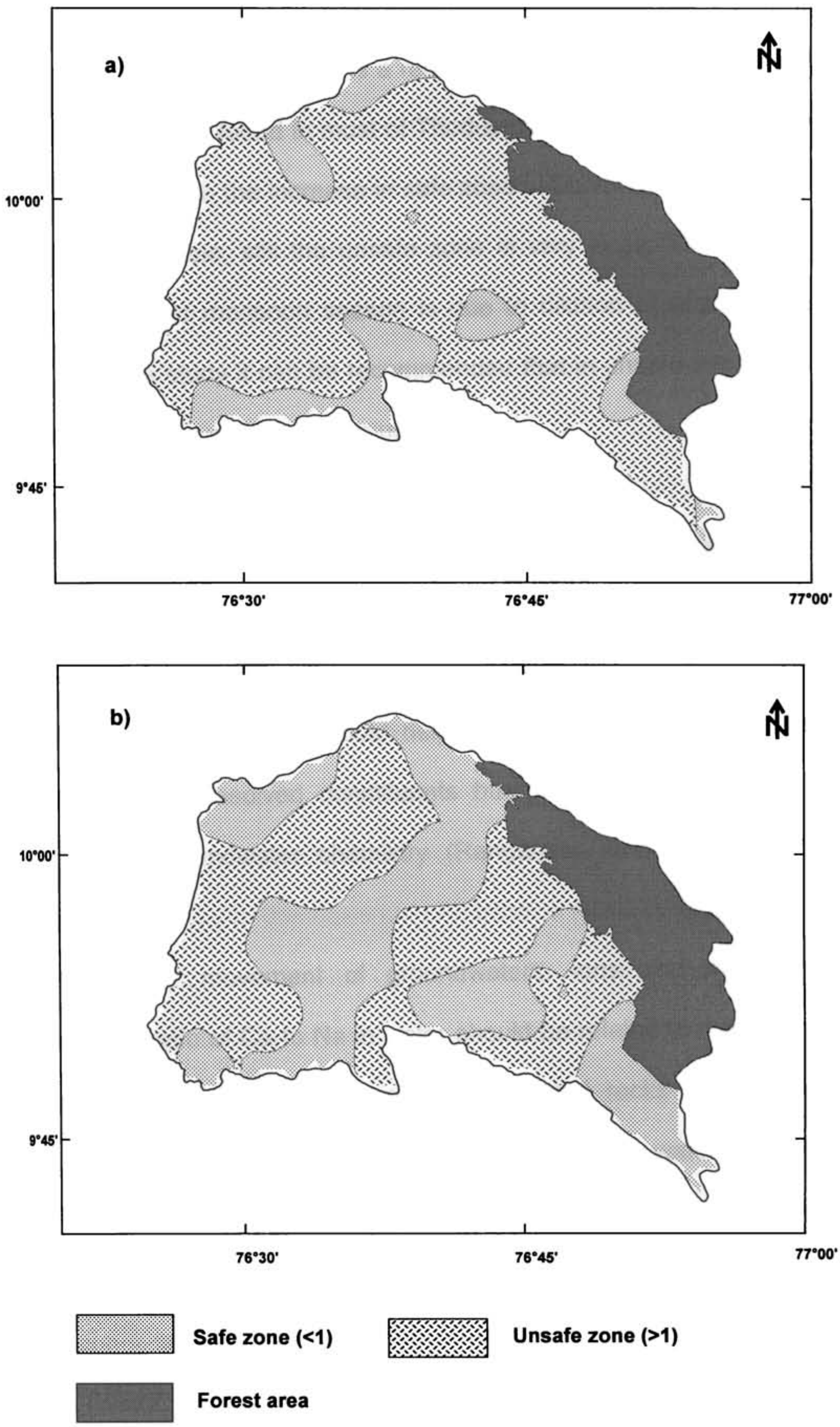


Fig. 5.17 Corrosivity ratio of groundwater in the Muvattupuzha river basin (a) pre monsoon and (b) post monsoon

share almost equal area i.e. there is a reduction in unsafe area. The increase in safe zone has been found in most of Thodupuzha and Kothamangalam sub basins. So also though the increase in safe zone in Muvattupuzha sub basin is very much appreciable, still the unsafe zone is very large. The reduction of unsafe area in post monsoon season is due to dilution of ground water by rainfall. From this study it can be recommended that in unsafe area Poly Vinyl Chloride (PVC) pipes will have to be used.

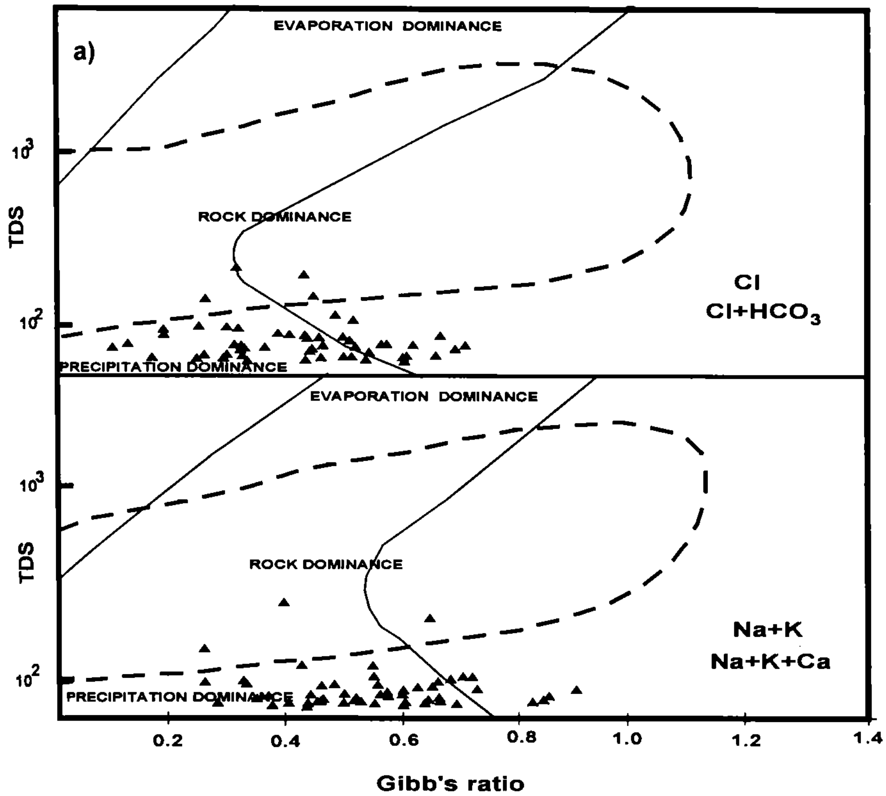
5.3 MECHANISM CONTROLLING THE GROUNDWATER CHEMISTRY

Hydrochemical water quality studies help to explain the relationship of water chemistry to aquifer lithology (Viswanathiah and Sastri, 1973, 1977; Sastri, 1976). Such relations would help not only to explain the origin and distribution of the dissolved constituents but also to elucidate the factors controlling the groundwater chemistry (Rangarajan and Balasubramanian, 1990).

During the movement of groundwaters, ions and molecules are absorbed. The ratio of Ca to Na in water should be related to the composition of plagioclase feldspars present in the associated rocks (charnockite and gneiss). Likewise the proportion of Mg to other cations in water is an index of relative abundance of ferromagnesium minerals in the environment (Aravindan, 1999). The characteristics feature of the groundwater in metamorphic terrain is the high concentration of sodium bicarbonate but relatively low concentration of chloride (White, 1957). Generally the metamorphic formations are likely to contain less dissolved solids thus resembling more closely with the waters of igneous rocks. Gibbs (1970) proposed an elegant and simple explanation for the general chemistry of streams and rivers. Later on so many workers have used Gibbs diagram to explain groundwater chemistry (Viswanathaiah and Sastri, 1973, 1977; Sastri, 1976; Rangrajan and Balasubramanian, 1990 and others).

The mechanism responsible to control the groundwater chemistry of the study area following Gibbs (1970) diagram have been represented in Figs. 5.18a & b. In the above diagrams ratios of (Na + K) / (Na + K + Ca) and Cl / (Cl + HCO_3) are plotted against TDS. The densities of sample points are maximum in precipitation dominance while only a very few points fall in the rock dominance for both seasons. The clustering of points in precipitation domain clearly shows that rock chemistry is not a major factor in controlling the groundwater chemistry of this basin but precipitation (Figs. 5.18a & b).

This basin is characterised by very low TDS during both seasons and more than 50 percentage of samples show values less than 75mg/l. The conclusion drawn through Gibbs diagram is substantiated by Johnson's (1975) facies diagram and Durov's diagram where in most of the samples fall in dissolution and mixing zones. Once a mixing of water takes place TDS will get reduced and this is due to abundance rainfall (see Chapter 1, section 1.6).



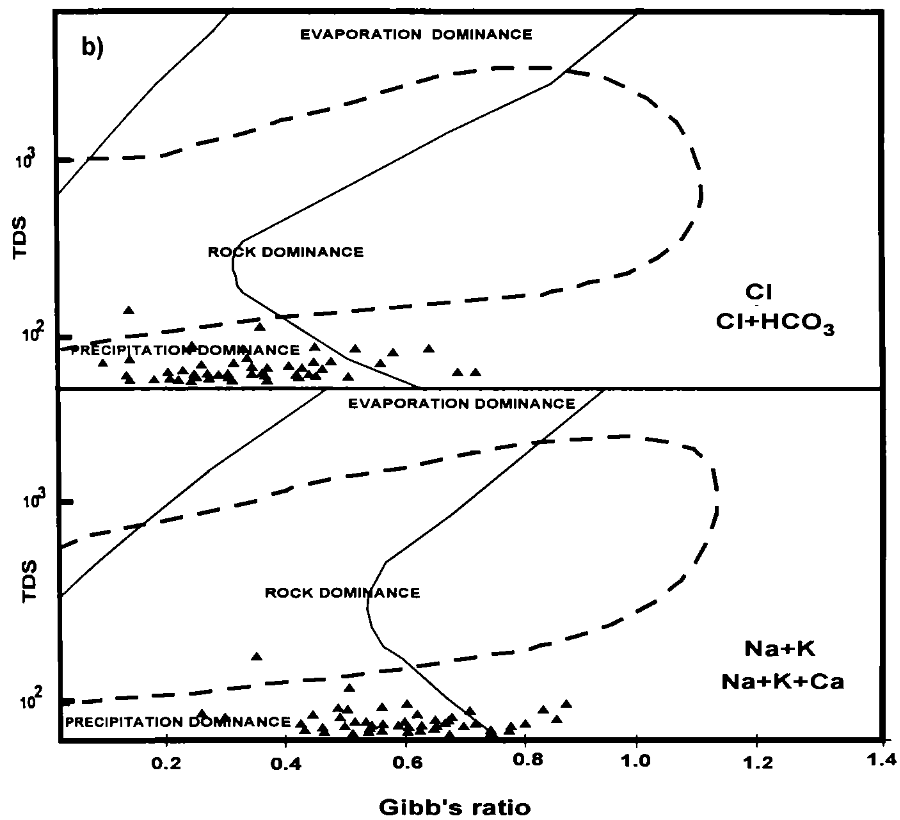


Fig. 5.18 Gibb's diagram illustrating the mechanism controlling the groundwater chemistry of the study area (a) pre monsoon and (b) post monsoon

5.4 STATISTICAL ANALYSIS OF GROUNDWATER CHEMISTRY

5.4a Correlation matrix

From the correlation matrix (Tables 5.12a & b) it is inferred that EC has a high significant correlation with Ca, Na, TDS and TH and a significant relation with K and Cl during both seasons. EC also exhibits a significant correlation with K, SO_4, Cl during pre monsoon and with Cl only during post monsoon. EC further reveals in highly significant correlation with HCO_3 only during pre monsoon while in the post monsoon the relation is only significant. The above relationship indicates that EC has a major role in controlling the groundwater quality irrespective of the season. Ca also shows a highly significance correlation with TDS and TH and a moderately significant correlation with HCO_3+CO_3 for both the seasons. Fluoride is negatively correlated with most parameters (pH, Ca, K, HCO_3+CO_3 and SO_4) for both the seasons. In addition to the above fluoride is negatively correlated with Na and Mg only in post monsoon period and is due to the widespread crystalline nature of the country rock. Total iron shows significant correlation with HCO_3+CO_3 in both seasons due to the leaching of considerable iron from laterites.

5.4b Cluster analysis

Cluster analysis has been carried out for various geochemical parameters of the Muvattupuzha river basin for pre and post monsoon samples (Figs. 5.19a & b). The dendrogram (Davis, 1973) for the two seasons show two major clustering patterns. The first group of the pre monsoon consists of EC, TDS, Ca TH, HCO_3+CO_3, SO_4, and Fe while the second group consists of

Table 5.12a Correlation matrix of the chemical parameters in the groundwater samples in the Muvattupuzha river basin (pre monsoon)

	EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T.Fe	TDS	T.H
EC	1.0000												
pH	0.2629	1.0000											
Ca	0.8486	0.3292	1.0000										
Mg	0.2355	0.0992	-0.0057	1.0000									
Na	0.8169	0.1507	0.6663	0.2025	1.0000								
K	0.6215	0.0744	0.4062	0.2027	0.5898	1.0000							
HCO_3+CO_3	0.8049	0.3468	0.6937	0.1770	0.5473	0.4012	1.0000						
SO_4	0.7513	0.0842	0.7097	0.0992	0.5473	0.4116	0.6160	1.0000					
Cl	0.7413	0.0345	0.6301	0.2077	0.7908	0.6175	0.4199	0.4915	1.0000				
F	0.0343	-0.0632	-0.0277	0.0677	0.0563	-0.0102	-0.0385	-0.0677	0.1248	1.0000			
T.Fe	0.4476	0.1923	0.4474	-0.1115	0.3366	-0.0180	0.5685	0.5524	0.2400	-0.0305	1.0000		
TDS	0.9920	0.2693	0.8491	0.2179	0.8193	0.6365	0.8228	0.7514	0.7391	-0.0012	0.4619	1.0000	
T.H	0.8794	0.3441	0.9379	0.3416	0.6965	0.4523	0.7133	0.7018	0.6636	-0.0034	0.3818	0.8737	1.0000

Table 5.12b Correlation matrix of the chemical parameters in the groundwater samples in the Muvattupuzha river basin (post monsoon)

	EC	pH	Ca	Mg	Na	K	HCO_3+CO_3	SO_4	Cl	F	T.Fe	TDS	T.H
EC	1.0000												
pH	0.4587	1.0000											
Ca	0.8382	0.6246	1.0000										
Mg	0.5423	0.3285	0.5968	1.0000									
Na	0.8333	0.2009	0.5569	0.3678	1.0000								
K	0.6092	0.2227	0.3760	0.0641	0.6300	1.0000							
HCO_3+CO_3	0.6137	0.6521	0.7887	0.7700	0.3484	0.1812	1.0000						
SO_4	0.4374	0.0410	0.3575	-0.0232	0.4097	0.2353	-0.0033	1.0000					
Cl	0.7181	-0.0082	0.3536	0.2028	0.8800	0.6424	0.0912	0.3441	1.0000				
F	0.0412	-0.0687	-0.0950	-0.1164	-0.0285	-0.1094	-0.0718	-0.0205	0.1147	1.0000			
T. Fe	0.3517	0.5041	0.5262	0.4396	0.1584	-0.0443	0.5931	0.0999	-0.0472	0.0019	1.0000		
TDS	0.9998	0.4580	0.8394	0.5426	0.8310	0.6096	0.6148	0.4353	0.7169	0.0435	0.3567	1.0000	
T. H	0.8285	0.5899	0.9687	0.7761	0.5458	0.3123	0.8544	0.2735	0.3420	-0.1020	0.5473	0.8295	1.0000

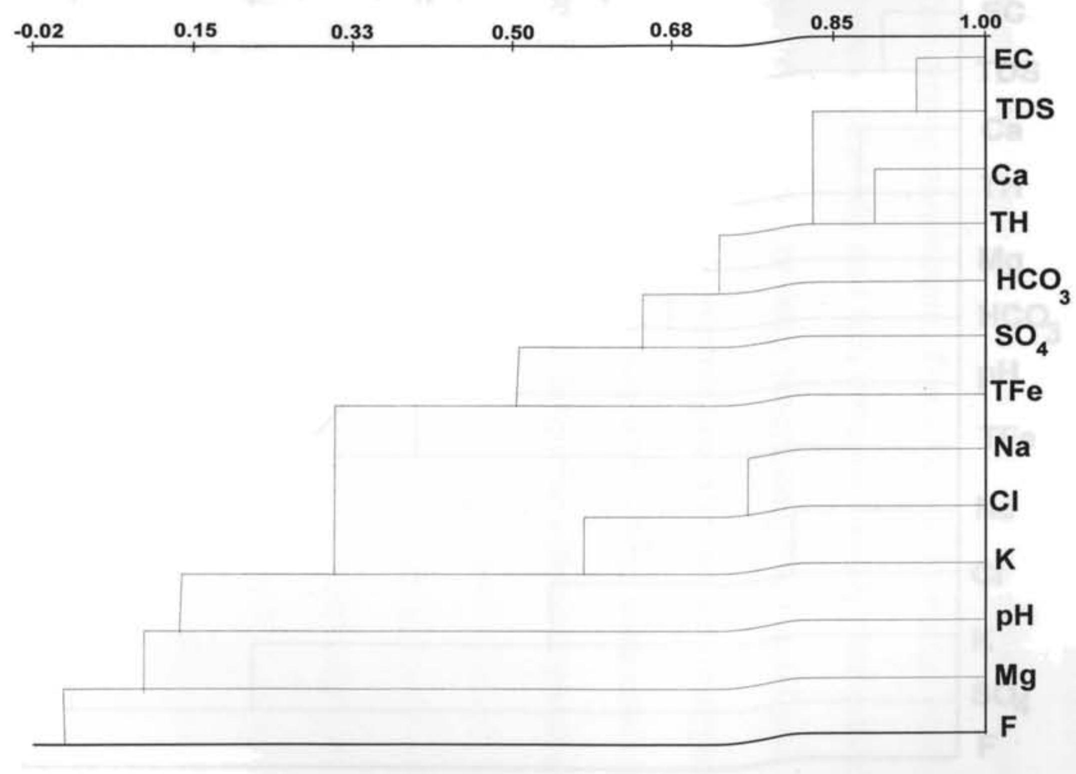


Fig. 5.19a Dendrogram of groundwater chemistry of Muvattupuzha river basin (pre monsoon)

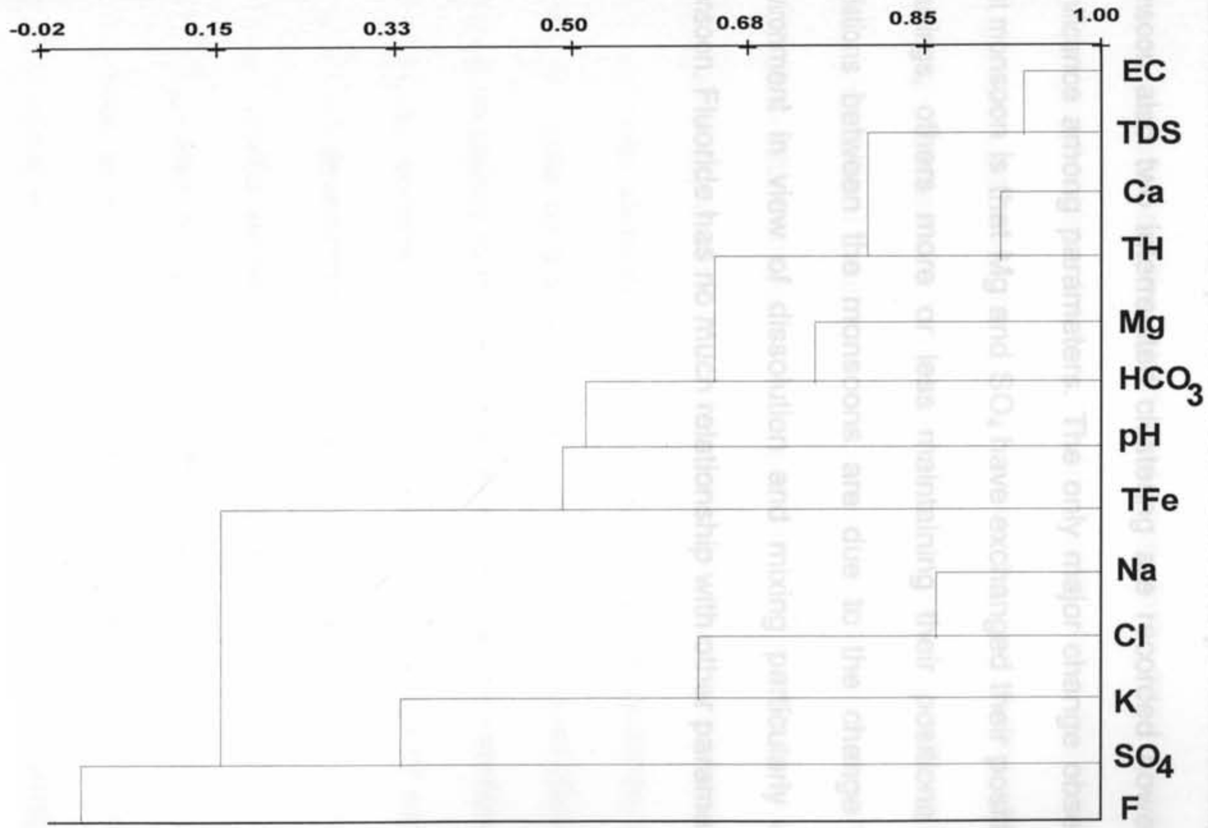


Fig. 5.19b Dendrogram of groundwater chemistry of Muvattupuzha river basin (post monsoon)

Na, Cl, K, pH, Mg and F. The close association between parameters within the first group indicates the control of EC over the others. Like wise Na play a significant role in the second group.

The clustering of parameters during post monsoon show a slight variation from that of the pre monsoon. Similar to pre monsoon, during the post monsoon also two interrelated clustering are recorded however, with a low significance among parameters. The only major change observed during the post monsoon is that Mg and SO_4 have exchanged their position between the groupings, others more or less maintaining their positions. The observed variations between the monsoons are due to the change in groundwater environment in view of dissolution and mixing particularly during the post monsoon. Fluoride has no much relationship with other parameters.

CHAPTER 6

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

6.1 INTRODUCTION

Remote sensing data, due to its synoptic and repetitive nature, are most suitable for studies like short and long term areal changes in landuse, preparation of various thematic maps, health status of vegetation, delineating groundwater potential zones etc. Likewise, geographic information system (GIS), with its capability to handle large quantity of spatial and non-spatial data is an excellent tool to analyse and integrate data generated by remote sensing method. In this chapter the application of remote sensing and GIS in groundwater exploration of the Muvattupuzha river basin has been taken up.

Remote sensing can be defined as the acquisition of data about an object or scene by a sensor that is far from the object (Colwell, 1983). This name is attributed to the recent technology in which satellites and spacecrafts are used for collecting information about the surface of earth. This was an outcome of development in various technological fields since 1960 onwards. Broadly, remote sensing is the science and art of obtaining information about an object, area or phenomena through the analysis of data acquired by a device that is not in contact with the object, area or phenomena under investigation (Lillesand and Kiefer, 1994). Hence, the term remote sensing is commonly used to identify earth features by detecting the characteristic of electromagnetic radiation that is reflected / emitted by the earth surface

Regular updating of data is an essential element in carrying out any kind of planning activity such as watershed management, surface water budgeting, landuse mapping, etc. The collection of these data through conventional means is not efficient and sufficient enough for modern day planning requirements. Thus satellite remote sensing data provide a means of locating, mapping and monitoring water resources, changes in morphology of rivers, landuse pattern and health status of vegetation etc. The remote sensing data, which are primarily in digital format, are processed further and hard copy images are generated. The use of satellite remote sensing data in conjunction with a GIS provide an opportunity to acquire, update and monitor the changes in a timely manner with a reasonable degree of accuracy.

Geographic Information System (GIS): The large volumes of spatial data, produced by remote sensing system can be handled only by an efficient GIS software and processing systems which will transform these data into usable information. GIS has been defined as a set of tools for collecting, storing, transforming and displaying geographically referenced spatial data with its corresponding attribute information to meet a specific requirement. Its origin can be traced back to 1960s in North America. Advancement in computer graphics and very high-speed microcomputers has mad a dramatic impact on the development of GIS since1980 (Taylor, 1991).

GIS is being used widely for natural resources management, environmental monitoring and planning socio-economic and demographic research. The applications of GIS provide wide scope for designing strategies for sustainable development and monitoring environment resources. Some of the most important areas of GIS application are micro-level and regional planning, estuary modelling, environmental impact assessment, hydro-geomorphological study, watershed management for balanced regional development etc. Geological research often calls for combination, comparison, and correlation of different kinds of spatial and non-spatial data. Such data sets are best handled in the form of GIS, which is a versatile system that can aid in decision making for better planning and management of natural resources.

Major components of GIS are (1) data input system, (2) data storage system and (3) data analysing system (Stenfanovia, 1989). Geographically referenced data in the spatial form collected by space sensor are presented in the form of photographs, paper prints and digital images. Examples for non-spatial data are soil properties, vegetation types, climate data, population, socio-economic data, hydrogeological data, etc. It is possible to transform and integrate these information into thematic data and process them in GIS. Geographical data describe objects in terms of (a) their position with respect to a co-ordinate system; (b) their attributes that are unrelated to position (such as colour, cost, pH etc.) and (c) their spatial inter relationships with each other.

GIS is normally categorized as either raster-based or vector-based system. Raster-based systems are typically associated with image-based GIS, while vector-based systems are usually more cartographically oriented. With the evolution of computer technology and computing facilities, it is possible to deal with large volumes and complexities of spatial data sets.

Integration of remote sensing and GIS: Remote sensing is increasingly used as one of the elements of an integrated GIS environment rather than an important source of the multispectral data to be moved from remote sensing domain to GIS domain (Jackson and Mason, 1986; Parker 1988; Star and Estes, 1990). The multispectral data can be successfully converted into information during planning and implementation. For a proper planning the criteria to be adopted are scale and resolution, quantitative versus qualitative model integration and linkage, operational linkage, costs, training, competency of computational overhead and standards.

Maps produced through conventional field surveys and remote sensing techniques can provide basic geometrical data. Combining the data from different sources either in the production phase and or in the analysis phase, one could improve the standards of information, which could usually be derived from the data set. For remote sensing, GIS offers possibilities for use and distribution of the output. Remote sensing imageries are mostly useful for specialists and not for users such as managers and decision-makers. Moreover, display of data and production of output can easily be customized with the GIS techniques. However, remote sensing gives advantages in the updating of the geo-database and for the monitoring of processes. Further for some specific requirements remote sensing data can give locally more information than a map can.

For the delineation of groundwater prospecting zones it is, therefore, necessary to integrate data from various terrain characteristics such as topography, lithology, geological structures, depth of weathering, extent of fractures, slope, drainage pattern etc, which can be achieved through different GIS techniques. Several studies are conducted to identify groundwater potential zones using remote sensing and GIS (Singh et al., 1993; Chi and Lee, 1994; Pal et al., 1997).

6.2 ROLE OF REMOTE SENSING AND GIS IN HYDROGEOLOGY

During the last three decades, remotely sensed data (both satellite images and aerial photographs) have been increasingly used in groundwater targeting exercise (Chatterjee et al., 1978; Seelan and Thiruvengadachari, 1980; Behera, 1989; Baker and Panciera, 1990: Das, 1997; Harinarayana et al., 2000). Satellite images are increasingly used in groundwater exploration because of their utility in identifying and outlining various ground features, which may serve as either direct or indirect indicators of presence of ground water (Dept. of Space, 1988; Ravindran and Jayaram, 1997). An effective evaluation of ground water potential zones can be done by the analysis of remotely sensed data of drainage, geology, geomorphology and lineament characteristics of the terrain in an integrated way. Similar attempts have been made in the generation of different thematic maps for the delineation of groundwater potential zones in different parts of the country (Obi Reddy et al., 1994; Krishna Moorthy and Sreenivas, 1995; Rao et al., 1996; Reddy et al., 1996). Satellite remote sensing is also proved beneficial in hydrogeomorphological mapping (Vaidyanathan, 1964; Prithviraj, 1980; Das et al., 1997; Kumar and Tomar, 1998; Tomas et al., 1999; Pratap et al., 2000; Subba Rao et al., 2001) and in defining spatial distribution of different features like forests and occurrence of groundwater prospective zones and other associated features (Bhattacharya et al., 1979; Millingtol and Townshed, 1986; Jones, 1986; Kundi, 1988; Sinha et al., 1990). The information obtained from remote sensing data is useful in proper management and development of water resource of the region. Moorthy and Venkateswara Rao (1999) while conducting a hydro-geomorphological mapping in association with IRS data in Varaha river basin, Andhra Pradesh found that areas covered by buried channels show not only shallow aquifer of good quality but also with an excellent yield. Based on remote sensing techniques Subba Rao et al. (2001) have identified groundwater potential zones in and around Guntur town, Andhra Pradesh. They have observed that shallow weathered pediplain, moderately weathered pediplain and deeply weathered pediplain are classified as poor to moderate, moderate to good and good ground water prospects. Sarkar et al. (2001) evaluated groundwater potentiality of Sharmi micro-watershed in Shimla taluk Himachel Pradesh using GIS and remote sensing techniques and delineated various landforms and features such as pediment, pediplain and flood plain. Obi Reddy et al. (2000) evaluated groundwater potential zones using remote sensing data in Gaimukh watershed, Bhandra, Maharashtra. The above investigation further shows that the deep valley fills with thick alluvium are categorised as 'excellent', shallow valley fills and deep weathered pediplains with thin alluvium fall under 'very good' category while moderately weathered pediplain are termed as 'good' groundwater prospects. These units are identified as highly favourable for groundwater exploration and development.

Repetitive and multispectral satellite remote sensing data, especially at high spatial resolutions, provide much information on the changing land-use patterns and urban growth in cities and settlements situated within the watershed (Gupta et al., 1998; Saini et al., 1999; Brahmabhatt et al., 2000). Such temporal information is indispensable for any watershed development or management plan

Normalized Difference Vegetation Index (NDVI) is a computation of ratio images using data in infrared and visible bands of the electromagnetic spectrum while ranges from 0.1 up to 0.6, with higher values associated with greater density and greenness of the plant canopy. Tucker et al. (1985) derived the NDVI from Global Area Coverage (GAC) data to map major vegetation types and seasonal changes for Africa over a period of 19 months in 1982 and 1983. Townshend et al. (1987) used GAC and Global Vegetation Index (GVI) data of South America to evaluate the different approaches for mapping landcover. The worldwide vegetation cover was mapped by Lloyd (1990), employing a supervised classification of multidated GVI. Zhu and Evans (1994) used Advanced Very High Resolution Radiometer (AVHRR) data for the classification of the forest of United States into twenty-five categories.

6.3 RESULTS AND DISCUSSION

Geomorphological, lineament and landuse maps are prepared by visual interpretation of satellite images (geocoded hard copy of IRS IC, LISS III), where as digital data of IRS ID, LISS III are used for image processing (for unsupervised landuse classification and NDVI). The False Colour Composite (FCC) of the Muvattupuzha river basin is shown in the Fig. 6.1. The 2nd and 3rd bands (Figs. 6.2 a & b) are stacked from LISS III in order to understand the spectral reflectance pattern of surface water body. The 3rd band is generally used for the demarcation of land-water and is very well used for surface water resource study.

In this study the remote sensing and GIS have been applied

a) for the preparation of various thematic maps and landuse pattern

b) to delineate the groundwater potential zone and

c) for the integration of spatial and non-spatial data sets.

6.3.1 Description of thematic maps

A detailed geological map of the Muvattupuzha river basin (1:50,000) has been prepared using maps of the GSI, 1995 (1:5,00,000). Different rock types of the study area are recognized based on their distinct texture, structure and colour. The drainage and contour maps are prepared from Survey of India (SOI) toposheet at a scale of 1:50,000. Hydrogeomorphology, landuse and lineament maps were also prepared from satellite imagery at a scale of 1:50,000. For the preparation of lineament density and drainage density map,

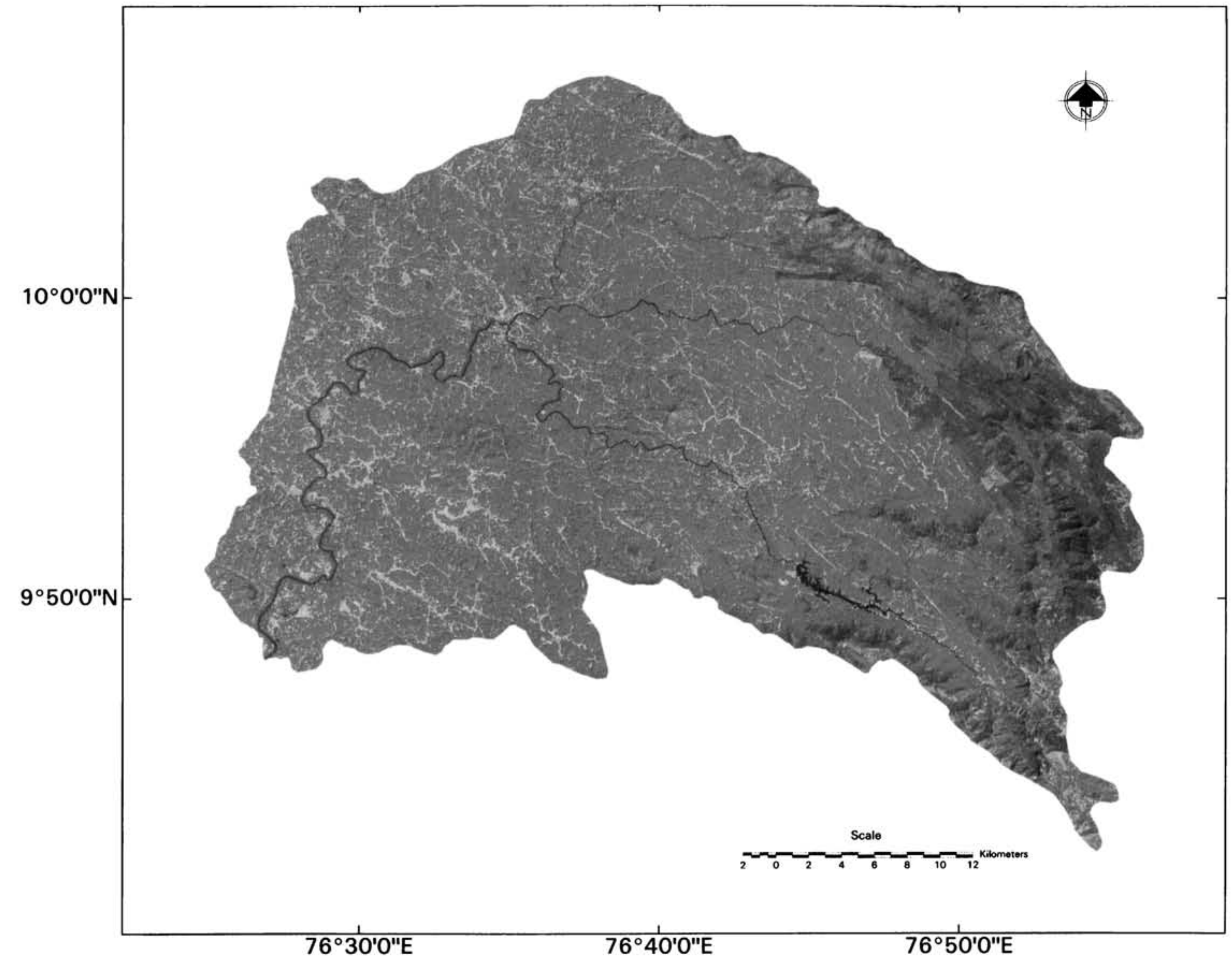


Fig. 6.1. False Colour Composite (IRS-ID, LISS III) of the Muvattupuzha river basin

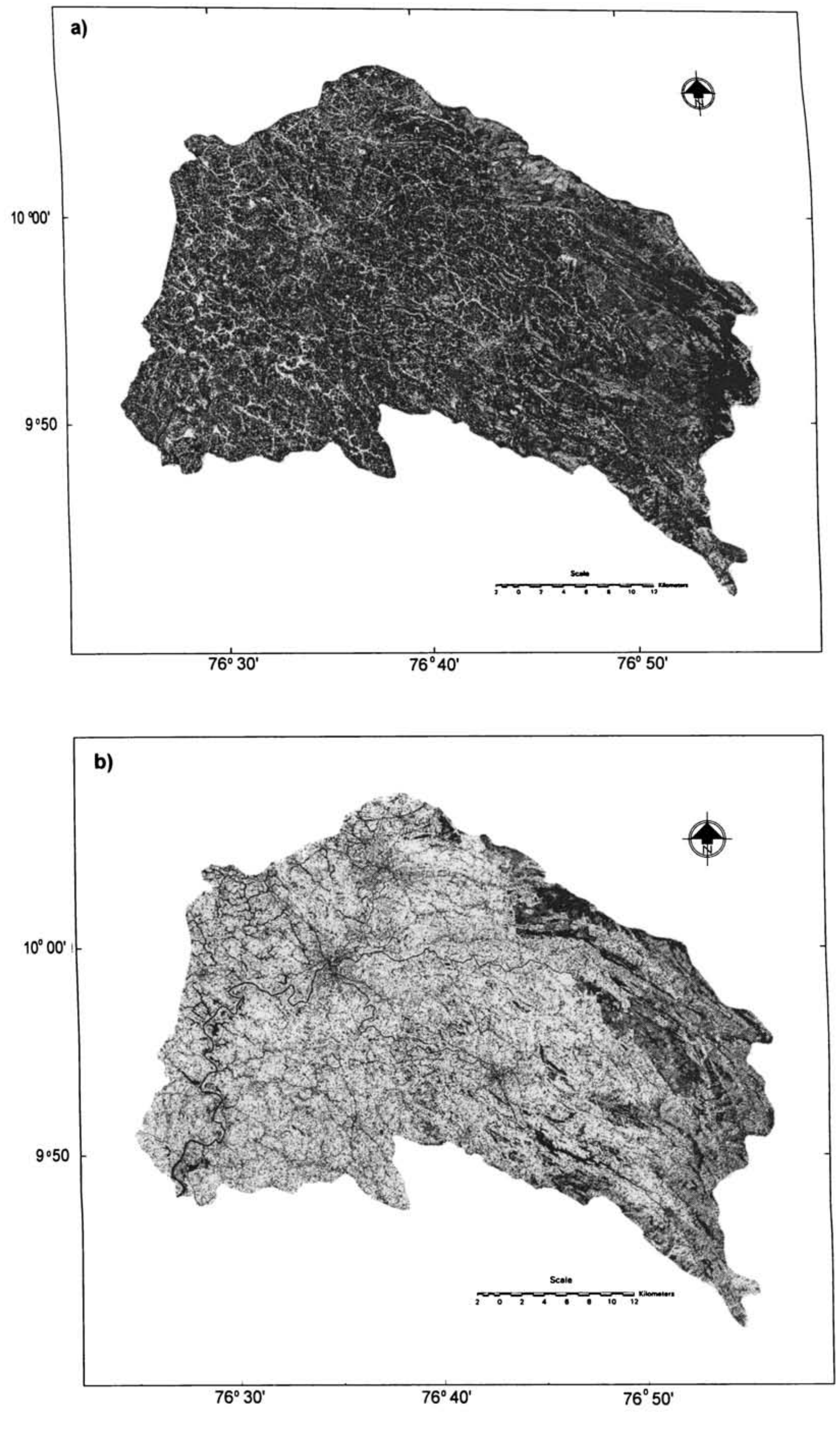


Fig. 6.2 Comparison of (a) band 2 (red) and (b) band 3 (NIR) of IRS- ID, LISS III

the basin is divided into 93 sub watersheds based on the watershed atlas of the Kerala, 1995 (Fig. 6.3).

6.3.1a Hydrogeomorphology

The landforms representing the erosional processes are mainly denudational hills, residual mounts, residual hills etc, whereas depositional landforms are pediments and valley fills. Linear ridges and structural hills are the other landforms identified. The size, shape, pattern and spatial network of various landforms that are interpreted from IRS IC, LISS III satellite imagery and various landforms formed due to geomorphic and structural processes are presented in Fig. 6.4. The nine hydrogeomorphological units identified in the basin in the ascending order of their groundwater potential are: water bodies, valley fills, lower plateau moderately dissected, residual mounts, residual mount complex, linear ridges, residual hills, structural hills and pediments, their areal extent in Table 6.1.

Structural hills: These are prominently found in the southern, southeastern and northeastern parts of Thodupuzha sub basin, eastern parts of Kaliyar (Plate 6.1) and Kothamangalam sub basins (Fig. 6.4) where the major rock type is hornblende-biotite gneisses. Chances of occurrence of groundwater depend on the geological structures in this area, although a region with structural hills is normally considered as poor source of groundwater. In this study area the structural hills are characterized by various lineament intersections. Therefore, these areas are suitable for extraction of groundwater through deep bore wells.

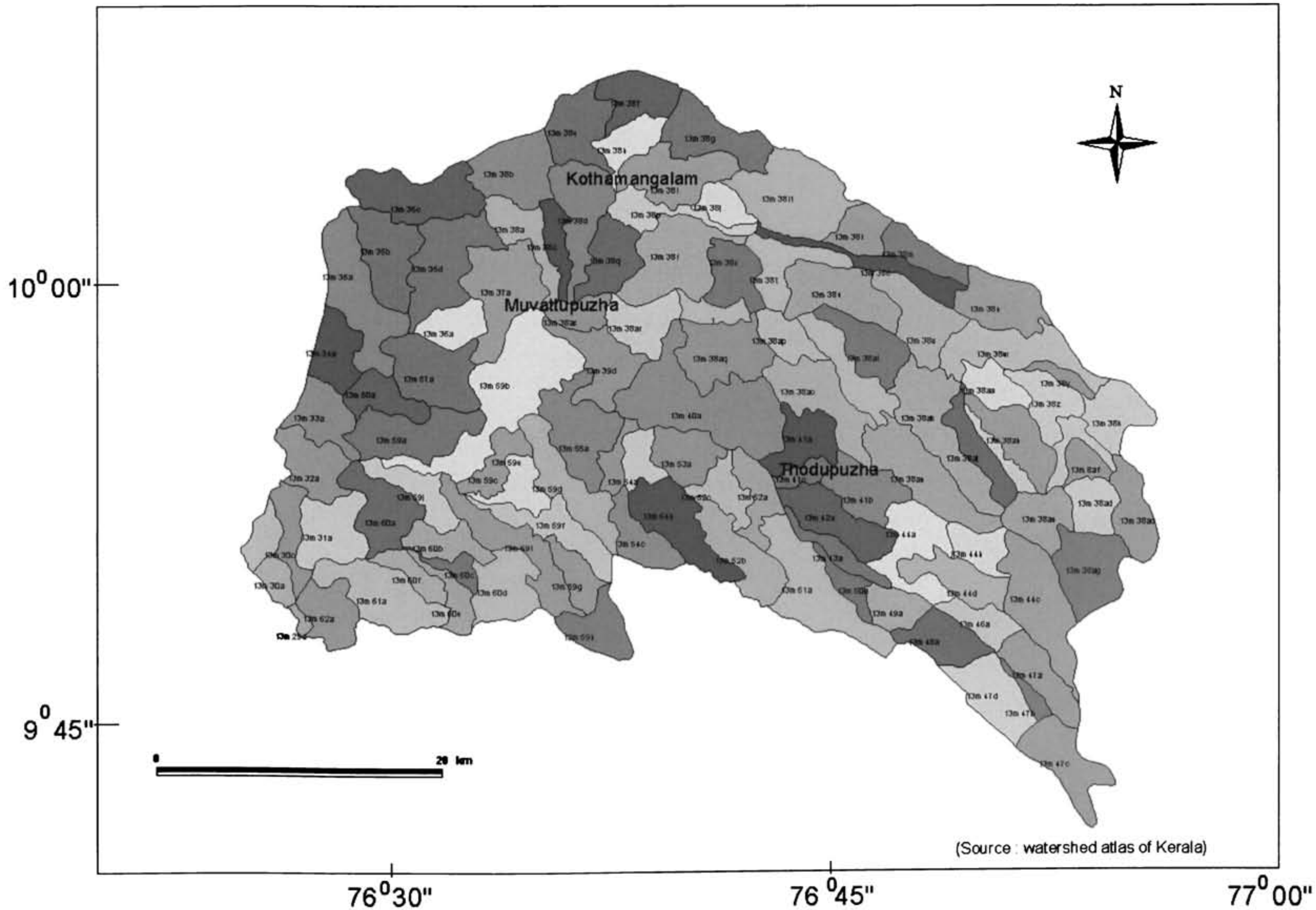


Fig. 6.3 Subwatersheds of the Muvattupuzha river basin

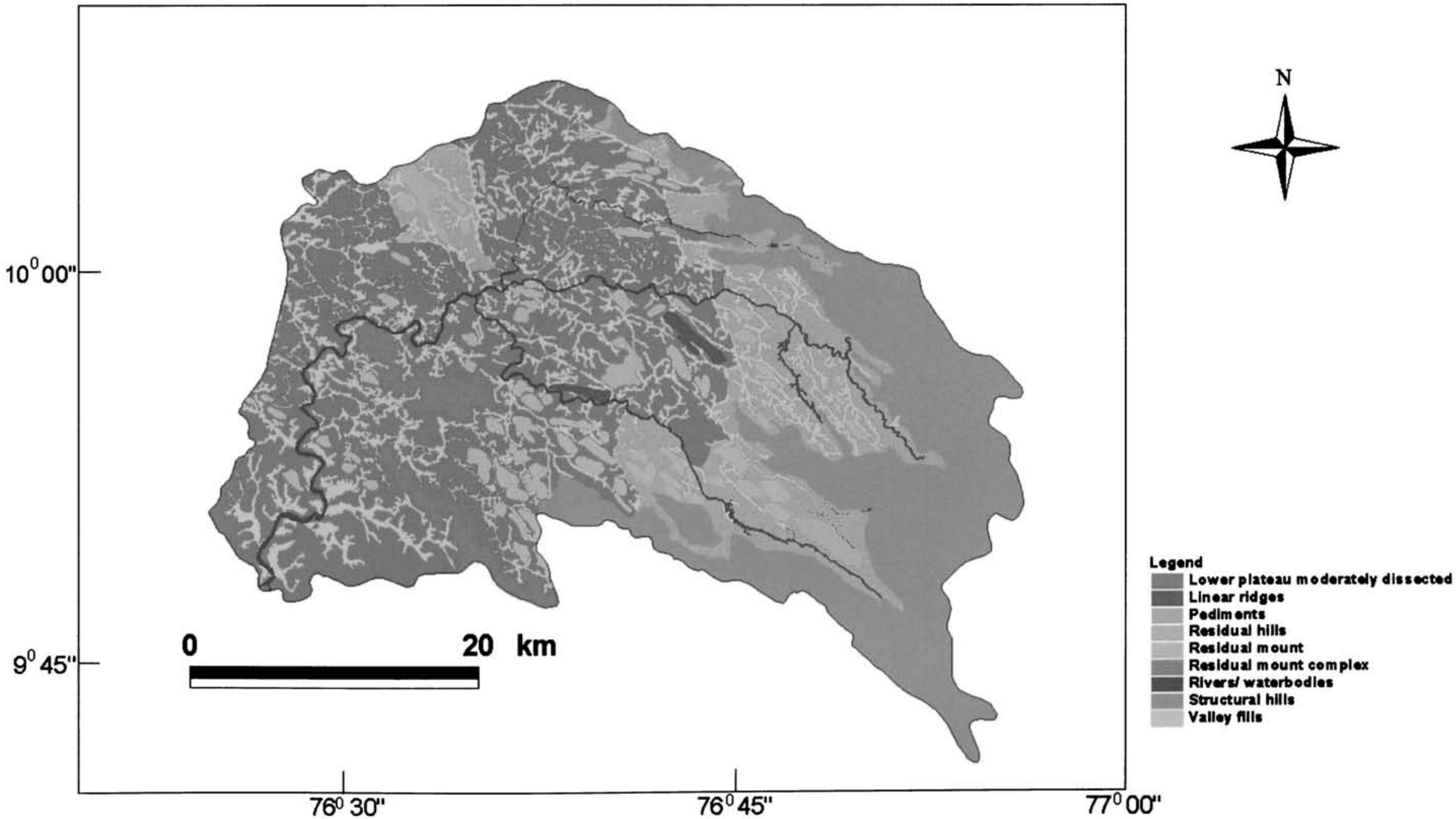


Fig. 6.4 Hydrogeomorphological map of the study area

Plate 6.1 The structural hills seen in the eastern part of the Kaliyar sub basin.

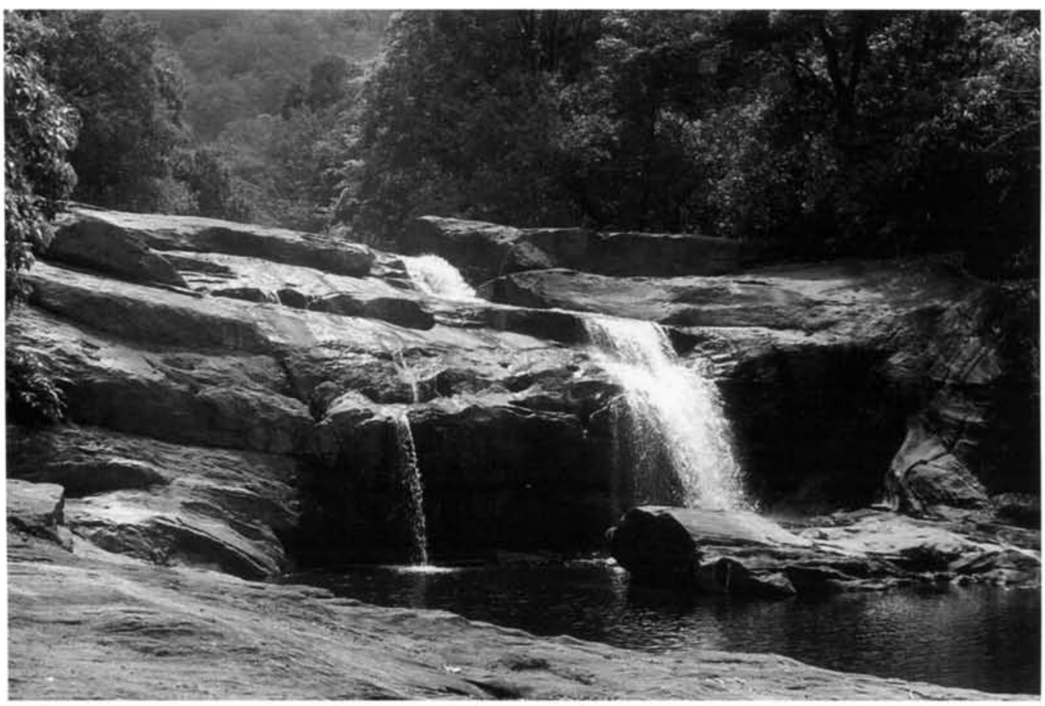


Plate 6.2 Thommankuttu waterfalls along a fault zone in the Kaliyar sub basin.

Table 6.1 Classification of groundwater potentials of the Muvattupuzha river basin based on geomorphic units and their areal extent.

Geomorphic Units	Geomorphic prospects	Area in km^2
Structural hills	Poor	357.73
Linear ridges	Poor	6.15
Residual hills	Poor	18.49
Residual mounts	Poor	65.38
Residual mount complex	Poor	42.93
Moderately dissected lower plateaus	Moderate	572.96
Pediments	Moderate	215.70
Valley fills	Good	187.34
Water bodies	Good	21.48
Total area		**1488.15**

Residual hills: Wherever charnockites and hornblende-biotite gneisses are not intricately folded, they are subjected to the process of physical disintegration and as a result they stand out as residual hills. Major residual hills are seen as isolated on eastern and northern parts of the Thodupuzha sub basin and northern part of the Muvattupuzha sub basin (Fig. 6.4). These geomorphological features are considered as 'poor' in ground water resource. Subba Rao et al. (2001) while investigating groundwater potential zones using remote sensing techniques in and around Guntur, Andhra Pradesh, have also opined that residual hills are, not suitable for groundwater exploration because of their poor storage capacity.

Residual mounts, complex and linear ridges: Residual mounts are formed by the prolonged erosion and weathering of pre-existing surface features of the plateaus, plains and of even original complex tectonic mountain. Residual mounts are scattered all over basin whereas residual mount complexes are found only in the southern and eastern part of the Muvattupuzha sub basin. Linear ridges are not abundant in the study area and only two ridges are found in the study area within Thodupuzha and Kaliyar sub basins (Fig. 6.4). Residual mounts, complex and linear ridges are considered as poor in groundwater prospecting.

Pediments: Pediments are formed where a thin veneer of soil overlie a hard rock terrain. Philip and Singhal (1991), while studying the importance of geomorphology for groundwater prospecting in hard rock terrain of Bihar Plateau through remote sensing, stated that dug wells located in shallow buried pediments have shallow water table as compared to those in deep buried pediments. The groundwater condition in pediments is expected to vary depending upon the type of underlying folded structures, fracture systems and degree of weathering. Groundwater prospecting in pediments can be considered as normal to poor (Sankar, 2002), but presence of any lineaments or fractures can provide some scope for movement of groundwater and hence the prospecting for groundwater exploration. In the present study area, pediments are widely distributed and their areal extent is 215.70 km^2. In this basin most of pediments are found in the eastern side of Thodupuzha and Kaliyar sub basins and to a smaller extent in the northern and northeastern parts of the Muvattupuzha and Kothamangalam sub basins respectively (Fig. 6.4). In this study pediments come under the category of moderate groundwater potential zone.

Lower plateau moderately dissected: This geomorphic landform is in a dissected nature and hence a moderate groundwater prospecting is expected. Due to dissected nature it accelerate more run off so it falls under the category of moderate potential zone. This has been noticed as a prominent geomorphological feature of the study area. A major portion of the Muvattupuzha sub basin and the western parts of the other three-sub basins are covered by this landform (Fig. 6.4).

Valley fills: These are seen as isolated patches, in the entire study area (Fig. 6.4). Valley fills result when streams dump their sediments suddenly due to obstruction and a reduction in their flow velocity. Since they have high moisture content, they are thickly vegetated and can be easily identified in the imagery by their tone and texture. Valley fills are considered as good potential zones for groundwater exploration (Auden, 1933; Kumar. and Srivatsava, 1991; Singh et al., 1993; Pal et al., 1997; Pratap et al., 1997). Sankar et al. (2001) have carried out hydrogeomorphological and remote sensing investigations in Agnigundala Mineralised belt, Andhra Pradesh and identified valley fills sediments over granites and granite gneiss. They have opined that valley fills are excellent (geological) areas for groundwater storage.

6.3.1b Lineaments and lineament density maps

Lineaments, being surface manifestations of structurally controlled linear or curvilinear features, are identified in the satellite imagery by their relatively straight tonal alignments. A lineament is defined as large-scale linear feature, which expresses itself in terms of topography of the underlying structural features. Lineaments can be joints, fractures, dyke systems, straight course of streams and vegetation patterns. In hard rock terrains, lineaments represent areas and zones of faulting and fracturing resulting in increased secondary porosity and permeability. They are good indicators for the accumulation and movement of groundwater. Lineaments provide the pathways for groundwater movement and are hydrogeologicaly very important (Sankar et al., 1996).

The lineaments are carefully identified and mapped from the IRS IC LISS II imagery (Fig. 6.5). More than 200 lineaments have been traced from the Muvattupuzha river basin. It is found that the length of lineaments varies from a few meters to kilometres. The general trend of the majority of the

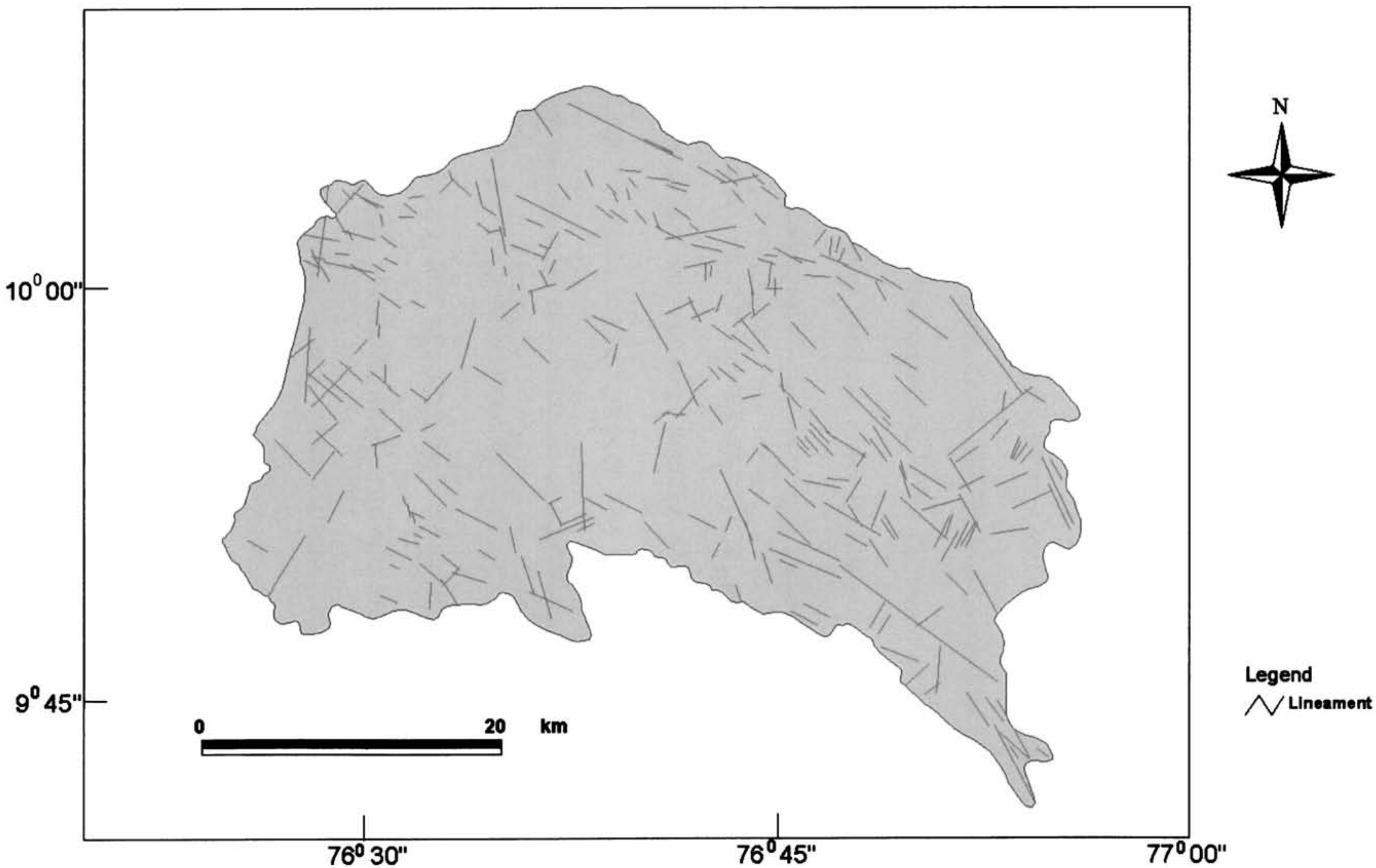


Fig. 6.5 Lineament map of the Muvattupuzha river basin

lineaments is NW-SE and WNW-ESE. Lineaments trending in NNE-SSW directions are found only in a few localities. The course of Muvattupuzha river is almost influenced by these lineaments. The major tributaries of the Muvattupuzha river, namely the Thodupuzha and Kothamangalam seem to be structurally controlled and flow along prominent lineaments. Thodupuzha lineament trending WNW-ESE is a major one whereas the Kothamangalam river course is influenced by a number of interconnected minor lineaments trending mostly in a NE-SW direction. In the eastern and southeastern part, the stream course is intersected by minor faults resulting in a cascade or waterfall. A major waterfall located at Thommankuttu in the upstream of Kaliyar river follows a major lineament, which trend in a WNW-ESE direction (Plate 6.2). It is evident from the foregoing results that structural patterns have a direct influence on the river course of the area than the topography. The numerous lineaments and lineament intersections identified in this basin are highly suitable for groundwater extraction through deep bore wells.

Lineament density map is a measure of quantitative length of linear feature expressed in a grid. Lineament density of an area can indirectly reveal the groundwater potential of that area since the presence of lineaments usually denotes a permeable zone. Areas with high lineament density are good for groundwater development (Haridas et al., 1994, Haridas et al, 1998). The basin is divided into 93 sub-watersheds and lineament density is calculated for each sub watersheds and is classified into three categories (Fig. 6.6). The highest lineament density (0.0012 – 2.068 m/m^2) is found in the eastern side of the

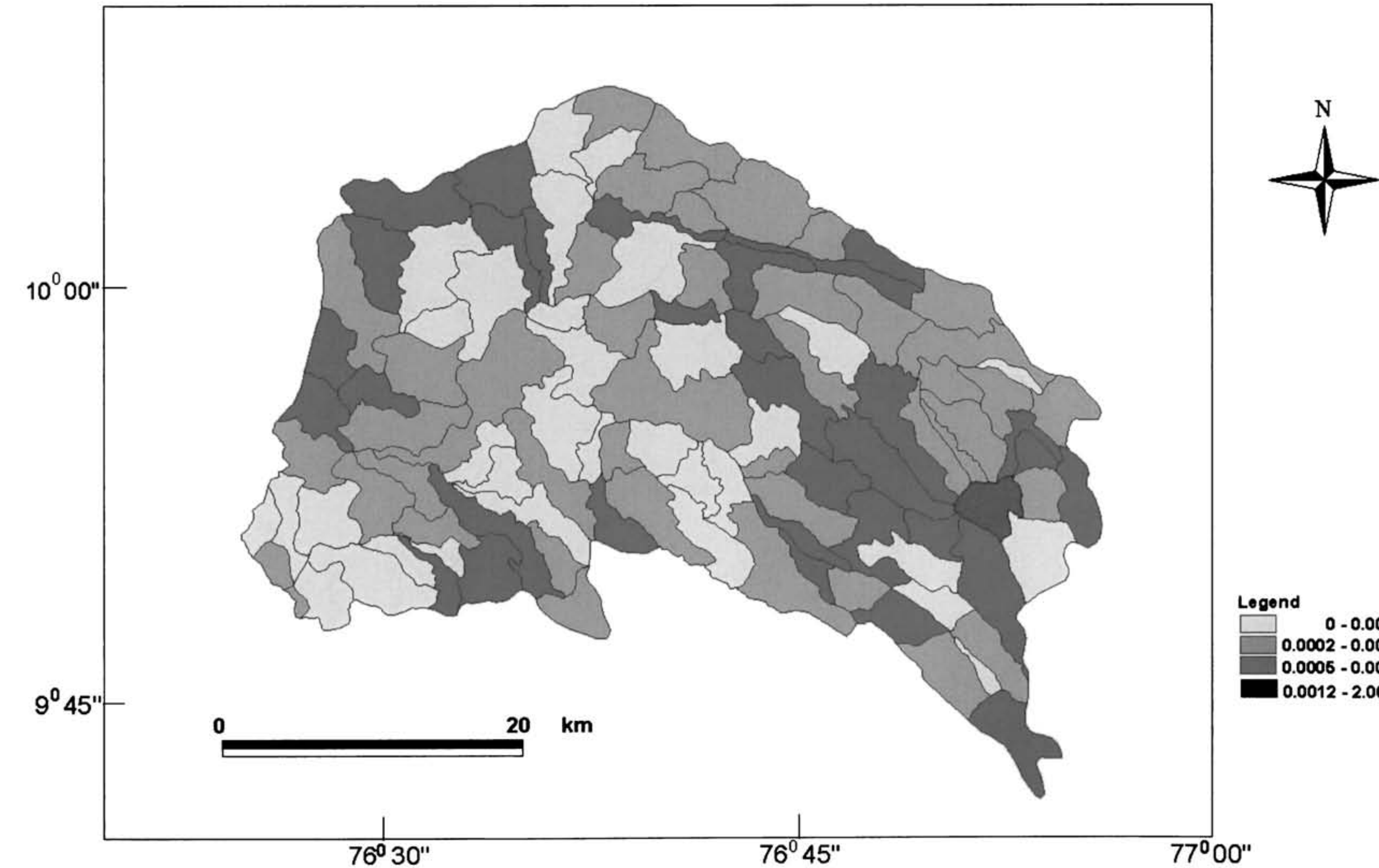


Fig. 6.6 Lineament density map of the study area

Kaliyar sub basin whereas the lowest (0.0 – 0.0002 m/m^2) is recorded as isolated patches in the entire basin.

6.3.1c Drainage density

In general the Muvattupuzha river basin exhibits a dendritic drainage pattern and particularly the Thodupuzha tributary shows a structural control. According to Strahler (1957) drainage density is an expression of the closeness of spacing of channels, thus providing quantitative measure of length of stream within a square grid of the area in terms of km/km^2. For the present work the basin is divided into 93 sub-watersheds and density is calculated for each sub watersheds in terms of m/m^2 (Fig. 6.7). Areas having high density are not suitable for groundwater development because of the grater surface run off. Most of the eastern part of Kothamangalam, Thodupuzha and Kaliyar sub basins (extreme upstream) show a high drainage density varying from 0.003 - 4.988 m/m^2. In the southern and northeastern parts of the Muvattupuzha basin, the drainage density ranges from 0.001- 0.003 m/m^2. The low drainage density (0.0- 0.001 m/m^2) covers a vast majority of the Muvattupuzha basin mostly towards the west.

6.3.1d Slope analysis and Digital Elevation Model (DEM)

Using the Survey Of India (SOI) toposheet a contour map (Fig. 6.8) has been prepared from which a slope map is generated for the area with the help of Arc/Info (GIS software). Accordingly, the entire Muvattupuzha basin is classified into four-categories based on the percentage of slope (Fig. 6.9). The figure indicated that there is general increase in the slope percentage towards

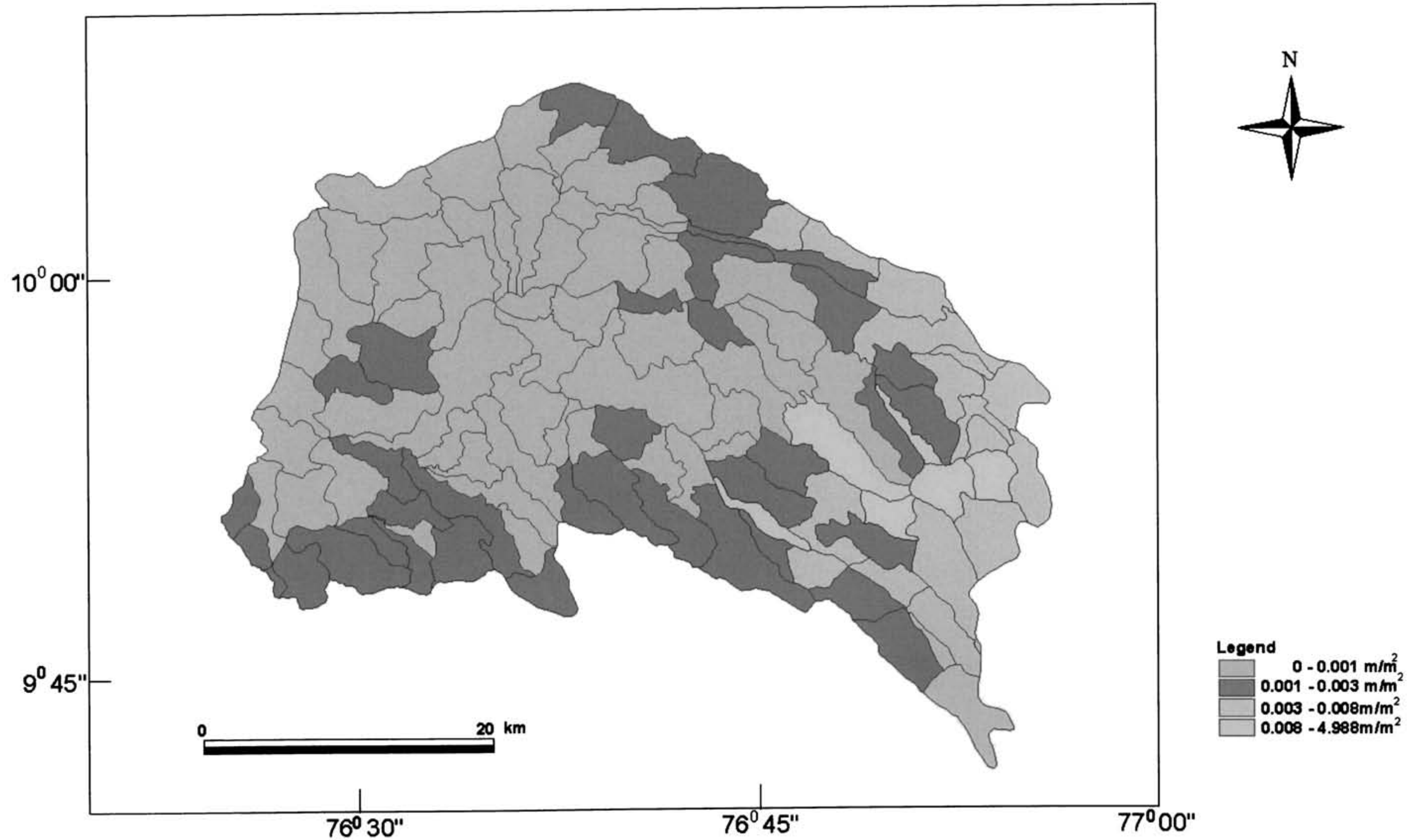


Fig. 6.7 Drainage density map of the study area

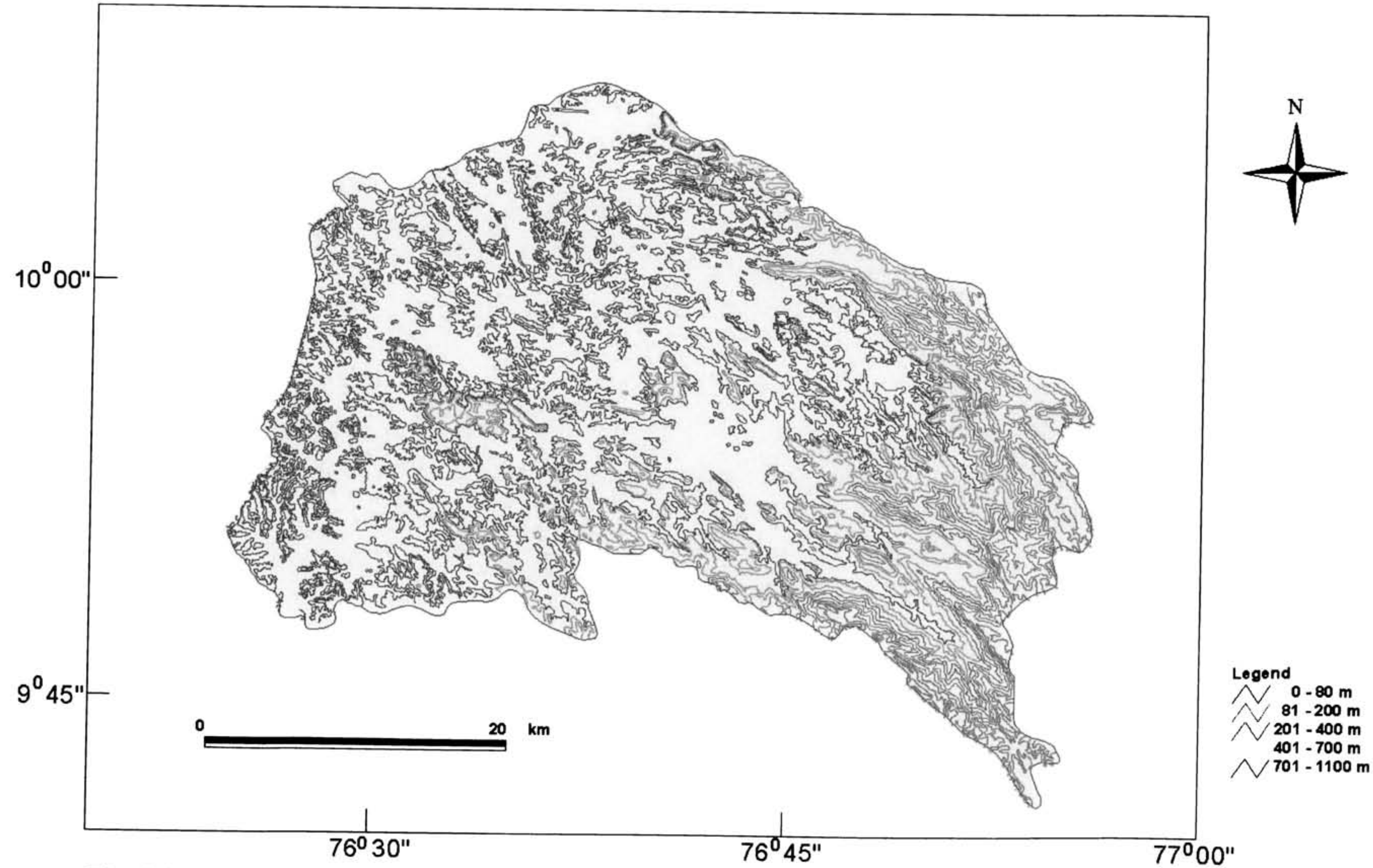


Fig. 6.8 Contour map of the study area

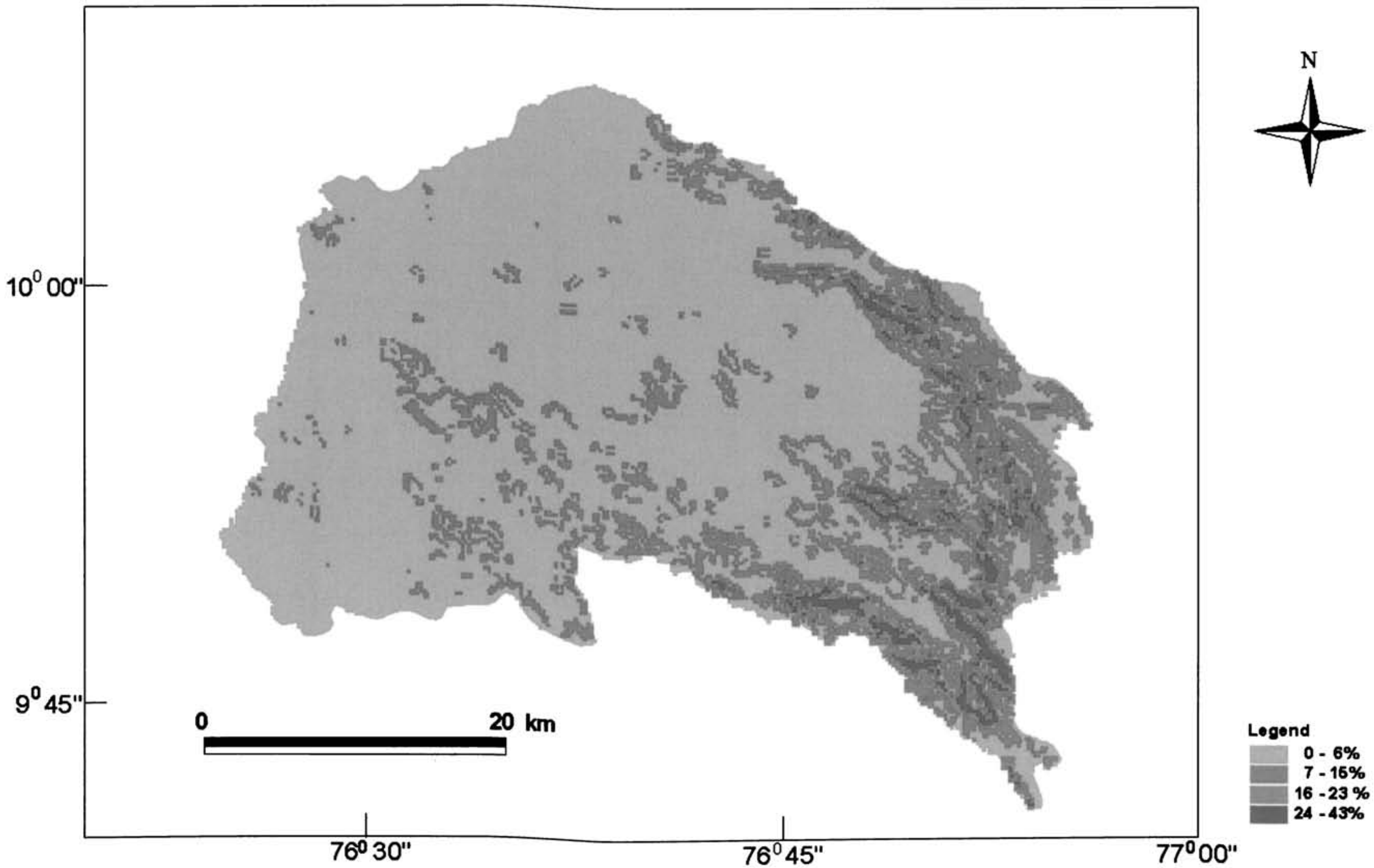


Fig. 6.9 Slope map of the study area

the eastern side of the basin. In the preparation of groundwater prospecting map least weightage is given to steep dip whereas more weightage is given to gentle slope as slope plays a significant role in infiltration verses runoff. Sarkar et al. (2001) have evaluated groundwater potentiality of Shamri micro watershed in Himachal Pradesh using remote sensing and Geographic Information System and found that lineaments and slope play a key role in the groundwater occurrence. As infiltration is inversely related to slope, a break in the slope (i.e. steep slope is followed by gentler slope) promote for an appreciable groundwater infiltration.

Using Surfer-7, a 3-D model (Digital Elevation Modelling) has been prepared from contour map. Thus a Digital Elevation Modelling (DEM) has been evolved by regular array of Z values (contour values) referenced to a common datum, which represents terrain relief. DEM created for the study area is given in (Fig. 6.10). This helps for appreciating the terrain and a supporting factor for the slope analysis.

6.3.1e Iso- apparent resistivity analysis:

Iso- apparent resistivity (Chapter 4) has been incorporated as one of the factors in the evaluation of groundwater potential zones.

6.3.1f Landuse classification

The landuse of the study area has been delineated using satellite imagery (IRS-ID, LISS III, 1999) by unsupervised classification of digital data, whereas detailed landuse maps are prepared by visual interpretation of (geocoded hard copy) IRS IC, LISS III.

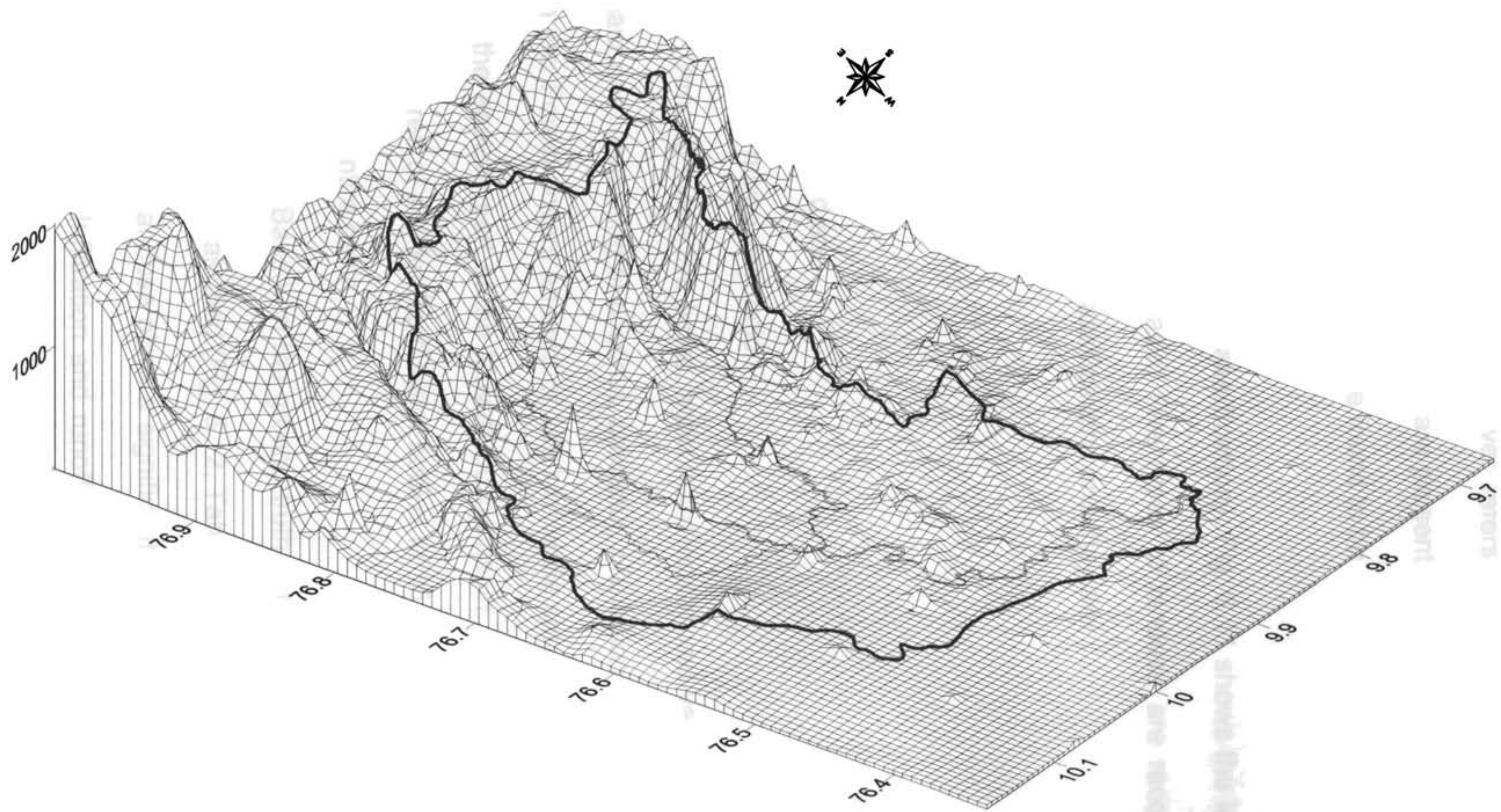


Fig. 6.10 Digital Elevation Model (DEM) of the study area

Landuse describes how a parcel of land is used for agriculture, settlements or industry, whereas landcover refers to the material such as vegetation, rocks or water bodies, which are present on the surface (Anderson et al., 1976). While both these terms are found to be used interchangeably, the term landuse is more commonly used.

Digital analysis (Unsupervised Classification): Fig. 6.11 shows the landuse pattern of Muvattupuzha river basin. Five types of landuse are recognised according to the unsupervised classifications and they are:

a) water body

b) forest

c) shrub land

d) built up / exposed land and

c) agricultural *land / mixed vegetation*

Among these five types, agricultural land/mixed vegetation is the predominant one, consisting of coconut, arecanut, plantation crops and rubber plantation etc. Forest covers an area of 119 km^2 while shrub land of 82 km^2 is noticed on the eastern part of the Muvattupuzha basin. The built up/exposed land having an area of 439 km^2 and water bodies of 15 km^2 is seen as isolated patches with in the entire basin.

Visual interpretation: Based on the ground truth verification, the landuse of the study area has been classified (Fig. 6.12, Table 6.2) into twenty categories with their areal extent. Landuse plays a significant role in the development of groundwater resources. Infiltration and runoff are controlled by the nature of

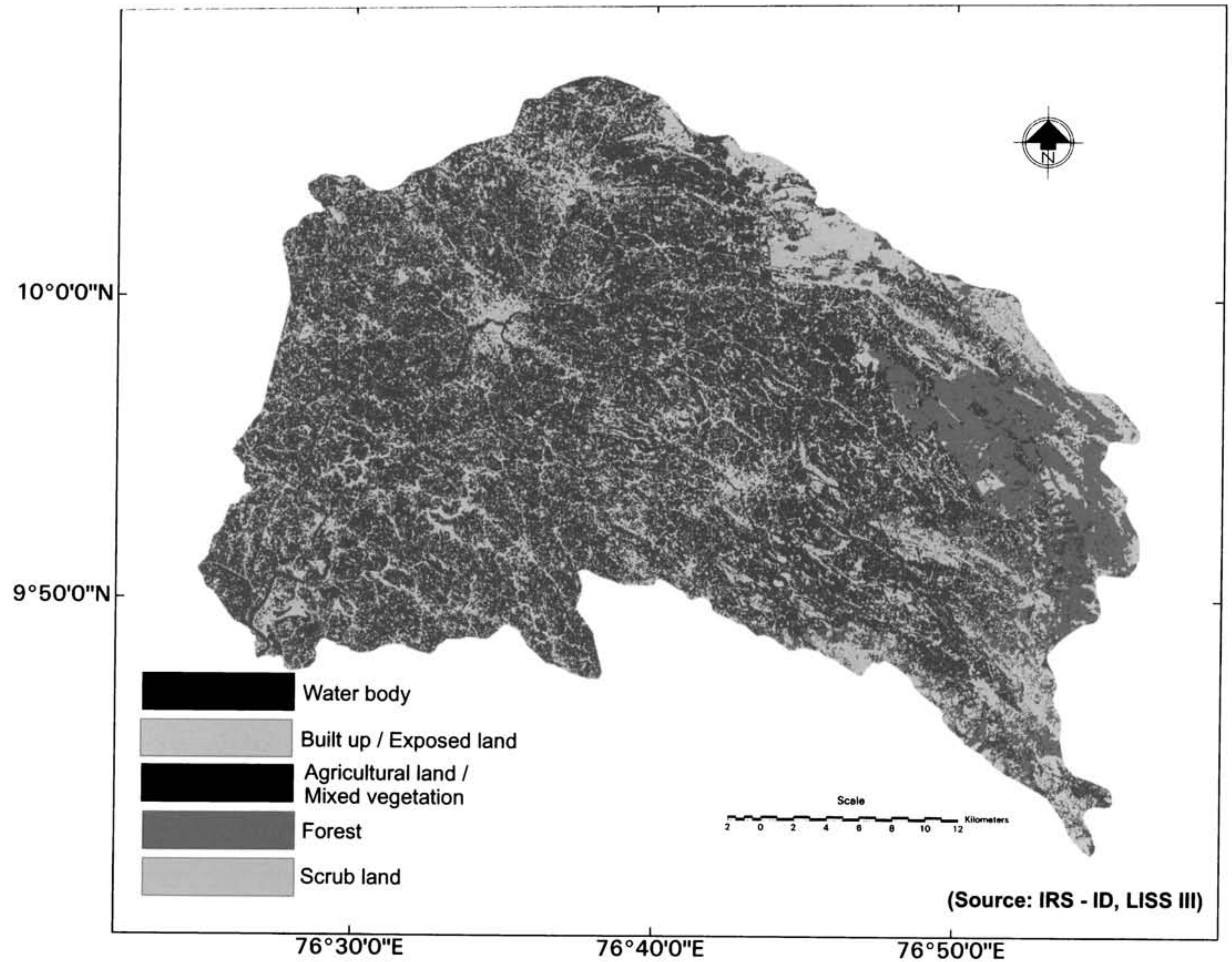


Fig. 6.11 Landuse pattern of the Muvattupuzha river basin (Unsupervised classification)

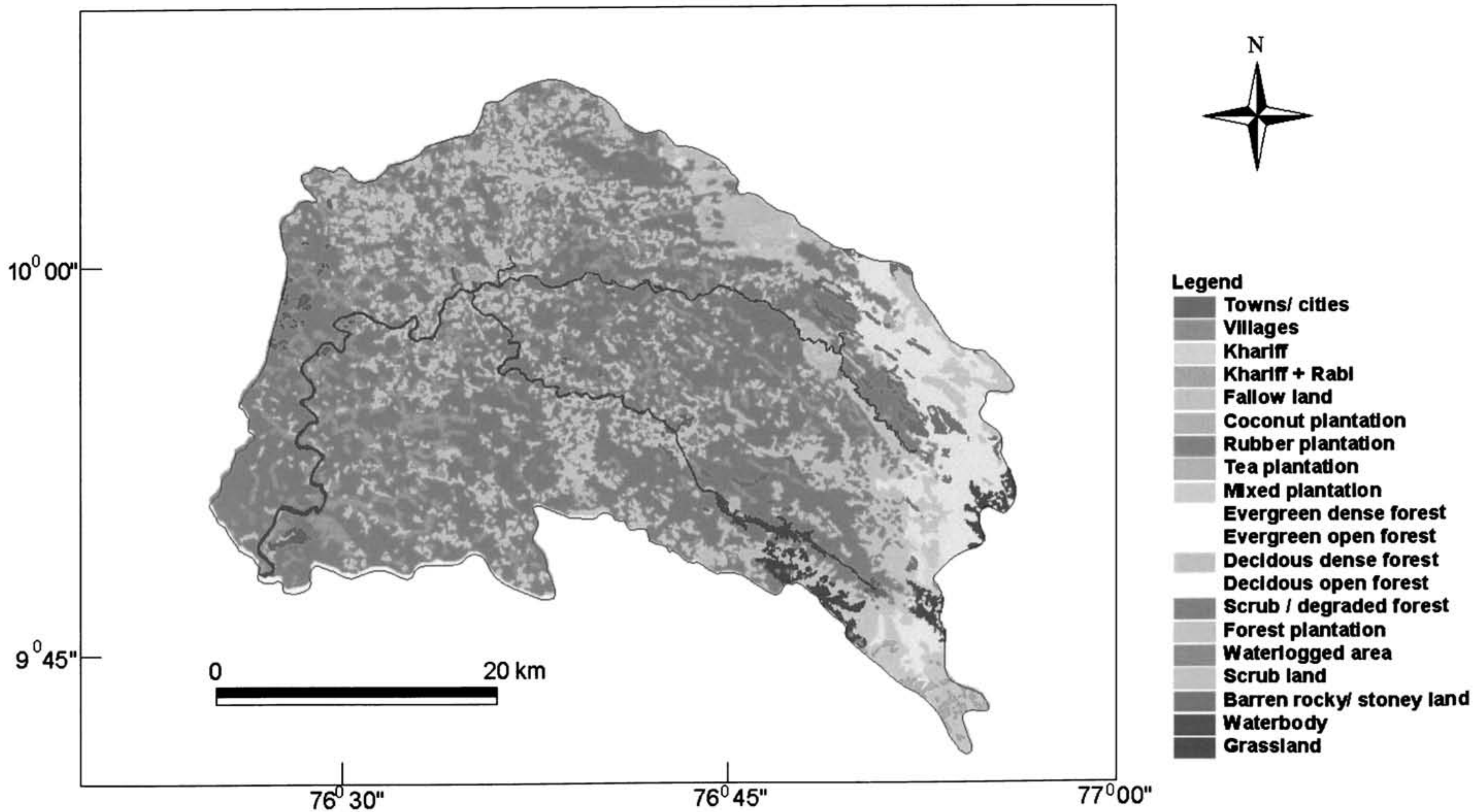


Fig. 6.12 Landuse classification of the Muvattupuzha river basin (visual interpretation)

Table 6.2 Spatial distribution of various landuse/ landcover with their areal extent of the study area (using IRS IC, LISS III)

S. No	Landuse type	Area in km^2
1	Towns/cities	6.34
2	Villages	0.16
3	Khariff	0.36
4	Khariff + Rabi	103.07
5	Fallows	4.96
6	Coconut Plantations	4.48
7	Rubber Plantations	843.04
8	Tea Plantations	5.42
9	Mixed Plantations	272.32
10	Evergreen Dense Forests	110.07
11	Evergreen Open Forests	0.54
12	Deciduous Dense Forests	40.26
13	Deciduous Open Forests	1.76
14	Scrub / Degraded Forests	0.34
15	Forest Plantation	2.61
16	Mangrove Forest	0.22
17	Land with scrub	41.90
18	Barren Rocky / Stony Waste	17.13
19	Reservoirs / Tanks	15.04
20	Grass Lands	18.38
	Total area	**1488.41**

surface materials and the landuse pattern. For instance the rate of infiltration is directly proportional to the crown density of forest cover i.e., if the surface is covered by dense forest, the infiltration will be more and the runoff will be less. Due to urbanisation, the rate of infiltration may decrease (Sarkar et al., 2001). In this study the landuse map is taken as one of the thematic layer for preparing groundwater potential zones. A major portion of the basin is characterised by rubber plantation; however, the eastern parts of the Kothamangalam, Kaliyar and Thodupuzha sub basins are having evergreen dense and open forests. All other landuse patterns are scattered over the entire basin. Pratap et al., (2000) have conducted groundwater prospect zoning in Dala-Renukoot area, Sonbhadra district, Uttar pardesh using remote sensing and GIS and given least ranking to the mining, settlement and industrial area while the highest one is given to river sand, river channel and water body.

Normalised Difference Vegetation Index (NDVI)

NDVI is determined to find out the health status of vegetation of the Muvattupuzha river basin. The typical range of NDVI is 0.1 to 0.6, with higher values associated with greater density and greenness of plant canopy (Lillisand and Kiefer, 1994). NDVI of the study area ranges from 0.1 to 0.7 and accordingly five classes are identified (Table 6.3). 'Poor' and 'moderate' vegetations of (0.1 to 0.4) are observed in isolated patches over the basin (Fig. 6.13) and are due to the mixed vegetation containing coconut, arecanut and plantation crops. The high NDVI (0.4 to 0.6) are observed more than 60% of the area indicating a good vegetation status. Thus it is evident that the

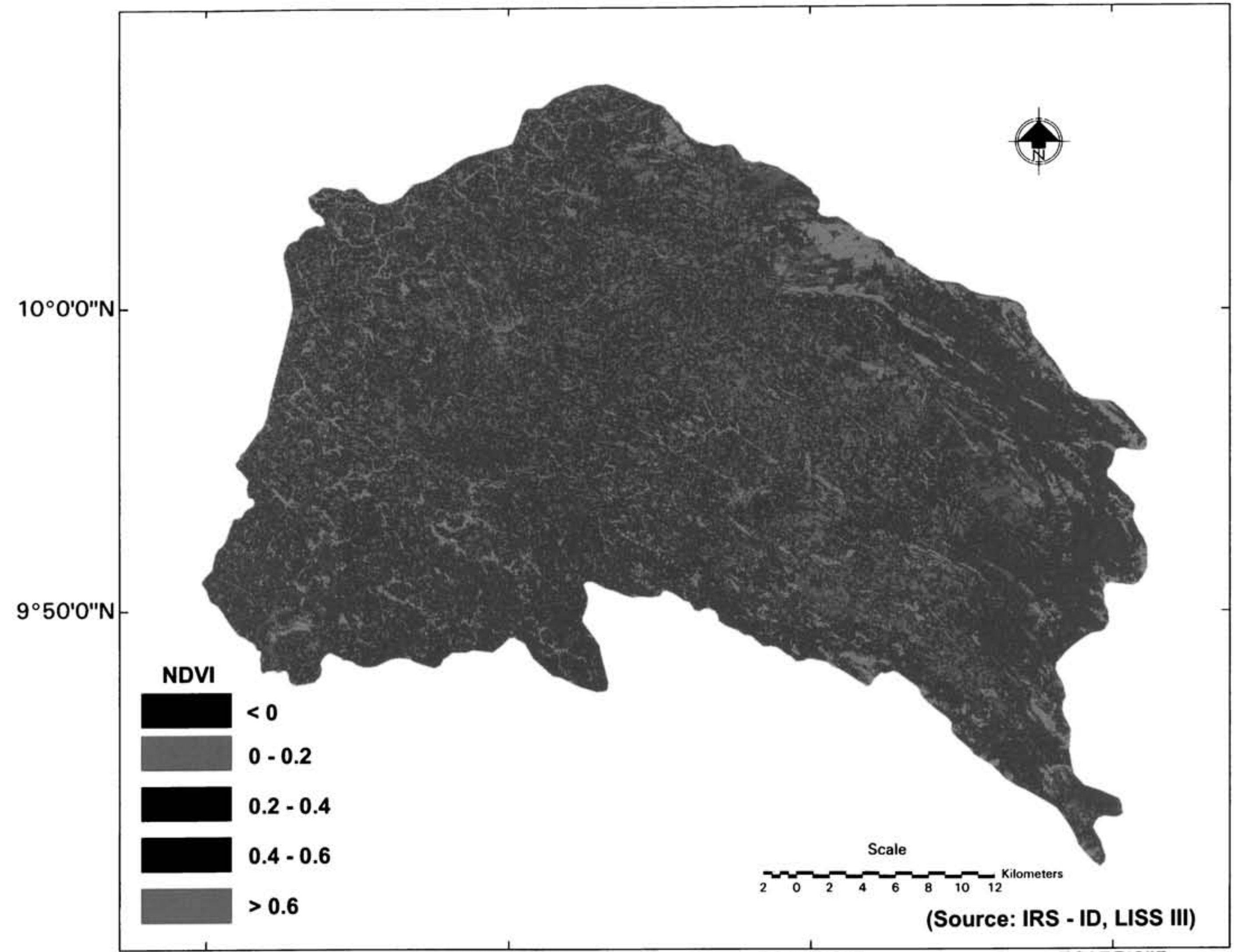


Fig. 6.13 Normalised Difference Vegetation Index for the Muvattupuzha river basin

southwestern part of the basin is having very good health status than southeastern part. 'Very good' vegetation is found in the southwestern side of the basin where water bodies typically show a negative index value.

Table 6.3 Classification of NDVI-index of the study area.

NDVI- Index	Health status
<0	No vegetated surface
0.1-0.2	Poor
0.2-0.4	Moderate
0.4-0.6	Good
>0.6	Very Good

6.3.2 Delineation of groundwater potential zones

The geology, nature of the terrain, geomorphology, drainage, lineament, iso-apparent resistivity, landuse etc. are taken into consideration in the delineation of groundwater potential zones. Different classes are assigned with suitable weightage, considering their importance with respect to the other classes and are given in Table 6.4. For each thematic layer, rank and score are given based on the criteria of movement and potentiality of groundwater. As an example, for geomorphology a maximum weightage of 50 is given and each class within geomorphology is assigned with a different or same rank and score (Table 6.4). To demarcate the different groundwater potential zones, all the thematic layers are integrated with one another according to their importance through GIS union concept. The sequences adopted in the present

Table 6.4 Weightage, rank and score assigned for different groundwater controlling parameters

(1) Geomorphology (wt. 50)		
Class	Rank	Score
Structural hill	1	50
Residual hill	1	50
Residual mount	1	50
Residual mount Complex	1	50
Linear ridge	1	50
Pediment	2	100
Lower plateau moderately dissected	2	100
Valley fills	3	150
Water bodies	4	200

(2) Slope (wt. 40)		
Class	Rank	Score
24 – 44 %	1	40
16 – 24 %	2	80
8 – 16 %	3	120
0 – 8 %	4	160

(3) Geology (wt. 30)		
Class	Rank	Score
Intrusives	1	30
Hornblende biotite gneiss	1	30
Archean charnockite	2	60
Pleistocene Laterite	3	90
Miocene formation	4	120

(4) Lineament density (m/m^2); (wt.30)		
Class	Rank	Score
0 - 0.0002	1	30
0.0002 - 0.0005	2	60
0.0005 - 0.0012	3	90
0.0012 - 2.0680	4	120

(5) Drainage density (m/m^2) ; (wt. 30)		
Class	Rank	Score
0.008 - 4.988	1	30
0.003 - 0.008	2	60
0.001 - 0.003	3	90
0 - 0.001	4	120

(6) Landuse (wt. 20)		
Class	Rank	Score
Town/cities	1	20
Villages	1	20
Barren rocky/stony waste	1	20
Grassland	1	20
Fallows	2	40
Coconut plantation	2	40
Rubber plantation	2	40
Tea plantation	2	40
Mixed plantation	2	40
Evergreen dense forest	2	40
Evergreen open forest	2	40
Deciduous dense forest	2	40
Deciduous open forest	2	40
Degraded forest	2	40
Forest plantation	2	40
Land with scrub	2	40
Kharif	3	60
Kharif + rabi	3	60
Waterlogged	4	80
Reservoirs /tank	4	80

(7) Iso - apparent resistivity (wt. 10)		
Class	Rank	Score
500 ohm-m	1	10
300-500 ohm-m	2	20
100-300 ohm- m	3	30
0-100 ohm- m	4	40

wt = weightage

exercise are as follows: (a) geomorphology, (b) slope, (c) geology, (d) lineament density, (e) drainage density, (f) landuse and (g) iso-apparent resistivity map. The groundwater potential zones are classified into (i) very good (ii) good, (iii) moderate and (iv) poor (Fig. 6.14, Table 6.5).

Table 6.5 Classification of Groundwater prospect zone and their areal extent.

Groundwater prospect zone	Area in km^2
Very good	608.55
Good	127.98
Moderate	504.18
Poor	247.42
Total area	1488.12

From Fig. 6.14 it is clear that the western part of the Muvattupuzha and Kothamangalam sub basins as well as central part of the Kaliyar sub basin are of very good groundwater prospect zone covering an area of 608.55 Some areas in the southern end of the Muvattupuzha sub basin and the central part of Kaliyar sub basin are of good groundwater prospecting with an areal coverage of just 127.98 km^2. Moderate prospect zones are found as small isolated pockets in all the sub basins. Most of the eastern periphery of the Muvattupuzha basin is having poor groundwater prospect. The poor prospect zone is having area of 247.42 km^2. A comparison of hydrogeomorphology map (Fig. 6.4) with that of groundwater prospect map (Fig. 6.14) indicates that most

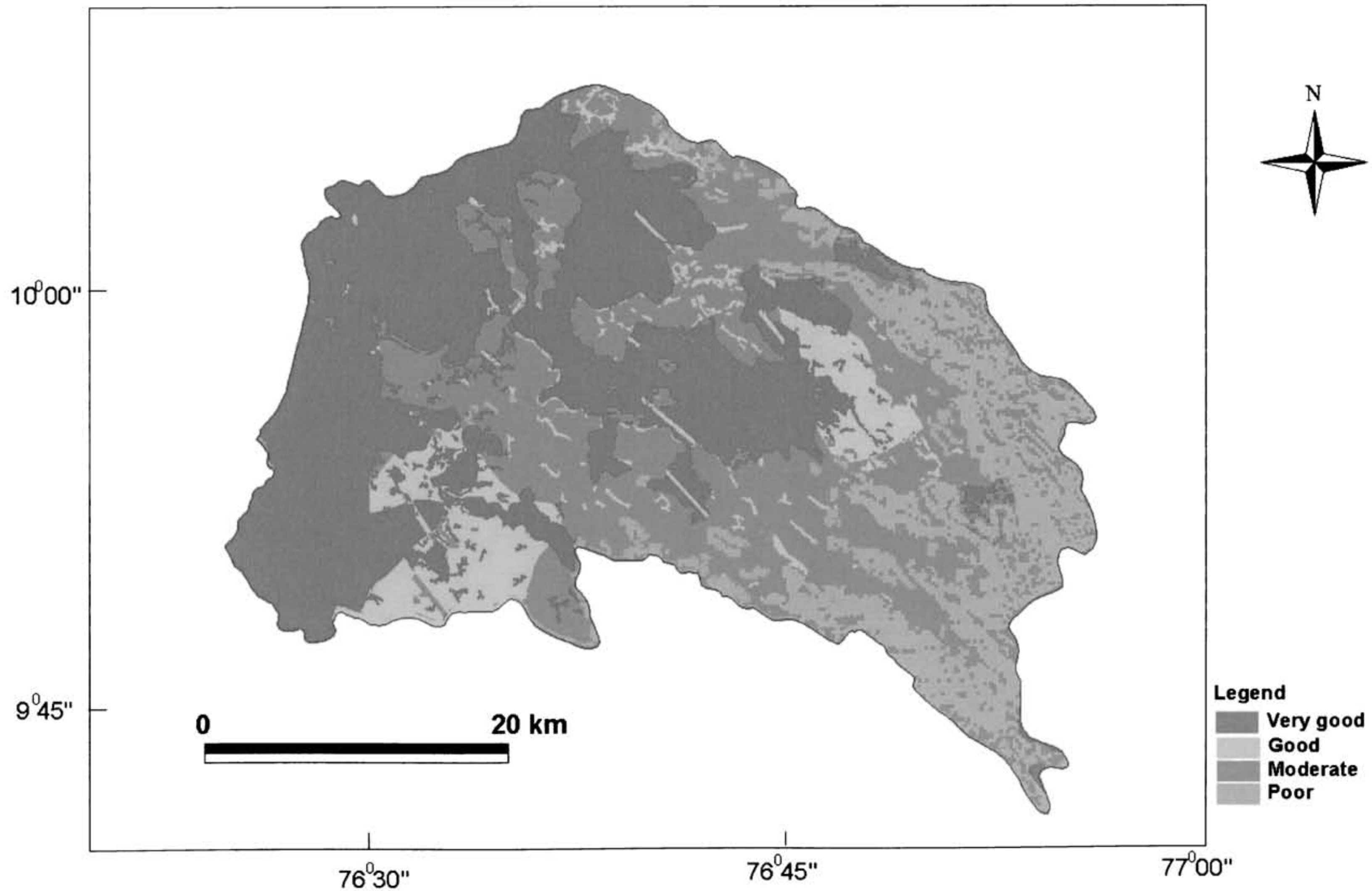


Fig. 6.14 Groundwater prospect map of the Muvattupuzha river basin

of the valley fills are of very good-good prospect zones whereas the structural hills are moderate- poor prospect zones. The eastern part of the Muvattupuzha basin with steep slope and high drainage density is categorised as poor to moderate prospect zone. The southwestern part of the Muvattupuzha sub basin is categorised as very good zone and is also matching well with high optimum yield and storage coefficient. The resistivity survey also substantiates the above. The central part of the Kaliyar basin with a good groundwater prospecting zone is also matched well with optimum yield.

6.3.3 Integration of spatial and non-spatial data

In GIS both spatial and non-spatial data can be integrated for information extraction. In the present study large volumes of non-spatial data have been generated by inputting hydrological, geophysical and hydogeochemical data. With the help of GIS it is possible to retrieve the information (hydrological, geophysical and hydrogeochemical) by selecting any locations (Figs. 6.15a, 15b, 15c, 15d & 15e) or all locations. This data will be helpful for the future planning and management of the Muvattupuzha river basin.

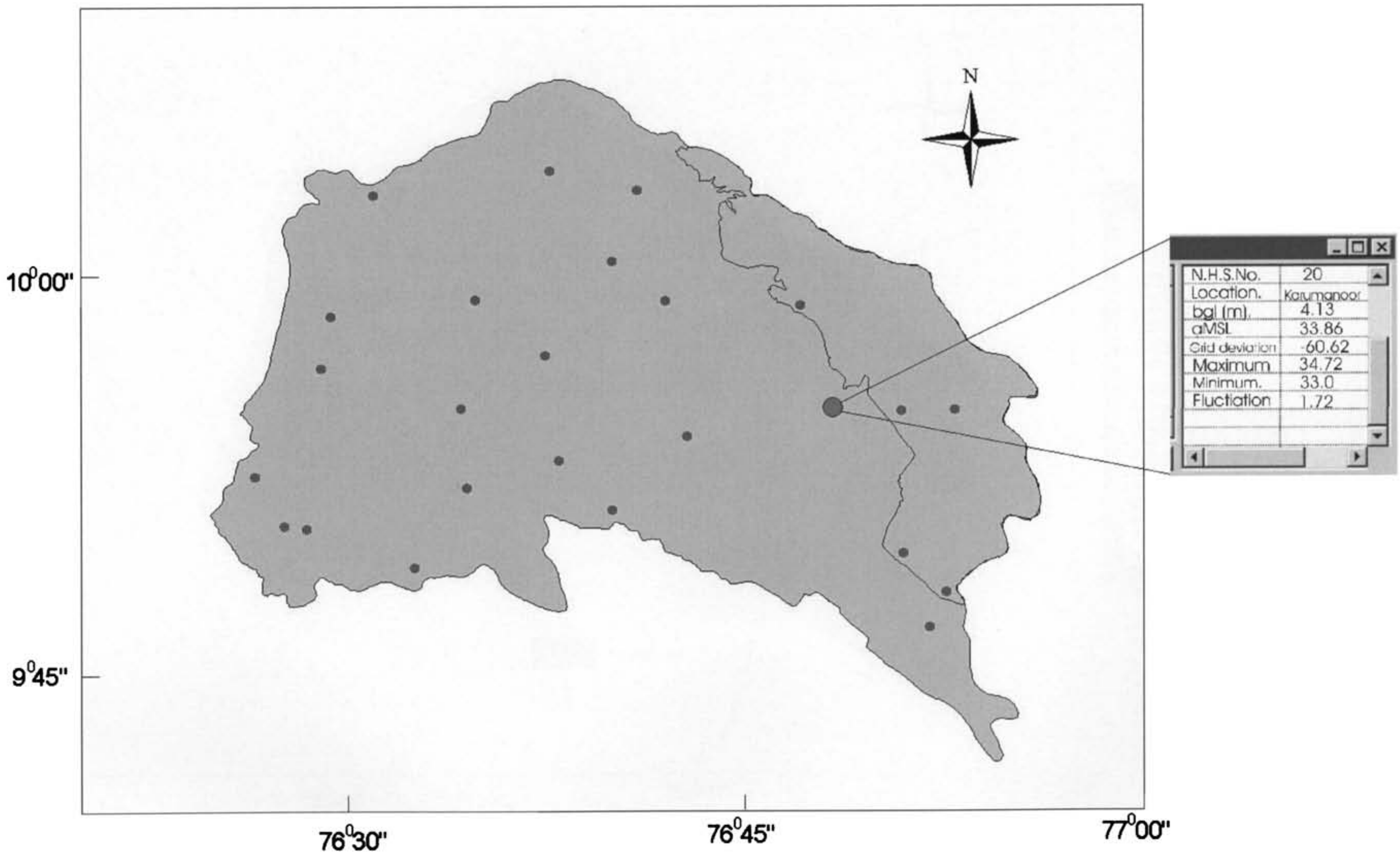


Fig. 6.15a Retrieval of water level data of the Muvattupuzha river basin - through GIS

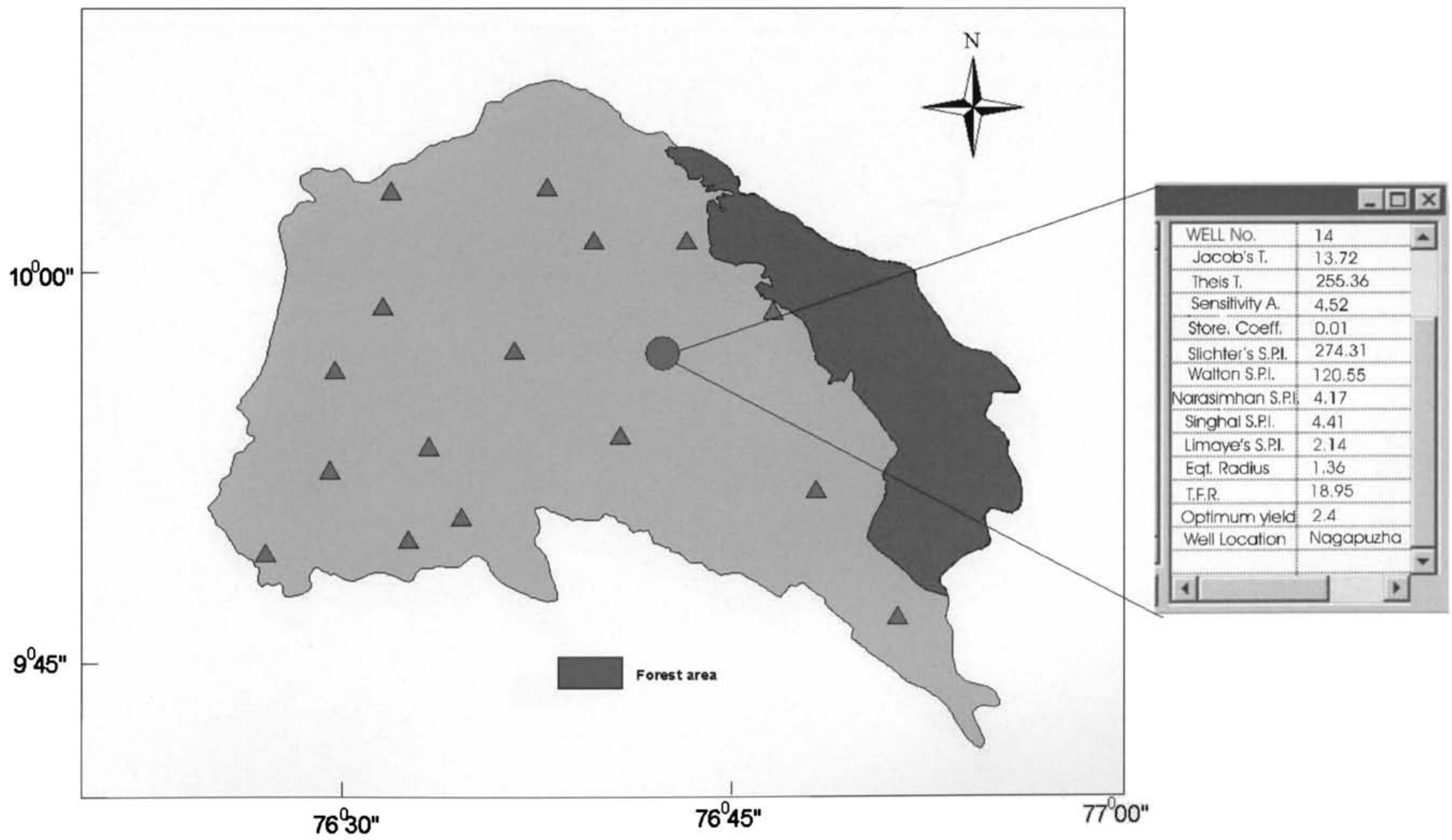


Fig. 6.15b Retrieval of pumptest data of the Muvattupuzha river basin - through GIS

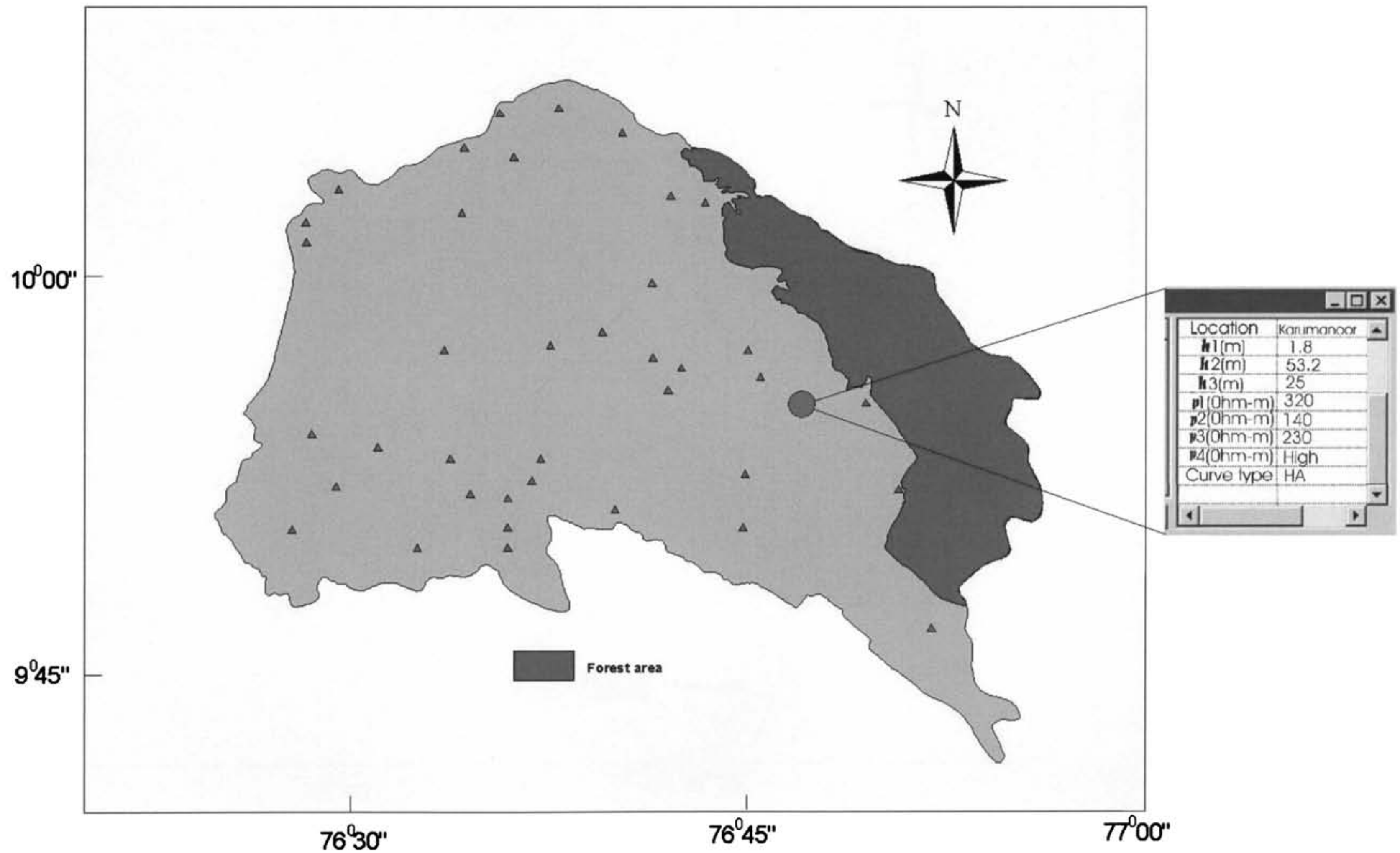


Fig. 6.15c Retrieval of analysed VES data of the Muvattupuzha river basin - through GIS

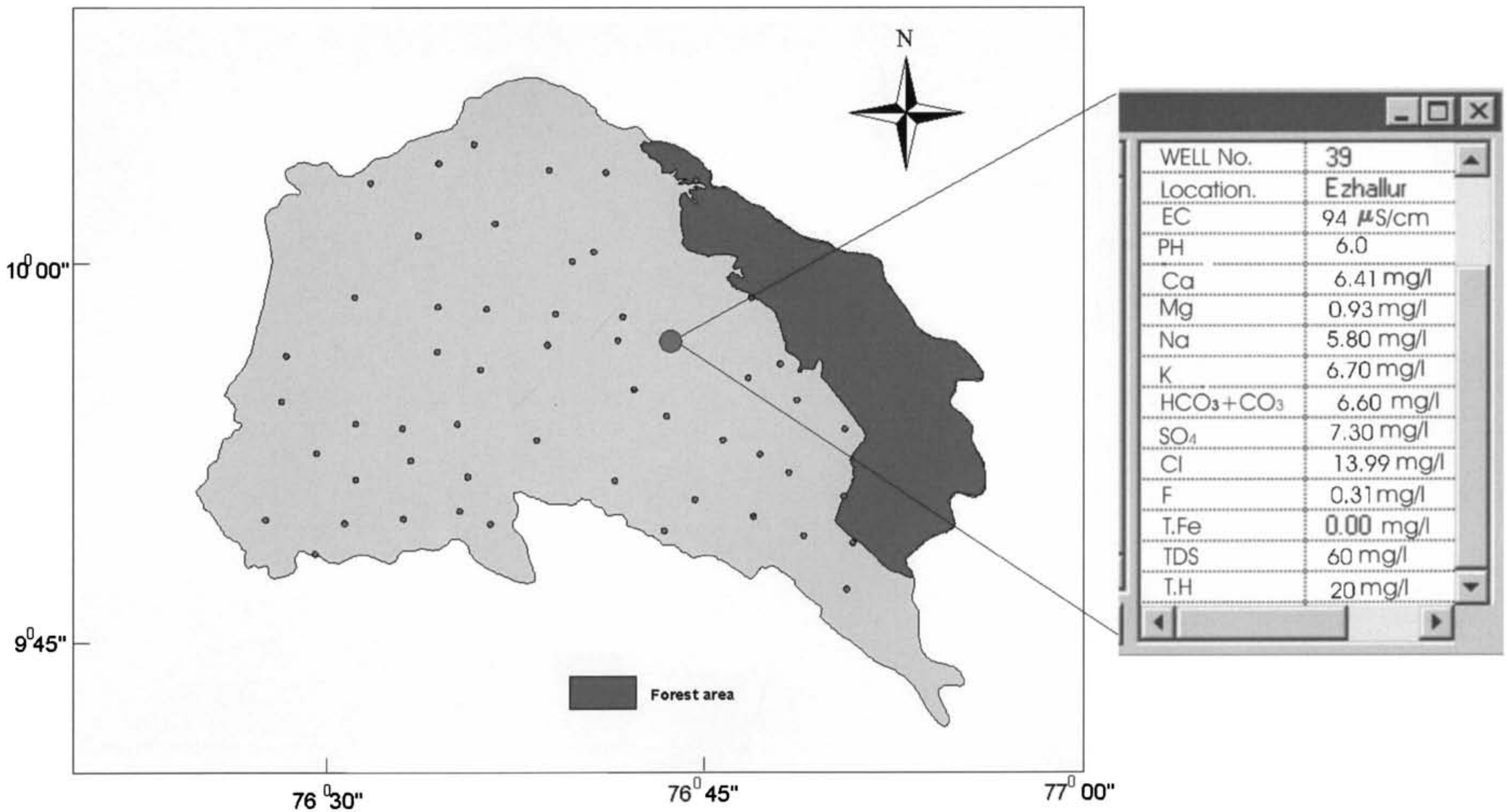


Fig. 6.15d Retrieval of various physical and chemical parameters of ground water during pre monsoon in the study area - through GIS

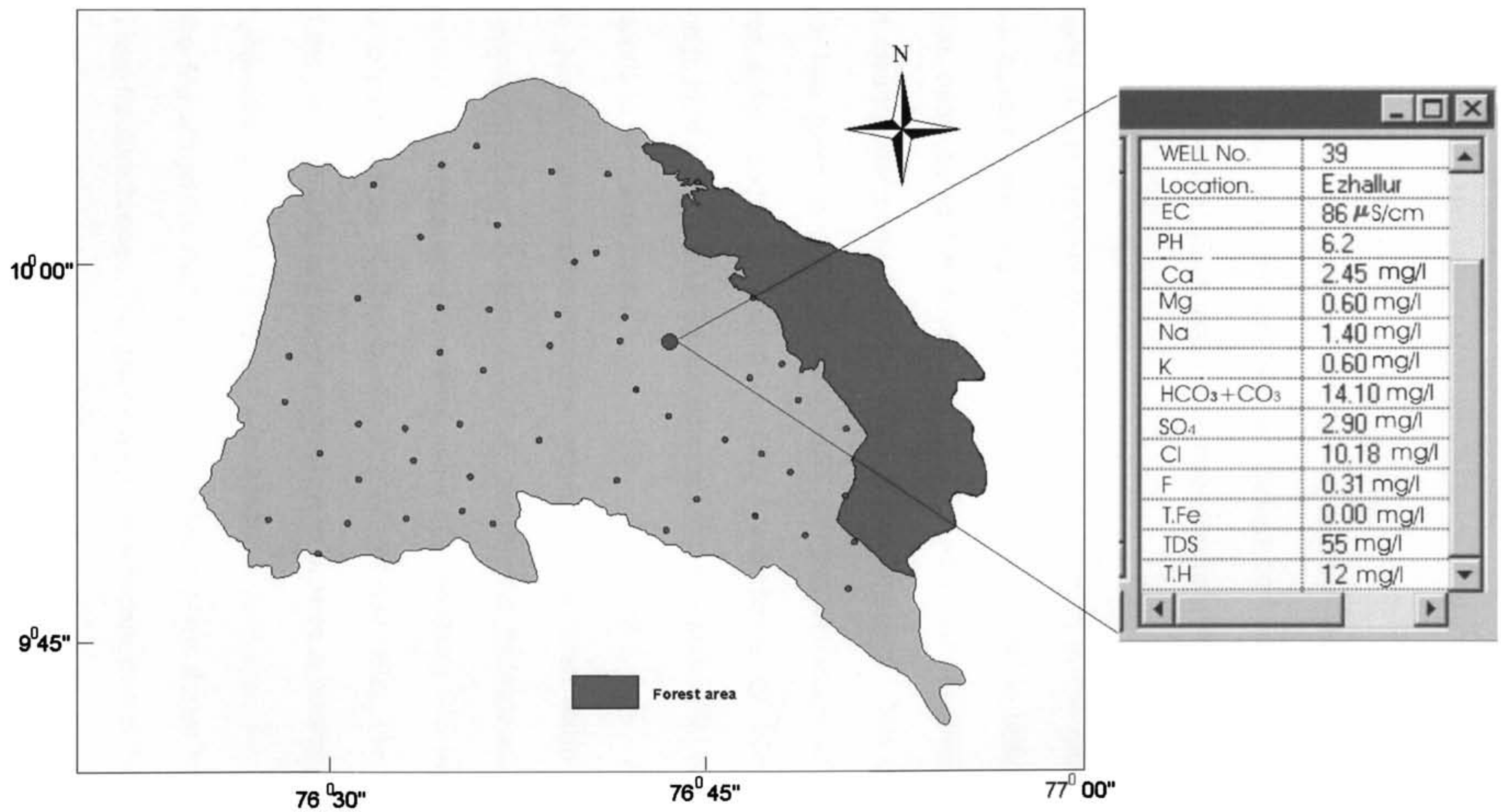


Fig. 6.15e Retrieval of various physical and chemical parameters of ground water during post monsoon in the study area - through GIS

CHAPTER 7

SUMMARY AND CONCLUSION

Water resources are dwindling very fast in recent years as the demand has been steadily increasing several folds on various accounts. The growing crisis on the availability of fresh water has been addressed in various fora throughout the world. Recently the water problem has been discussed simultaneously at two different international meetings held in the month of March 2003 in Japan and Italy. The major problem discussed in both these meetings has been about the severe shortage of adequate quantities and qualities of clean water particularly for drinking and sanitation. One of their suggestions has been to find out new ways for the extraction of more groundwater safely and environment friendly. Areas far away from river courses and in hard rock terrains, groundwater are the only source for drinking water that leads to over exploitation.

The present investigation on the Muvattupuzha river basin is an integrated approach based on hydrogeological, geophysical, hydrogeochemical parameters and the results are interpreted using satellite data. GIS has also been used to combine the various spatial and non-spatial data. The salient findings of the present study are accounted below to provide a holistic picture on the groundwaters of the Muvattupuzha river basin.

In the Muvattupuzha river basin the groundwaters are drawn from the weathered and fractured zones. The groundwater level fluctuations of the basin from 1992 to 2001 reveal that the water level varies between a minimum of 0.003 m and a maximum of 3.45 m. The above water level fluctuations are almost a constant all over the years when compared to the adjoining Periyar river basin. Based on the water level data the basin is divided into a negative zone or discharge area (western part of the basin), which covers more than 70% of the study area, and a positive zone or recharge area covering the rest of the area mainly on the eastern part of the basin. The average annual rainfall of the basin is 2677 mm. The groundwater level fluctuation and rainfall show good relation, which means that the groundwater fluctuation is affected by rainfall.

Various aquifer parameters like transmissivity, storage coefficient, optimum yield, time for full recovery and specific capacity indices are analysed. The transmissivity values obtained from sensitivity analysis vary from $4.51 m^2/$ day to $225.63 m^2/$ day with an average of $68.81 m^2/$ day. Transmissivity shows a general increase towards the southwestern part of the basin. Storage coefficient obtained from sensitivity analysis ranges from 0.012 to 0.393 with an average of 0.241. The high storativity on the southwestern part of the Muvattupuzha sub basin is related to the occurrence of Miocene formation and presence of large number of irrigation canals. In this basin the optimum yield varies from $0.9 m^3/$ day to $50.1 m^3/$ day with an average value of $14.29 m^3/$ day. Relatively high values are observed in the southwestern and north central parts of the basin. These areas are suitable for well development.

The analysis on the time required for full recovery indicates that the maximum value of 68.55 h is recorded in the western part of the Kothamangalam sub basin at Kozhipalli while the minimum of 2.7 h in the southern part of the Thodupuzha sub basin at Kolani. Based on this it is found that an increase in the radius of wells in crystalline terrain will reduce the time for recuperation. The highest Slichter's capacity indices are recorded in the central and the northern parts of the Thodupuzha sub basin and the southwestern part of the Muvattupuzha sub basin. Based on the Slichter's specific capacity indices it is found that the specific capacity indices of dug well are controlled by the equatorial radius rather than the lithology of the basin.

Based on the VES analysis the general sequence of high resistivity is in the first layer consisting of dry lateritic soil followed by low resistivity layer (fractured and or weathered saturated zone) and again high resistivity layer (massive rock). Most of the sounding curves obtained in the basin are H type and different combinations of H type. Also resistivity contour map of the second layer of the basin depicts hydrogeoloical condition of phreatic aquifer; a resistivity value of below 500 ohm -m is considered as good prospective zone for ground water.

The depth to the bedrock of the basin varies widely from 1.5 to 17 mbgl. A ground water prospective map for phreatic aquifer has been prepared based on thickness of the weathered zone and low resistivity values (<500 ohm-m) and accordingly the basin is classified into three phreatic potential zones as good, moderate and poor. The southern part of the Muvattupuzha sub basin and few pockets in the Kaliyar sub basin are identified as good prospects zone though limited in areal extent. Certain promising stations have been identified from vertical electrical sounding analysis (st. 2, 7-9, 11, 12, 15, 16, 18, 19, 24, 29, 30- 32, 35-37 and 40) for drilling medium to deep bore wells that can be made up to third or fourth layers in view of moderate resistivities ($\cong$ 200 ohm-m)

The groundwater of the Muvattupuzha river basin is acidic in nature as the pH value ranges from 5.5 to 8.1. A major part of the study area during pre and post monsoon seasons show pH values less than 6.5, which is below the values prescribed by WHO and ISI. The groundwater of the basin is having low electrical conductivity (av. pre monsoon - 97.9 μS/cm and post monsoon - 69.2 μS/cm), low total dissolved solids (av. pre monsoon - 40.0 mg/l and post monsoon - 61.7 mg/l) and low hardness (av. pre monsoon- 23.8 mg/l and post monsoon- 19.3 mg/l), which are within the potable limits of WHO, ISI and EEC. So the water is good for other domestic consumption, irrigation practices and industrial uses particularly for low- pressure boilers.

The total iron content in the western part of the basin is more than 0.3 mg/l indicating contamination in ground water and this is mainly due to leaching of iron from laterite under low pH condition. The fluoride content of the basin is very negligible; the maximum value of 0.4 mg/l has been recorded during pre monsoon season.

Durov's diagram indicates that over two third of the pre monsoon samples have shifted towards the mixing zone during post monsoon, however, about 31% of the samples do no show any shifting. The trilinear diagram shows that the groundwater of the pre monsoon are $CaCl_2$, $Ca(HCO_3)_2$, and NaCl types whereas in the post monsoon the water types are $Ca(HCO_3)_2$, $NaHCO_3$ and NaCl and this is due to the shift of samples towards the zone of bicarbonate and sodium. The overall increase in bicarbonate again attributes that the groundwater is recharged by rainfall so that it plays a vital role in the groundwater chemistry of this basin.

Hydrochemical facies diagram reveals that most of the samples in both the seasons fall in mixing and dissolution facies and a few in static and dynamic regimes. Indicating an overall shift of pre and post monsoon samples from static regime to mixing and dissolution zone of the facies diagram. Thus it is concluded that mixing and dissolution plays a vital role for shifting one facies to another. It is clear from the facies diagram groundwater is having neither too much in contact with the rock nor in a dynamic condition.

In general the percentage of Na in groundwater is at a bearable limit (< 10%). However, a few pockets show high Na percent, but within the standard limit and is attributed to the use of fertilizers. U.S.S.L. diagram clearly indicates that most of samples fall in CISI field and a very few in C2SI indicating low salinity/ low sodium alkali hazard. Likewise the concentration of Residual Sodium Carbonate (RSC) in the study area is with in the limit (<1.25 meq/l). These indicate that the groundwater of Muvattupuzha river basin is good for irrigation.

A corrosivity ratio of <1 is considered as a safe zone. During pre monsoon more than 70% of the area comes under safe zone, but in the post monsoon period the areal coverage of both safe and unsafe zones are equally distributed. It is therefore, recommended that PVC pipes will have to be used for water transportation in those areas falling under unsafe zone.

Based on Gibb's diagram it is concluded that the groundwater chemistry is primarily controlled by precipitation rather than lithology and the above finding is substantiated by trilinear facies diagram in which most of the samples fall around dissolution and mixing zone. The mixing in this basin is characterized by high rainfall and seepages from canal network.

Hydrogeomorphological map prepared from the satellite data exhibits nine geomorphic landforms. Among the major landforms, the valley fills are proved to be the best landform for the occurrence of ground water quantitatively. By the integration of various thematic maps the ground water potential zones of the basin is classified into four categories viz., (i) very good, (ii) good, (iii) moderate and (iv) poor. The structural hills on the eastern part of the basin are characterized by poor groundwater prospect and this is due to steep slope and high drainage density. The southwestern part of the Muvattupuzha sub basin comes under the category of very good and is matched well with the high optimum yield and storage coefficient. The groundwater prospect map indicates that the down stream part of the Muvattupuzha river basin is good prospect zone than the upstream part.

The current landuse pattern of the study area have been demarcated into 20 classes and the major landuse pattern in the area is rubber plantation followed by mixed plantation, evergreen dense and open forest etc. Based on the NDVI analysis it is concluded that more than 60% of area is having a good vegetative status and also it is evident that the southwestern part is in better health status than the rest of the area.

A strong database on the hydrogeology of the Muvattupuzha river basin is generated by integration of spatial and non-spatial data using Arc/Info. The above data could be used for information extraction and base line inventory for future sustainable development.

The major conclusions drawn from this study are:

- The movement of groundwater is mainly controlled by topography, lithology and lineaments and the basin experiences a low level of water fluctuation.
- Based on aquifer parameter analysis the southwestern part of the basin is having very good prospect zone with high optimum yield, low time for recuperation and high storage coefficient.
- Resistivity analysis indicates that the Muvattupuzha sub basin is having good groundwater phreatic potential zone and certain promising zones for medium and deep bore wells in the entire basin.
- Geochemically the groundwater is good for all domestic, irrigational and industrial uses because of low content of EC, TDS, total hardness, fluoride, major cations (Na^+, K^+, Ca^{++} and Mg^{++}) and anions (HCO_3^-, CO_3^{--}, SO_4^{--} and Cl^-). The salinity and sodium alkali hazards are also low.

- The significant environment, which represents the chemical characteristics of the groundwater is dissolution and mixing rather than static and dynamic conditions.
- The prime mechanism controlling the groundwater chemistry is precipitation; lithology and evaporation play only a minor role.
- Integrated study reveals that among the four sub basins, the Muvattupuzha sub basin is having good groundwater prospect zone.
- Based on various status and other integration study it is clear that the groundwater condition of the Muvattupuzha river basin is highly satisfactory.

Further study is needed on:

- Impact of dykes on the occurrence and movement of groundwater.
- Impact of seepages from irrigation canals on the groundwater quality and resources of this basin.
- Influence of inter-basin transfer of surface water (from Periyar to Muvattupuzha basin) on groundwater.

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